UNDERSTANDING THE DETERMINANTS OF OBESITY IN URBAN CANADA

I dedicate this thesis to
my parents, Yiorgos and
my beloved husband Dimitris

OVERWEIGHT AND OBESITY IN CANADA:

UNDERSTANDING THE INDIVIDUAL AND SOCIO-ENVIRONMENTAL DETERMINANTS

BY

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Abstract

This research examined the geographic variability as well as the individual- and neighbourhood-level determinants of overweight and obesity in Canada. Overweight and obesity represent a significant public health problem with grave implications for individuals as well as populations. Over the past two decades, the prevalence of overweight and obesity has reached epidemic proportions with the most substantial increases observed in economically developed countries. The World Health Organization indicated that globally 1.6 billion adults (age 15+) are overweight and at least 400 million adults were obese. In a Canadian context, recent data from Statistics Canada confirms that over the past twenty-five years, adult obesity rates in Canada have doubled (23%), while childhood obesity rates have nearly tripled.

Until recently, research has focused on biological and behavioural determinants of obesity, and currently there is a great deal of knowledge regarding the relationships between weight status and various risk factors at the individual-level (e.g. age, sex, socio-economic deprivation, diet, physical activity). However, the majority of existing research has ignored the potential role played by the environment in the development of these conditions, despite a growing consensus that environmental and/or societal constraints may be major influences on increasing prevalence rates.

Using data from the Canadian Community Health Surveys and the Desktop Mapping Information Technologies Incorporated spatial database, this research addressed the following objectives: (1) to examine sex-specific spatial patterns of overweight/obesity in Canada as well as investigate the presence of spatial clusters (2) to investigate the prevalence and determinants of overweight and obesity in Canada using spatial analysis and geographical information systems (GIS) and (3) to identify heterogeneities associated with the relationships between individual and socio-environmental determinants and overweight and obesity at the individual- and community-levels.

Results revealed marked geographical variation in overweight/obesity prevalence with higher values in the Northern and Atlantic health-regions and lower values in the Southern and Western health-regions of Canada. Significant positive spatial autocorrelation was found for both males and females, with significant clusters of high values or 'hot spots' of obesity in the Atlantic and Northern health-regions of Alberta, Saskatchewan, Manitoba and Ontario. Results also demonstrate the important role of the built-environment after adjustment demographic, socio-economic and behavioural characteristics. With regard to the built environment measures, landuse mix and residential density were found to be significantly associated with BMI. This study also demonstrated significant differences at the area-level of analysis, supporting related research that has suggested that individual-level factors alone cannot explain variation in obesity rates across space. In particular, average dwelling value was related to BMI independently of individual-level characteristics. Ultimately, this research has demonstrated that Canadian urban environments play a small but significant role in shaping the distribution of BMI. Yet, reversing current trends will require a multifaceted public health approach where interventions are developed from the individual- to the neighbourhood-level, specifically focusing on altering obesogenic environments.

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Preface

This thesis is presented as a collection of research papers, which are published, under review or under preparation for submission. The research papers are as follows:

Chapter 2:

Pouliou T. and S.J. Elliott (2009), "An exploratory spatial analysis of overweight and obesity in Canada" Preventive Medicine, Vol. 48, No. 4, p. 362 – 367.

Chapter 3:

Pouliou T. and S.J. Elliott (2009), "Individual and socio-environmental determinants of obesity in urban Canada", (submitted to Health and Place, revise and resubmit)

Chapter 4:

Pouliou T. ,S.J. Elliott, K.B. Newbold and A. Paez (2009) "Building obesity in Canada: Neighbourhood as a determinant of recent trends" (in preparation for Social Science and Medicine)

While all of the research papers were co-authored, the first author and PhD candidate undertook the primary research, involving problem formulation, literature review, data analysis and manuscript writing. Drs. Susan J. Elliott, K. Bruce Newbold and

Antonio Paez provided guidance on the conceptualization and direction of the research as well as editorial advice.

Different formatting styles were used in the chapters in order to satisfy the stylistic criteria of each journal.

CHAPTER ONE

Introduction

1.1 Research Context

Overweight and obesity are now widely recognized not only as a major public health problem but as an epidemic (World Health Organization, 2000). Over the past two decades, the prevalence of overweight and obesity has risen with the most substantial increases observed in economically developed countries (Katzmarzyk, 2002b). Globally, approximately 1 billion adults are overweight and at least 300 million of these individuals are obese (World Health Organization, 2006).

Within the Canadian context, the problem of excess adiposity was recognized almost 50 years ago and was the impulse for the 1953 Canadian Weight-Height Survey (Katzmarzyk, 2002a). Since then, the tracking of obesity trends relies on a number of different population-based surveys with varying methodologies (for example, self-reported vs. measured height and weight) and after 1994 based only on self-reported data[1]. More recent self-reported data from the 2005 Canadian Community Health Survey (CCHS) identified that approximately 4 million adults (17.55 percent) were obese and an additional 8 million adults (33.77 percent) were overweight.

[1] The use of self-reported data is generally considered a limitation because people tend to over-report stature and under-report body mass, which tends to result in an underestimate of the prevalence of overweight and obesity (Paccaud et al., 2001).

The health consequences of overweight and obesity are well known and vary from cardiovascular disease and type 2 diabetes mellitus, to cancer and premature death (Raine, 2004, Freedman et al., 2006, Katzmarzyk et al., 2001, Pickett et al., 2005, Trakas et al., 1999, Reeder et al., 1997). In addition, overweight and obesity have been associated with various psychosocial problems and the general degradation of quality of life (Falkner et al., 2001, Xie et al., 2005).

In addition to impacting personal health, the increasing trends of overweight and obesity translate into an increased burden on the health care system (Katzmarzyk and Janssen, 2004). In particular, according to Katzmarzyk and Janssen (2004), the direct and indirect medical costs associated with overweight and obesity in Canada in 2001 were estimated at C$1.6 billion and C$2.7 billion respectively, representing 2.2 percent of the total health-care costs.

Current obesity-related research has mainly focused on temporal trends (Tremblay et al., 2002, Stam-Moraga et al., 1998, Marques-Vidal et al., 2002, Visscher and Seidell, 2004, Flegal et al., 1998, Torrance et al., 2002). Very few studies have documented the spatial patterns of overweight and obesity especially in Canada. A notable exception is a study by Katzmarzyk et al. (2002a) who focused, on national/provincial levels of aggregation. More recently, Vanesse et al., (2006) demonstrated the geographic variability in the prevalence of obesity at the health region level, revealing that health regions with higher rates of obesity being strongly associated with low rates of physical activity and fruit and vegetable consumption. However, the Vanesse et al., (2006) study assumed that observations (i.e. overweight/obesity rates) are independent of each other.

Yet, prevalence of overweight/obesity at one health region are likely to be correlated with prevalence in nearby regions, indicating the presence of clusters (Bailey and Gatrell, 1995). In addition, it is worth noting that in Canada, health regions are administrative areas that are responsible for assessing and prioritizing needs and health goals as well as developing an integrated approach toward population health and health promotion. Therefore, examination of the geographical variability of overweight and obesity as well as detection of overweight/obesity clusters using geographical information systems (GIS) and spatial analysis techniques could be an effective tool for public health professionals and policy makers to identify areas of elevated risk and therefore effectively direct scarce public health resources and services on vulnerable regions.

Moreover, there is a growing body of evidence pointing to the significant roles that the social and physical environments can play in determining overweight and obesity (Macintyre et al., 2002, Duncan et al., 1998, Curtis and Taket, 1996). Existing literature on the determinants of obesity has placed emphasis on the demographic and socio-economic characteristics of individuals (Falkner et al., 2001, Lahti-Koski et al., 2000, Pickett et al., 2005). This research provides us with a partial explanation of prevalence and trends of this important public health issue. In particular, there is a growing consensus that individual risk factors may be unable to slow and/or reverse current obesity trends at the population level, as individuals are embedded within social and built environments that may also play a significant role in shaping health (Macintyre et al., 2002, Duncan et al., 1998, Curtis and Taket, 1996). In particular, a shift in attention to environmental determinants of behaviour has recently occurred as it has been acknowledged that a major driving force for the increasing overweight and obesity prevalence may be the built and social environments, also known as *obesogenic environments*, which encourage over-consumption of energy-dense foods and discourage physical activity (Hill and Peters, 1998). As stated by Rothchild (1999), the likelihood that an individual will engage in a healthy behaviour is largest when someone is motivated to act healthily, has the abilities to engage in the healthy behaviour and the environment offers the right opportunities to engage in the healthy behaviour.

The relationship between the built environment and obesity has been examined in many studies (Nelson et al., 2006, Frank and Engelke, 2001, Gordon-Larsen et al., 2006, Reidpath et al., 2002). Nevertheless, there is still a lack of a clear rationale for choosing built environment measures. A number of studies have used urban form indicators, such as the urban sprawl index (Ewing et al., 2003) and the walkability index (Frank et al., 2004) while more recent studies have also employed various accessibility measures (e.g., access to fast-food restaurants, supermarkets as well as walking paths, trails and recreational centers) (Scott et al., 2007, Powell et al., 2007). Yet, no existing studies have explored the association between weight status and the built environment using both urban form (e.g., residential density) as well as accessibility measures (e.g., density of fast-food restaurants). Comparing and integrating various measures of the built environment measures could offer new evidence with regard to the relationship between the built environment and overweight and obesity.

In addition, there is a recent interest in studying the area-level characteristics that may influence current rates of overweight and obesity, independently of individual-level features (Ellaway et al., 1997, Janssen et al., 2006). The study of area-level effects on overweight and obesity has also led to a growing interest in multilevel studies that allow for the possibility that different factors contribute to within-area and between-area variability, and permit estimation of area-level effects after accounting for individual differences across areas. However, most of the current studies have focused on either the area-level socio-demographics or the built environment, making it very difficult to illustrate potential interactions between them and overweight/obesity. That is, the actual mechanism by which such factors may affect weight gain is still at the level of speculation and requires further investigation.

Finally, the majority of contributions on the obesity-related literature comes from Europe and the United States (Novak et al., 2006, Ewing et al., 2003); there is a distinct lack of research in the Canadian setting.

What is therefore apparent is that while the volume of literature exploring the determinants of overweight and obesity is expanding, the field offers important opportunities for further study, specifically related to uniting different methodological approaches in assessing the potential contribution of the built environment to the development of overweight and obesity as well as framing overweight and obesity as functions of individual characteristics operating within local social and built environments.

1.2 Research Objectives

This research examines the determinants of overweight and obesity with particular emphasis on social and environmental risk factors, incorporating both individual and community level indicators. Further, this study focuses on Canada's two largest metropolitan areas, Toronto and Vancouver. Choosing Canada's largest CMAs is more likely to capture the socio-cultural diversity of Canada's population since both CMAs are characterized by various neighbourhood designs ranging from high to low on a continuum of walkability and density and contain at least 15% of the Canadian population. In view of the foregoing, the primary objectives of this study are to:

1. Examine the sex-specific spatial patterns of overweight/obesity in Canada as well as investigate the presence of spatial clusters;
2. Explore the relative contribution of built environment measures to the development of overweight and obesity using spatial analysis and geographical information systems (GIS).
3. Identify heterogeneities associated with the relationships between individual and socio-environmental determinants and overweight and obesity at the individual- and community-levels.

1.3 Geographic Context

The objectives of this study place this research firmly within the realm of traditional medical geography. In general, approaches to the study of health in geography are commonly grouped into two major categories: "traditional medical geography" and "contemporary health geography". Traditional medical geography is concerned with the spatial patterning and diffusion of disease -also known as disease ecology – as well as the geography of health care (Kearns, 1994, Curtis and Jones, 1998). In particular, disease ecology involves the study of infectious diseases (e.g., malaria, HIV/AIDS, infant diarrhoea) including the spatial distributions of social, economic, political and environmental factors associated with disease. The study of health care delivery includes spatial patterns of health care provision and patient behaviour as well as issues such as health inequalities in terms of utilization and accessibility. Central to both has been their reliance on positivist approaches and quantitative methods (Curtis and Jones, 1998). Contemporary health geography, which is comprised of numerous theoretical approaches including structuralism, social interactionism and post-structuralism, is typically concerned with the role of human awareness, beliefs, meaning and particular forms of social, economic and cultural values in health experience (Gatrell, 2002). The methodological approach typically involves qualitative designs to study health and illness in place.

While positivist medical geography has dominated the landscape in the past, recent years have seen a shift in emphasis towards health geography. Despite this shift, one approach should not be considered superior to another (Curtis and Taket, 1996; Gatrell, 2000). The approach that is adopted is dependent on the questions or objectives of the study as well as the data sources available (Eyles, 1997). These in sum determine the appropriateness of the methods of inquiry adopted (Elliott, 1999).

This study, however, goes beyond the biomedical approach to understanding the determinants of overweight and obesity by extending the range of potential determinants examined to include social, economic and environmental factors. Past research on overweight and obesity has focused mainly on physiological and modifiable lifestyle factors, while critical for clinical decision-making, do not address the more fundamental broad determinants of health. Using population based data, statistical techniques are employed to analyse the spatial pattern of overweight and obesity, explore the relative contribution of built environment measures as well as identify heterogeneities between individual and socio-environmental determinants and overweight and obesity at the individual- and community-levels.

1.4 Theoretical and Analytical Frameworks

1.4.1 Population Health Framework

This study is informed by the population health perspective which highlights the importance of broad determinants of health (Evans et al., 1994). Specifically, in 1974 the federal government's White Paper "A New Perspective on the Health of Canadians", known also as the Lalonde Report, provided a new conceptual framework to inspire a paradigm shift related to the determinants of health (Lalonde, 1974). Lalonde's report identifies four main elements: human biology, lifestyle, the organization of health care and the social and physical environments in which people live. However, Evans and Stoddart (1994) point out that because of its focus on individual level risk factors and specific diseases, the report "has tended to lead not away from but back to the health care system itself". Therefore, although the four-field health concept broadened the range of determinants of health, it did little to shift the perspective on health away from the biomedical focus.

The second report was the "Achieving Health for All: A Framework for Health Promotion"*(Epp, 1986).* The release of this document further broadened the conceptualization of the determinants of health by focusing on the broader social, economic and environmental factors that affect health. The factors, or determinants of health to be considered are income level, education, and the physical environment as well as social stratification, and social network.

In 1989, the Canadian Institute for Advanced Research (CIAR) introduced, the population health concept, altering the research agenda beyond health care to the social, economic and cultural forces that serve as determinants of health, as well as the importance of values such as equity, solidarity and participation in a population context. More recently, members of CIAR conceptualized the basis of the determinants of health and their complex interactions (Evans and Stoddart, 1990) which was later repeated and amplified in a collaborative and critically acclaimed book *Why Are Some People Healthy and Others Not?(Evans et al., 1994).*

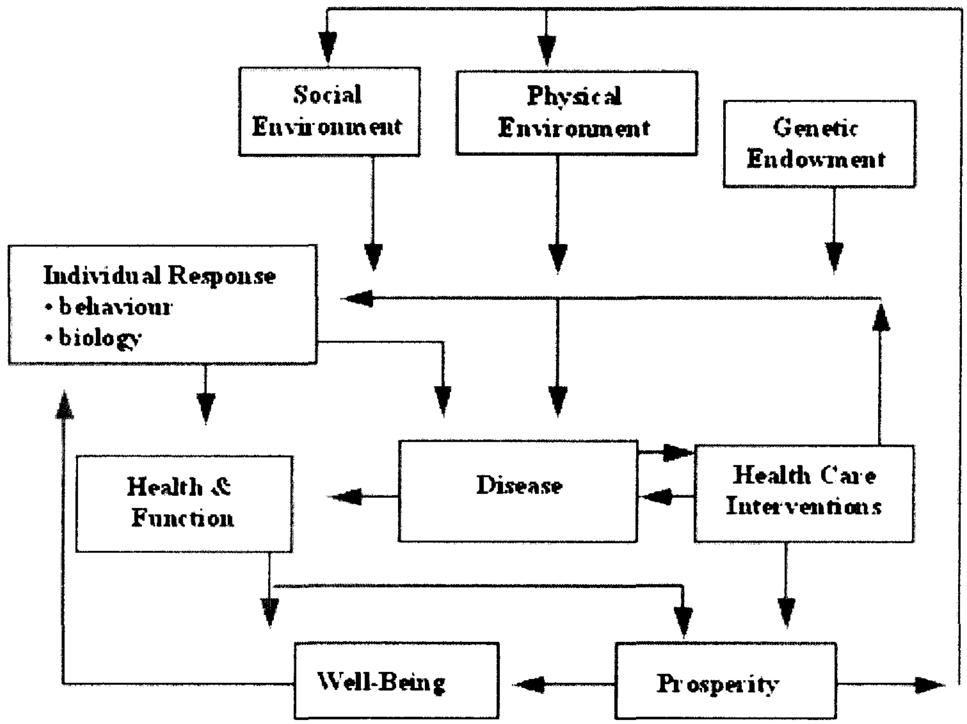

Figure 1.1: The population health framework (Source: Evans and Stoddart, 1990)

The framework shows the links between key determinants of health - social environment, physical environment, genetic endowment and individual response - and various notions of health (Figure 1.1). It illustrates the direct impact of these determinants on disease and individual response to the incidence of disease. It also illustrates the indirect impact on health and function, health care, well being and prosperity. Thus, within the framework, a distinction can be made among disease (as perceived from the biomedical perspective) and health, function and well being (from the individual perspective) (Evans and Stoddart, 1990). The framework extends the health field concept by permitting a more complex and subtle consideration of social and physical environmental influences on both behaviour and biological constitution. This framework represents the socio-ecological perspective on health, offering an expanded scope for research on the health of both individuals and populations. The authors note, however, that its utility will be tested by the extent to which it provides meaningful categories for organizing the diverse determinants of health.

The overarching goal of the population health perspective is "to maintain and improve the health of the entire population and to reduce the inequalities in health between population groups" (Health Canada, 2001). It reflects the evolution related to the definition of health by recognizing that human biology, lifestyle, the social, economic and physical environment as well as the availability of health services may affect health. The outcomes or benefits of a population health approach extend beyond improved health status by recognizing the complexity of the broader determinants of health and the interaction between them.

Yet, the population health perspective has seen controversies in academic discourses and policy debates. For instance Zollner and Lessof (1998) pointed out that population health has been taken as justifying the diversion of resources from the health sector to support economic development or prioritizing those investments that impact health, such as socio-economic policies that address inequity. It has also been criticized for ignoring the broader social and political forces (for example, globalization, and class structure) that may warrant a comprehensive analysis of the determinants of health (Poland et al., 1998). Also, Hayes and Dunn (1998) indicated that findings from population health research addressing health inequalities have yet to be applied to health policy. Notwithstanding, the population health perspective has become a persuasive and pervasive framework for the Canadian and U.S. health and health promotion policies (Hamilton and Bhatti, 1996) as well as for research studies (Elliott et al., 1998; Eyles et al., 2001).

1.4.2 The ANGELO Framework

For the purposes of this study, the analysis grid for environments linked to obesity (ANGELO) framework (Swinburn et al., 1999) was applied to effectively identify and categorize elements of the local environment that could potentially be driving the obesity epidemic in Canada.

The ANGELO framework divides the environment into two dimensions: the size (micro and macro) and the type of environment. Microenvironments are environmental settings where groups of people meet and gather (e.g. homes, schools, restaurants and neighbourhoods). Such settings are often geographically distinct and allow direct mutual influences between individuals and the environment. Macro-environments include the broader infrastructure that may support or hinder health behaviours (e.g. town planning, transport infrastructure, the health system and the media). The 'types' of environments distinguished in the ANGELO framework are the physical, socio-cultural, economic and political environment.

1. The physical environment refers to the availability of opportunities for healthy and unhealthy choices, for instance the availability and accessibility of healthy and unhealthy foods.

2. The socio-cultural environment refers to the social and cultural subjective and descriptive norms and other social influences such as parental influences and peer pressure.
3. The economic environment refers to the costs related to healthy and unhealthy behaviours, for instance costs of fruit and vegetables and household income.
4. The political environment refers to the rules and regulations that may influence food choice or availability, for example, bans on snack vending machines in schools.

Though the application of the ANGELO grid as a framework for guiding neighbourhood and obesity research has been limited, it has been applied to a systematic review of the environmental determinants of physical activity (Wendel-Vos et al., 2007), which was used as a guide for deconstructing aspects of neighbourhood for this study. This broader framework on the elements of obesogenic environments may improve our understanding on the determinants of overweight/obesity, allowing us to point in a useful policy direction vis-à-vis response.

1.5 Chapter Outline

This thesis is organized into five chapters including this introductionory section. Chapters 2 to 4 chapter have been either published, submitted for publication or are in preparation for submission. Together these chapters address the main objectives of this research outlined above. Chapter 2, published in the journal of Preventive Medicine, examines the sex-specific spatial patterns of overweight/obesity in Canada as well as investigates the presence of spatial clusters. This work underscores the importance of geographically focused prevention strategies informed by population-specific needs and sets the stage for chapter 3 which explores the relative contribution of built environment measures to the development of overweight and obesity using spatial analysis and geographical information systems (GIS). This chapter has been submitted for publication to the journal of Health and Place. Chapter 4 identifies heterogeneities associated with the relationships between individual and socio-environmental determinants and overweight and obesity at the individual- and community-levels. Multilevel models were estimated using a range of physiological, behavioural, social, economic and environmental variables both at the individual and area-level of analysis. This paper is in preparation for submission to the journal Social Science and Medicine. Finally, chapter 5 summarizes the major findings and conclusions drawn from this study. It further discusses the major, theoretical, methodological and substantive contributions. Finally, future research directions are highlighted.

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CHAPTER TWO

An exploratory spatial analysis of overweight and obesity in Canada

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Abstract

Objective:

The identification of spatial clusters of overweight and obesity can be a key indicator for targeting scarce public health resources. This paper examines sex-specific spatial patterns of overweight/obesity in Canada as well as investigates the presence of spatial clusters.

Methods:

Using data on Body Mass Index (BMI) from the 2005 Canadian Community Health Survey (20 years and older) cycle 3.1, a cross-sectional ecological-level study was conducted. Sex-specific prevalence of overweight and obesity were first mapped to explore spatial patterns. In order to assess the degree of spatial dependence, exploratory spatial data analysis was performed using the Moran's I statistic and the Local Indicator of Spatial Association (LISA).

Results:

Results revealed marked geographical variation in overweight/obesity prevalence with higher values in the Northern and Atlantic health-regions and lower values in the Southern and Western health-regions of Canada. Significant positive spatial autocorrelation was found for both males and females, with significant clusters of high values or 'hot spots' of obesity in the Atlantic and Northern health-regions of Alberta, Saskatchewan, Manitoba and Ontario.

Conclusions:

Findings reveal overweight/obesity clusters and underscore the importance of geographically focused prevention strategies informed by population-specific needs.

Keywords: Overweight, obesity, spatial clustering, GIS, Canada

2.1 Introduction

For many years, overweight and obesity have been studied as important risk factors for cardiovascular and other chronic diseases with major implications for individuals as well as populations (National Institute of Health, 2004). Overweight/obesity increase the risk of diabetes and heart disease, contribute to greater risk for hypertension and insulin resistance as well as impact the psychosocial state and quality of life of individuals and families (Raine, 2004). Further, overweight/obesity have been associated with increased prevalence of primary-care visits, exacerbating the load on an already overburdened health-care system (Bertakis and Azari, 2005). According to Katzmarzyk and Janssen (2004), the cost associated with obesity in Canada in 2001 was $4.3 billion, representing 2.2 percent of total health-care costs.

The problem of excess adiposity was recognized in Canada almost 50 years ago and was the stimulus for the 1953 Canadian Weight-Height Survey (CWHS)(Katzmarzyk, 2002a). The CWHS was the first nationally representative survey of measured stature and body mass in Canada. Since then, data on obesity trends have been informed by a number of different surveys based primarily on self-reported information. Survey data indicate that the national prevalence of obesity in adults increased from 5.6 percent in 1985 to almost 15 percent in 1998 (Katzmarzyk, 2002). More recent self-reported data from the 2005 Canadian Community Health Survey (CCHS) identified that approximately 4 million adults (17.55 percent) were obese and an additional 8 million adults (33.77 percent) were overweight.

Few studies have also documented regional differences in the prevalence of obesity in Canada (Katzmarzyk, 2002). An exception is Katzmarzyk et al. (2002) who presented surveillance maps for Canadian adults from 1985 to 1998. In 1985, all provinces reported prevalence of obesity less than 10 percent, while in 1998, all provinces except British Columbia and Quebec reported prevalence of more than 15 percent. Further, based on the 2005 CCHS, the prevalence of obesity in most of the Atlantic Provinces, Saskatchewan, Nunavut, Yukon and the Northwest Territories was more than 20 percent.

However, most of these studies have focused on national/provincial levels of aggregation, making it very difficult to illustrate clearly vulnerable regions. A notable exception is a study by Vanasse and colleagues (Vanasse et al., 2006), which indicates that interest has started shifting from global to local relationships. In partiular, Vanasse and colleagues (2006) assessed the relationship between obesity, leisure-time physical activity and daily fruit and vegetable consumption at the health region level across Canada. Findings revealed that the prevalence of obesity varied substantially between health regions with higher values being strongly associated with low values of physical activity and fruit and vegetable consumption. Further, Vanasse el al. (2006) made use of cartograms to adjust the distortion caused by huge differences in population density between health regions. However, the use of cartograms assumes that observations (i.e. overweight/obesity rates) are independent of each other. Yet, prevalence of overweight/obesity at one health region are likely to be correlated with prevalence in nearby regions, indicating the presence of clusters (Bailey and Gatrell, 1995). Therefore, we felt that it would be worthwhile to examine the overweight/obesity spatial patterns taking into account the overall as well as local variability in the data. In particular, cluster analysis is applied in order to identify areas with higher rates of overweight/obesity as well as generate hypotheses based on the emerging spatial patterns. Further, this study illustrates that cluster analysis provides a great potential to uncover region-specific risk factors of overweight/obesity as well as be a useful tool for public health professionals and policy makers to effectively direct scarce public health resources on vulnerable regions.

2.2 Methods

2.2.1 Data sources and study design

We conducted a cross-sectional population based ecological-level analysis to assess the spatial patterns in overweight and obesity in Canada. The Public Use Microdata File (PUMF) of the CCHS 3.1 cycle was used to obtain information on the prevalence of overweight/obesity among Canadians. The CCHS is a cross-sectional national survey (n=132,221) that covers the population aged 12 and older in all provinces and territories, except individuals living on Indian reserves, institutions and some remote areas. A detailed description of the CCHS design and questionnaire is available elsewhere (Statistics Canada, 2005).

The CCHS 3.1 cycle included self-reported data on weight and height for all individuals 18 years and older, excluding pregnant women; however, we included only those 20 years and older (n=115,915) allowing for comparison with other surveys (e.g.

CHHS 2.1). Overweight and obesity were defined according to the body mass index (BMI) (weight in kilograms divided by height in meters squared - kg/m^2)(Statistics Canada, 2005). Following the guidelines of the World Health Organization (2000), risk levels were defined as follows (kg/m^2): under 18.5 (underweight); 18.5–24.9 (healthy weight); 25.0–29.9 (overweight); 30.0– 34.9 (obese-Class I); 35.0–39.9 (obese-Class II); 40 or greater (obese - Class III). Using demographic data from the (2001) census as the standard population, we estimated directly age-standardized rates of overweight/obesity for individuals 20 years or older at the health region level. Data with missing BMI records due to invalid data were excluded from the analysis (n=3,968) Therefore, the total sample size for all individuals aged 20 and older and with no missing BMI records was 111,947. Data were weighted using the combined sampling weight provided by Statistics Canada, to ensure the representativeness of the covered population.

While data were collected in 125 health regions, some health regions had population sizes that were considered small to appear individually in the PUMF. These health regions were thus collapsed resulting in the 101 health regions used in the analysis.

2.2.2 Statistical Analyses

A three-step analysis process was followed: first the spatial distribution of age-standardized overweight/obesity rates was mapped for males and females. Following this, the analysis focused on two aspects of the spatial clustering: the overall 'global' spatial clustering in the prevalence of overweight/obesity and the 'local' patterns of overweight /obesity.

The Moran’s I statistic was used as a measure of the overall clustering and was assessed by testing a null hypothesis (i.e. the spatial pattern is random). Rejection of the null hypothesis implies a non-random spatial pattern also referred to as spatial autocorrelation. In particular, spatial autocorrelation measures the nature and strength of interdependence between data. We speak of positive spatial autocorrelation where similar values tend to occupy adjacent locations, whereas negative autocorrelation implies that high values tend to be located next to low ones. On the other hand, if the spatial arrangement is completely random, then this implies absence of spatial autocorrelation. Moran's I ranges approximately from + 1 (for positive spatial autocorrelation) to -1 (negative autocorrelation), and its expected value in the absence of autocorrelation approximates zero. Neighbour relationships are typically expressed in a row-standardized spatial weights matrix `W`, the elements of which wij correspond to the spatial weights assigned to pairs of units (i.e. health regions) i and j (Anselin, 1994). In the present analysis, neighbours were defined using rooks case adjacency, which considers that all health regions with common borders are neighbours.

In order to ensure regions meet the minimum population size of about 70,000, the regions of Nunavut, Yukon and Northwest Territories were collapsed. It is important to note that these territories are sparsely populated and culturally unique. For example, Nunavut is home to a population of approximately 29,000, eighty percent of whom are Inuit. Therefore, the collapsed regions were excluded from the analysis as they would not properly reflect the neighbourhood structure of the area and thus question the validity of data.

Moran's I is a global test that does not indicate where the clusters are located or what type of spatial autocorrelation is occurring (e.g. positive or negative) (Anselin, 1995). The local indicator of spatial autocorrelation (LISA) was therefore applied as an indicator of local spatial association (Anselin, 1995). The LISA measures whether, for each health region, the standardized rate of overweight/obesity is closer to the values of its neighbours or to the national average. To test for significance, a Monte Carlo permutation approach was used. This permutation approach assumes that the data are equally likely to be observed at any location. The observed values were randomly shuffled over all locations and the LISA was re-calculated for each permutation. The significance of the LISA was then determined by generating a reference distribution using 999 random permutations. Finally, the LISA significance map was created incorporating information about the significance of the local spatial patterns. In particular, the map results in a spatial typology consisting of five categories of health regions: (i) `high-high` indicates clustering of high values of age-standardised overweight/obesity rates (positive spatial autocorrelation), (ii) `low-high` indicates that low values are adjacent to high values of age-standardised overweight/obesity rates (negative spatial autocorrelation), (iii) `low-low` indicates clustering of low values of age-standardised overweight/obesity rates (positive spatial autocorrelation), (iv) `high-low` indicates that high values are adjacent to low values of age-standardised overweight/obesity rates (negative spatial autocorrelation), (v) `not significant` indicates that there is no spatial autocorrelation. Analyses were conducted using GeoDA (Anselin, 2003) and ArcView (ESRI, 2002).

2.3 Results

Results revealed that, age-standardized rates of overweight/obesity were higher in males than females (Figures 1, 2 and 3). This difference is seen at the provincial level, as well (Tjepkema, 2005). Also, the three major metropolitan areas of Vancouver, Toronto and Montreal exhibited overweight and obesity rates below the Canadian overall standardised rates of 34.99 and 18.53 percent respectively (Figure 1).

Age-standardized rates of overweight differed substantially across health regions ranging from 17.19 percent in Vancouver, British Columbia to 37.39 percent in Interlake, Manitoba for females and from 32.27 percent in Richmond, British Columbia to 52.61 percent in Zone 5 in Nova Scotia for males (Figure 2). Obesity rates varied substantially across health regions: from 7 percent in Richmond, British Columbia to 28.07 percent in Zone 1 in Nova Scotia for females and from 8.03 percent in Vancouver, British Columbia to 32.37 percent in Prince Albert, Mamawetan, Keewatin and Athaba in Saskatchewan for males (Figure 3). With the exception of Quebec (data not available for all health regions), every province and territory had at least one health region with an obesity rate higher than the national average (18.53 percent).

Based on the aforementioned, there was an increasing gradient in the prevalence of overweight/obesity from western to eastern Canada indicating potential presence of clusters or 'hot spots'. To test this hypothesis, the Moran's I statistic was first applied. Table 1 presents the Moran's I statistic with significance p-values. The results indicated that there is significant positive spatial autocorrelation in the data. The level of autocorrelation differed among overweight/obesity as well as between males and females.

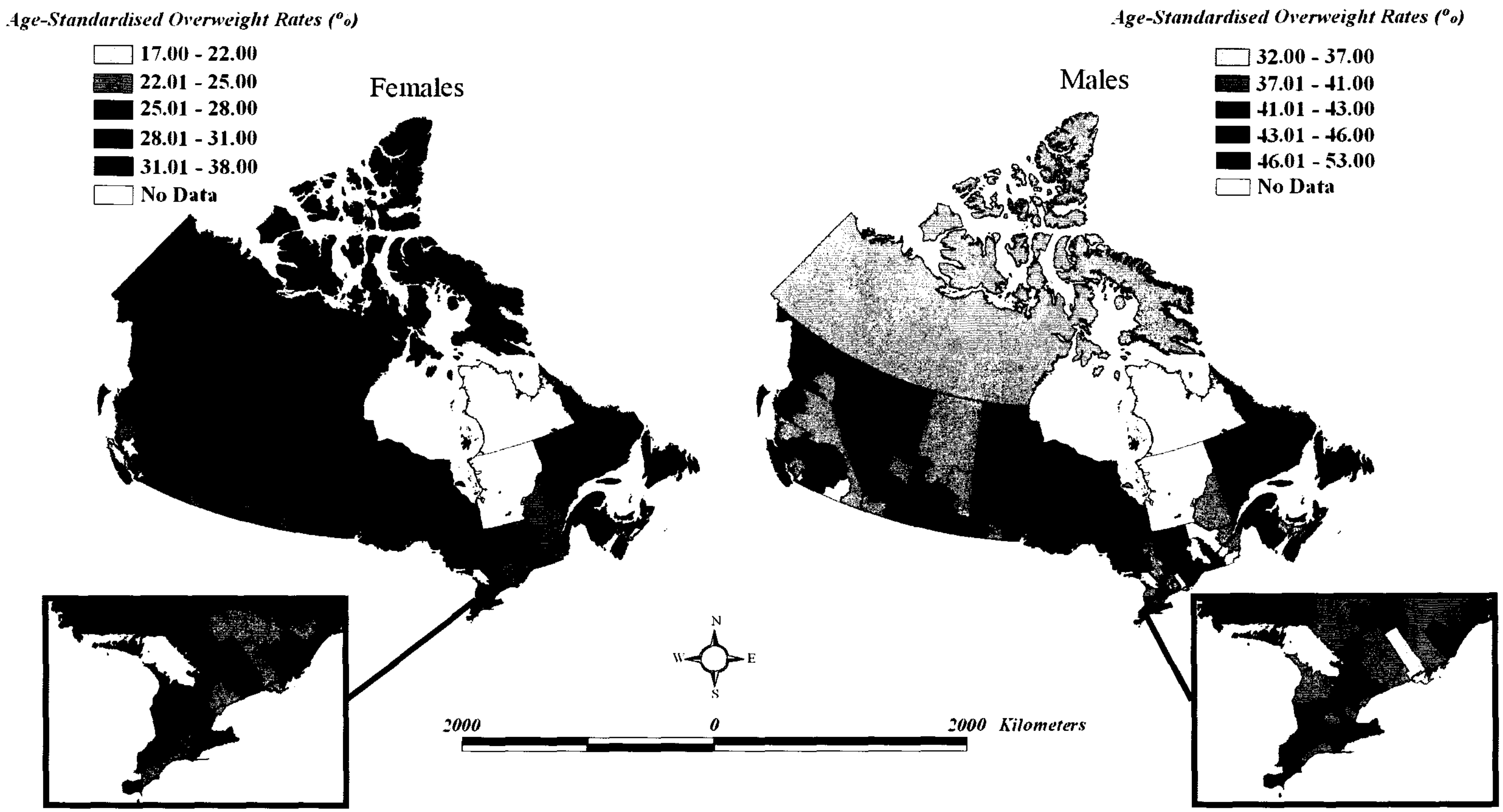

Figure 1: Age-standardised overweight rates for males and females in 2005 by health region in Canada

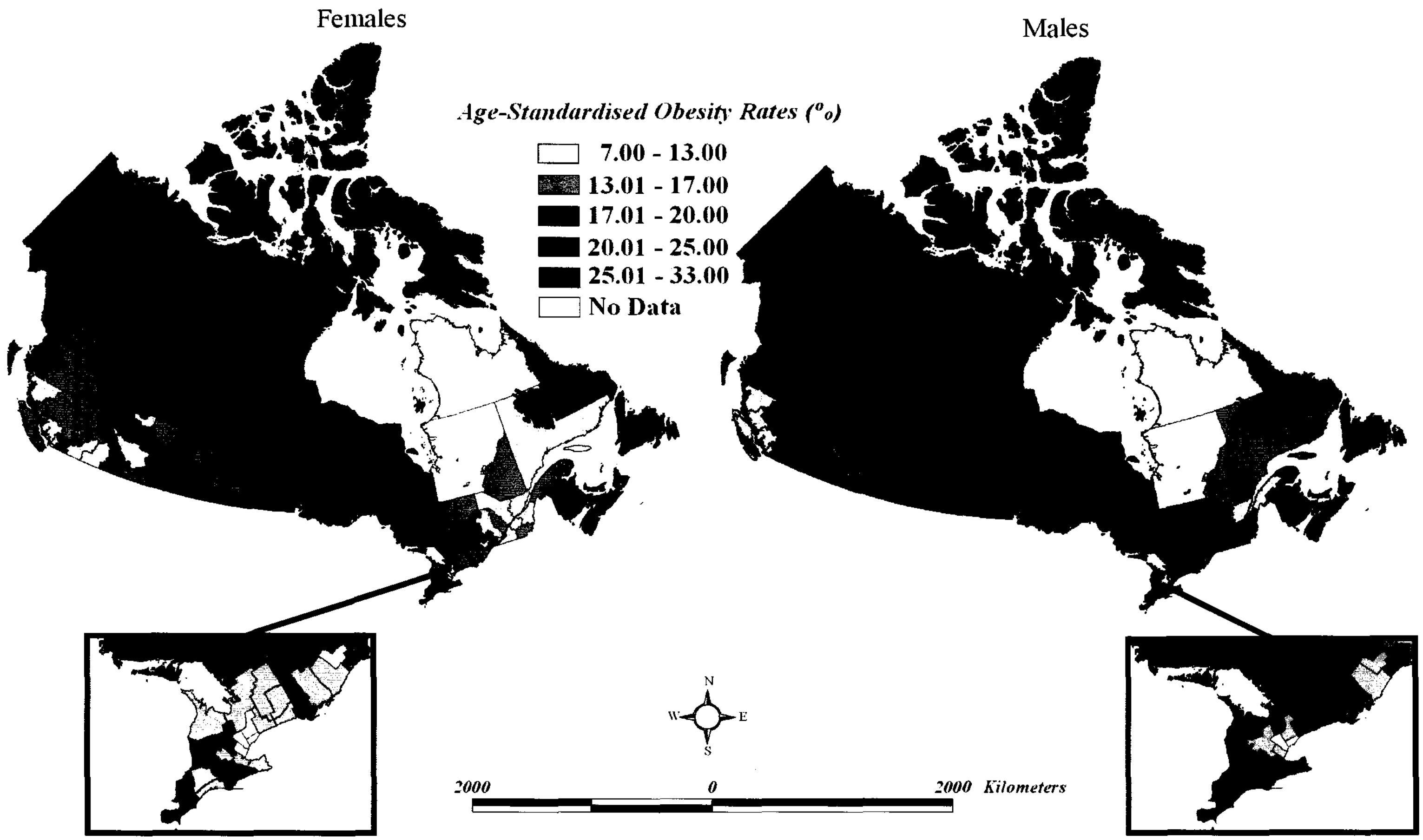

Figure 2: Age-standardised obesity rates for males and females in 2005 by health region in Canada

TABLE I
Spatial autocorrelation of age-standardized overweight and obesity rates in Canada in 2005

Overweight	**Moran's I**	**p-value**
Males	0.1406	0.037
Females	0.1775	0.017
Both sexes	0.2308	0.004

Obesity	**Moran's I**	**p-value**
Males	0.4558	<0.001
Females	0.4625	<0.001
Both sexes	0.5383	<0.001

In particular, the level of spatial autocorrelation across health regions for age-standardized overweight rates was 0.1406 (p-value = 0.037) for males and slightly higher for females (0.1775; p-value = 0.015). In addition, the level of spatial autocorrelation for the age-standardized obesity rates, was significant and in particular 0.4558 for females and 0.4625 for males with p-values below 0.001.

The Moran's I statistic results suggest non-randomness in the overall spatial pattern of both overweight and obesity in Canada. More information on the type of clustering may be present was provided by the LISA. Significant clusters of high values or 'hot spots' were detected for both overweight/obesity. Specifically, for overweight among males, a hot spot was detected in Saskatchewan, comprising of the aggregated health region of Sun Country, Five Hills and Cypress. For females, the hot spot was comprised of the Central Regional Integrated health region in Newfoundland and Labrador and Region 1 in Nova Scotia (Figure 4a). However, the pattern of clusters for obesity was different compared to that of overweight (Figure 4b). In particular, for both males and females significant clusters of high values of obesity were detected in the northern health regions of Alberta (i.e. Northern Lights and Peace Country), Saskatchewan (i.e. Prince Albert, Mamawetan, Keewatin and Athaba), and Manitoba (i.e. Parkland, Norman, Burntwood and Churchill) as well as the Eastern Regional Health Region of Prince Edward Island and Zones 1 and 2 in Nova Scotia and Regions 1 and 2 in New Brunswick. In addition, a cluster of low values of obesity or "cold spot" was observed in the health regions of Sauguenay-Lac-Saint-Jean, La-Mauricie, L'Estrie, Chaudiere-Appalaches and Lanaudiere in Quebec.

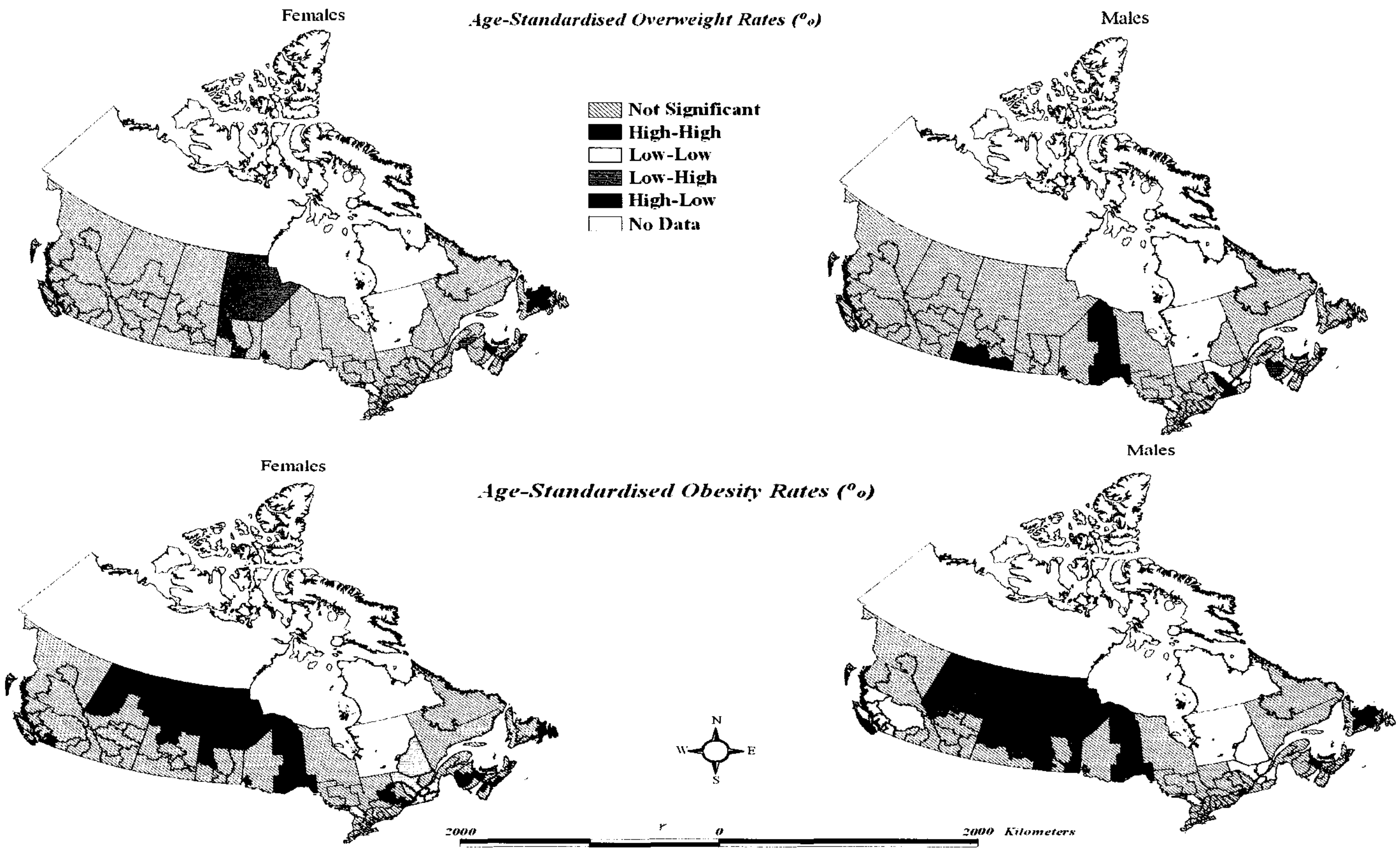

Figure 3: LISA cluster maps for age-standardised overweight (a) and obesity rates (b) in 2005 by health region in Canada

2.4 Discussion

This study illustrates the marked variability of overweight/obesity prevalence in Canada at the health region level. In addition, the significant positive spatial autocorrelation identified by Moran's I for both males and females as well as the significant local clusters identified by LISA confirm the presence of spatial heterogeneity (Anselin, 1994) and suggest the importance of developing/refining prevention programmes and health-related policies that are thus far mainly based on assumptions of spatial homogeneity (Vanasse et al., 2006; Katzmarzyk, 2002).

The difference in overweight/obesity between men and women is although not systematic is consistent with results from previous studies in Canada and abroad (Tjepkema, 2005). Differences in age structure cannot explain this finding, as data have been age-standardized. Instead, the higher age-standardized rates of overweight in men compared to women could be associated with biologic/genetic dissimilarities. In addition, differences in the spatial patterns of overweight/obesity might be explained by differences in educational attainment and income (Case and Menendez, 2007) as well as cultural norms and lifestyle characteristics (Tremblay et al., 2005).

This study demonstrates also that in the Northwest Territories/Yukon/Nunavut and the Atlantic health regions, age-standardized rates of overweight/obesity are much higher than the national average. A potential explanation for these differences might be the large proportion of Aboriginal peoples in these areas. In particular, although comprehensive data are not available for people living on reserves, some evidence from selected First Nations communities revealed high prevalence of overweight/obesity in these settings (deGonzague et al., 1999). Efforts to reduce burden of overweight/obesity must be therefore directed accordingly. Locally, hot spots were identified in the northern regions of Saskatchewan and Alberta as well as the eastern regions of Newfoundland and Labrador and Nova Scotia indicating that it may be also important not to treat each health region as an independent unit (`island`). Potential explanations for the identified clusters in this study include individual-level risk factors (Falkner et al., 2001; Lahti-Koski et al., 2000) (e.g. behavioural, demographic and socio-economic characteristics). However, the presence of clustered health regions could also indicate that these areas are fostering obesogenic environments in some manner, although further research would be necessary to tease out the actual mechanism driving the gradient in overweight/obesity in these high-risk areas.

It is worth noting though that in Canada, health regions are administrative areas defined by provincial ministries of health that are responsible for assessing and prioritizing needs and health goals as well as developing an integrated approach toward population health and health promotion. Therefore, detection of overweight/obesity cluster using the Moran's I and LISA could be an effective method of public health surveillance. That is, new clusters can be identified quickly, and public health responses can be utilized accordingly to minimize morbidity and/or mortality risks compounded by the overweight/obesity problem. For instance, based on the potential explanations for the identified clusters mentioned earlier, changes in existing policies and practices could include providing funding for physical education as well as recreation centres in communities most in need. In addition, initiatives could include developing culturally relevant obesity campaigns for high-risk population groups (e.g. Aboriginals). Further, while many researchers tend to focus on the detection of high-risk areas, it may be advantageous from the perspective of health promotion to further explore areas of low prevalence to ascertain for example, which factors might account for this populations` decreased risk. In general though, further research is required on the determinants of overweight/obesity on targeted/clustered areas, as this would improve our understanding of disease aetiology.

2.5 Study Limitations

There are two issues that need to be addressed. First, the overweight/obesity data used were based on self-reported information. However, given that individuals tend to over-report their stature and under-report their weight (Katzmarzyk, 2002a) the prevalences' of overweight/obesity reported in this study should be considered conservative. Second, the spatial patterns of overweight/obesity identified may change depending on the spatial scale used, an issue which is also referred to as the Modifiable Areal Unit Problem (MAUP). Nevertheless, we were unable to test for the influence of the MAUP in this study, due to data availability (i.e., the smallest unit of analysis available was the health region). Further, despite the promise of a number of methods for mitigating the MAUP, a widely accepted solution to this issue has yet to be found (King, 1979). Nonetheless, the regional variations in the prevalence of overweight/obesity established in this study verify the effectiveness of spatial data analysis methods and in particular cluster analysis as a helpful means for public health professionals and policy makers to tailor intervention strategies more effectively given the limited public health resources.

2.6 Conclusions

The findings established in this study strengthen previous studies' results by confirming marked sex-specific regional differences in the prevalence of overweight and obesity in Canada. In addition, the identification of spatial clusters provides additional valuable information on the local geographical variation of overweight/obesity in Canada. Application of Moran`s I and LISA verify the effectiveness of spatial data analysis methods and in particular cluster analysis as a helpful tool for public health professionals and policy makers to identify areas of elevated risk; therefore enabling regionally focused prevention and health promotion strategies as well as the effective allocation of resources and services based on regional and population specific demands. Yet, in order to move forward and tackle the problem of overweight/obesity, it will be necessary to address the broader determinants of this substantial public health issue. In particular, further research is required to demonstrate that the underlying mechanisms driving the increasing prevalence of overweight/obesity may be characteristics of the social- and built-environments. In that way, the overall health of the entire population could make substantial advances and the overall burden of overweight/obesity could be alleviated.

Endnote

The term 'hot spots' is widely used in spatial statistics (Anselin, 1994; Bailey and Gatrell, 1995), and has been used in various disciplines for identifying critical locales in a wide range of fields, including seismology (Chulick et al., 2001), epidemiology (Crighton et al., 2007; Tiwari et al., 2006) and criminology (Ratcliffe, 2004). Essentially, 'hot spots' simply refers to a significant cluster of homogenous data values.

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Conflicts of Interest

The authors declare that this research forms part of the Canadian Heart Health Surveys Follow-Up Study, an interdisciplinary, multi-site study funded by the Canadian Institute for Health Research (CIHR) and the Heart and Stroke Foundation of Canada.

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CHAPTER THREE

Individual and Socio-Environmental Determinants of Overweight and Obesity in Urban Canada

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Abstract

Overweight/obesity represent a significant public health problem in Canada and abroad. The objective of this paper is to identify heterogeneities associated with the relationships between overweight/obesity and individual as well as socio-environmental determinants. The data sources used are the 2003 Canadian Community Health Survey and the Desktop Mapping Technologies Incorporated database. Geographical Information Systems are first employed to create neighbourhood-level variables such as population density, neighbourhood walkability and fast food accessibility. Multivariate analysis is then applied to estimate the relative effects of individual- and neighbourhood-level risk-factors of overweight/obesity. Results demonstrate the important role of the built-environment after adjustment demographic, socio-economic and behavioural characteristics. Findings support the rationale that reversing current trends will require a multifaceted public health approach where interventions are developed from the individual- to the neighbourhood-level, specifically focusing on altering obesogenic environments.

Keywords: Obesity, determinants, built environment, walkability index, socio-economic status, Canada, population health framework

3.1 Introduction

Overweight and obesity are now widely recognized as not only a major public health problem but literally an epidemic. Over the past two decades, the prevalence of obesity has risen with the most substantial increases observed in economically developed countries (Katzmarzyk and Mason, 2006). In particular, in developed countries, between ten and twenty percent of people are obese, and the problem is not unknown in less developed countries (Katzmarzyk, 2002). For many years, obesity has been studied as an important risk factor for cardiovascular and other chronic diseases with grave implications for individuals as well as populations (National Institute of Health, 2004). It has been recognized that obesity increases the risk of diabetes, heart disease and hypertension as well as impacts the psychosocial state and quality of life of individuals and families (Raine, 2004). Further, overweight/obesity have been associated with increased prevalence of primary-care visits, exacerbating the load on an already overburdened health-care system (Bertakis and Azari, 2005). According to Katzmarzyk and Janssen (2004), the direct and indirect medical costs associated with overweight and obesity in Canada in 2001 were estimated at \$1.6 billion (CAD), and \$2.7 billion (CAD) respectively, representing 2.2 percent of the total health-care costs.

Within the Canadian context, the problem of excess adiposity was recognized almost 50 years ago and was the stimulus for the 1953 Canadian Weight-Height Survey (CWHS) (Katzmarzyk, 2002a). The CWHS was the first nationally representative survey of measured stature and body mass in Canada. Since then, data on obesity trends have emerged through a number of different surveys based primarily on self-report. These data indicate that the national prevalence of obesity in adults increased from 5.6 percent in 1985 to almost 15 percent in 1998 (Katzmarzyk, 2002). More recent self-reported data from the 2005 Canadian Community Health Survey (CCHS) identified that approximately 4 million adults (18 percent) were obese and an additional 8 million adults (34 percent) were overweight.

Obesity research to date has primarily been informed by a biomedical model of health and illness, thus focusing on the physiological risks and temporal trends of obesity (Willms et al., 2003; O'Loughlin et al., 1998) as well as the demographic and socio-economic risk factors of overweight and obesity(Stam-Moraga et al., 1999; Lahti-Koski et al., 2000). For example, obesity and overweight has been linked to diet, physical activity levels, education and income (Shields, 2005; Tjepkema, 2005). This provides us with some but very limited explanation of prevalence and trends of this important public health issue. In particular, there is a growing consensus that individual factors may be unable to slow and/or reverse current obesity trends at the population level, as individuals are embedded within social and physical environments that may also play a significant role in shaping health (Macintyre et al., 2002; Duncan et al., 1998; Curtis and Taket, 1996). What is therefore needed is a focus on a broader range of socio-environmental determinants towards a more complete picture of how and why obesity occurs in its current form in order that we may intervene and therefore stem the tide of this growing public health problem.

In view of the foregoing, the current research is well placed to explore the aforementioned gaps in the existing literature. In particular, there are two objectives of this research:

(1) To investigate the prevalence and determinants of overweight and obesity in Canada using spatial analysis and geographical information systems (GIS).

(2) To identify heterogeneities associated with the relationships between individual and socio-environmental determinants and overweight and obesity at the individual- and community-levels.

3.2 Obesity and the environment

This paper addresses the individual and socio-environmental determinants of overweight and obesity through the lens of the population health perspective (Evans et al., 1994). This perspective attempts to understand and explain health at the level of populations by going beyond the characteristics of the individual (e.g., diet, physical activity levels) to incorporate aspects of the broader environments, both physical (e.g., the built environment) and social (e.g., social cohesion). This broader perspective on the determinants of health may improve our understanding of overweight/obesity, allowing us to point in a useful policy direction vis-à-vis response.

Much research on the determinants of overweight and obesity has primarily focused on exploring and identifying individual risk factors. In particular, several studies have found overweight and obesity to be associated with genetic, physiological and behavioural characteristics such as age, gender, diet and physical activity (Tjepkema, 2005; Bouchard, 1994; Trakas et al., 1999; Raine, 2004; Hill et al., 2003). While these studies have had some success in informing intervention approaches for overweight and obesity, they have failed to fully explain and/or reverse the rapid growth in overweight and obesity over the past two decades, reflecting in this way, the widespread and relatively democratic nature of the current obesity epidemic.

The possibility that socio-economic status (SES)[1] might also be related to body weight was first raised more than a century ago by Veblen (1889: in Sobal and Stunkard, 1989) in his speculation that thinness became an ideal of feminine beauty when it served as a status symbol of an emerging leisure class. Since then, the relationship between socio-economic status and obesity has been examined in many studies; however, there is no consensus about the assessment of socio-economic status as different researchers have chosen different indicators. Among them, education level (Robert and Reither, 2004; Molarius et al., 2000), income (Isaacs and Schroeder, 2004) as well as occupational attainment (Lahti-Koski et al., 2000; Galobardes et al., 2000) have been widely used as indicators of SES. Findings generally indicate an inverse association between overweight/obesity and SES, regardless of the SES indicator used (McLaren, 2007). For example, Galobardes et al. (2000) have found that overweight men were more likely to have low education while overweight women had lower education and lower occupation.

In addition, recent studies refer to the social environment that includes the family, neighbourhood and general socio-cultural network. To date, measures of the social environment including social cohesion and collective efficacy have been found to be

[1] In this case, Socio-Economic Status (SES) has been used to include one or more of the following indicators: income, education and occupational status as well as both individual and community levels of analysis.

positively associated with obesity. For example, Cohen et al (2006) found that relationships between neighbors (used as an indicator of social cohesion) are significantly associated with obesity and CVD in the United States. Alternatively, objective indicators of the social environment such as policing levels and recorded crime rates have also been found to have a significant association with obesity (Robert and Reither, 2004).

Currently, there is a growing consensus among the scientific community that aspects of the physical environment serve as potential determinants of overweight and obesity. In general, we have seen that existing literature demonstrates that aspects of the physical environment contribute to the unexplained variation for a range of health-related issues (Macintyre et al., 2002). However, a major barrier has been the conceptualization, measurement of the built environment. In particular, Ewing et al., (2003) were the first to demonstrate an association between obesity and the built environment. Later, Lopez (2004) examined this relationship among U.S. adults using the urban sprawl index, developed based on the percentage of populations living in low and high-density areas and adjusted to a scale ranging from 0-100. Higher values of the index indicate areas characterized by more sprawl. After controlling for gender, age, race/ethnicity, income, and education, Lopez (2004) found that for every 1-point increase in the urban sprawl index, the risk for being obese increased by 0.5 percent. However, the aggregate data used in this study required that the built environment be measured at the county level. The walkability of the built environment varied considerably from one neighbourhood street to the next, suggesting that whole counties may not capture the unique urban form stimuli experienced by each person at their place of residence.

Research has therefore started focusing on more local environmental indicators that could be associated with overweight and obesity. However, the majority of studies has focused on perceived rather than objective measures of the local environment (Saelens et al., 2003). A notable exception is a study by Frank et al. (2004) who used geographic information systems (GIS) techniques to develop measures of walkability at the neighbourhood level based on landuse mix, number of intersections and residential density. In particular, Frank et al (2004) demonstrated that the likelihood of obesity decreased by 4.8 percent with each additional kilometer walked per day and by 12.2 percent for every quartile increase in land-use mix. Although Frank et al. (2004) adjusted for socio-demographic covariates including age, gender, income, education and race/ethnicity, they did not take into consideration the potential contribution of the dietary habits, exercise practices of the participants (other than walking) as well as density of opportunities (e.g. fast-food restaurants and recreation centers).

Lately, GIS and spatial analysis have been used to explore the accessibility to various opportunities for eating and physical activity, including access to fast-food restaurants, supermarkets as well as walking paths, trails and recreational centers (Scott et al., 2007; Powell et al., 2007). For example, Powell et al. (2007) examined the association between adolescent weight and food stores accessibility and found that increased availability of chain supermarkets was significantly associated with lower BMI and greater availability of convenience stores was significantly associated with higher BMI in adolescents. However, Powell et al. (2007) did not account for the potential contribution of other environmental features such as land-use mix and network connectivity, which might modify the effect of accessibility measures on BMI.

In addition, the major contributions on the obesity-related literature come from Europe and the United States (Novak et al., 2006; Ewing et al., 2003); there is a distinct lack of research in a Canadian setting. Yet, the population of Canada differs in important ways: population demographics, distribution of social and economic resources, and availability and quality of health care (Katzmarzyk, 2004; Ross, Wolfson, Dunn et al., 2000). Thus, more research is required in order to identify determinants specific to the Canadian population.

What is therefore apparent is that while the volume of literature exploring the determinants of overweight and obesity is expanding, the field offers important opportunities for further study. In particular, this brief review of literature revealed the general lack of a theoretical framework that underpins the broader individual as well as environmental (physical and social) determinants of overweight and obesity. Further, current research findings suggested that the social context of the determinants of overweight and obesity is generally not well explored and requires further investigation. In addition, no existing studies have explored the association between weight status and the built environment using both the neighbourhood-level (i.e. walkability index) as well as various accessibility measures (i.e. density of fast-food restaurants). Therefore, we felt that it would be worthwhile to apply the population health framework in order to identify as well as better understand the environments that foster high-energy diets and sedentary lifestyles. This research will thus contribute to the existing literature by (1) applying the population health framework towards an empirical exploration of the individual as well as environmental determinants of overweight and obesity, (2) building upon the relatively limited number of studies on the environmental determinants of obesity using objectively measured environmental features (e.g., walkability index, accessibility measures) and (3) exploring the potential contribution of the social environment using a nationally representative health-related database in Canada.

3.3 Research Design and Methodology

This research will explore the determinants of overweight and obesity with particular emphasis on social and environmental risk factors, incorporating both individual and community level indicators. Spatial data analysis and GIS techniques were employed to assess the contribution of the built environment. The use of such methodologies for measurement and analysis of the built environment is still in its infancy; however as mentioned earlier obesity has been linked to several aspects of the built environment such as landuse mix, network connectivity as well as the density of fast-food outlets and grocery stores.

For the purposes of this study we chose Canada's two largest metropolitan areas for several reasons. First, approximately one-third of all Canadians live in these metropolitan areas. Secondly, choosing Canada's largest CMAs is likely to capture the socio-cultural diversity of Canada's population. Finally, both CMAs are characterized by various neighbourhood designs ranging from high to low on a continuum of walkability and density. Thus, Toronto and Vancouver CMAs provide a useful case study for the individual and socio-environmental determinants of overweight/obesity in Canada.

3.3.1 Data Sources

The data sources used for the purposes of this research were: 1) 2003 Canadian Community Health Survey (CCHS), Cycle 2.1, master file and 2) the 2003 CanMap RouteLogistics (CMRL) spatial information database on land-uses as well as the 2003 enhanced points of interest (EPOI) file from the Desktop Mapping Technologies Incorporation (DMTI). These data sources were matched based on postal code residential information available in the master files of the CCHS database.

The CCHS provides cross-sectional health and social indicator data on a large sample of Canadians and is intended to provide reliable estimates of health outcomes and health determinants at sub-provincial scales of analyses. The target population of the CCHS is individuals 12 years of age and over living in private dwellings, excluding those living on Indian Reserves or Crown lands, clientele of institutions, full-time members of the Canadian Armed Forces, and residents of certain remote regions. Using a multistage stratified cluster design approach a total of 134,072 individuals participated in the survey, with a response rate of 80.7%. A detailed description of the CCHS design and questionnaire is available elsewhere (Statistics Canada, 2005). The use of the micro-data file allowed for access to a sub-national disaggregation of the data (postal codes are available only in the CCHS master files) as well as linkage with the DMTI spatial database, using the Statistics Canada's postal code conversion file.

The CCHS 2.1 cycle included self-reported data on weight and height for all individuals 20 years and older, excluding pregnant women (N=115,548). Using the weight and height data, the body mass index (BMI) was calculated by Statistics Canada based on the following (2005):

$$BMI = weight\ (kg)/height^2\ (m^2)$$

Individuals with missing BMI records due to invalid data were excluded from the analysis (n=4,080) Therefore, the total sample size for all individuals aged 20 and older and with no missing BMI records was 111,468. A number of outliers were excluded from the analysis as we deemed their BMI values to be inaccurate (i.e. cases were excluded if the reported BMI was more than 100 kg/m^2 and could not be justified by all other characteristics of the individual). All data were weighted using the combined weight provided by Statistics Canada as part of the public use micro-data file. This has the effect of generating estimates relevant to the Canadian population under study. Further, as mentioned earlier, we included only those individuals residing in the Toronto and Vancouver CMAs. Therefore, the final sample included in the analysis was based on 5,418,218 (N weighted) participants 20 years and older.

3.3.2 Independent variables

Multiple independent variables were used to account for individual, socio-economic and built and social environmental characteristics. Based on a review of the literature, demographic, health status, lifestyle, and socioeconomic features were drawn from the CCHS data set. The determinants of health included within this analysis may be divided into four categories, including health status, demographic, socio-economic, and lifestyle variables (Table 1). Health status variables included chronic disease status, such as cardiovascular diseases, rheumatoid/arthritis and anxiety mood disorders.

Socio-economic variables included income adequacy (based upon income and household size), employment status, home ownership, and education level. Demographic variables included age, gender, martial status, period of arrival in Canada, race/ethnicity, while smoking, drinking, and physical activity and fruits and vegetable consumption defined the lifestyle variables. Characteristics of the social environment of the individuals was also acquired from the CCHS data and included information on whether the individual was a member of a voluntary organization as well as their sense of belonging to the local community. Categorical representations of these explanatory variables were included within the models based upon a priori expectations, with one value of each variable used as the reference category, typically representative or linked to poorer states of health (i.e., regular smokers, heavy drinkers, suffering from a chronic disease).

The existing geographic databases (CanMap RouteLogistics) provided by the DMTI maintains a current street address database as well as many other data layers (e.g., boundary files, street networks and land-use information) from which the characteristics of the built-environment relevant to this study were derived. Such measures could further assist toward a better understanding of the potential impacts of accessibility to different amenities on health (e.g., access to fast-food restaurants versus fitness centres).

Table 1: Variables of interest

Variable Name	Type	Units/Categories
Age	Continuous	Years
Gender	Categorical	Male; Female
Marital Status	Categorical	Married/common law; Other
Recent Immigrant	Categorical	Less than 10 years in Canada; More than 10 years in Canada
Ethnicity/Race	Categorical	White; Asian; Other
Smoking	Categorical	Regular smoker; Non-regular smoker
Alcohol	Categorical	Regular drinker; Non-regular drinker
Energy Expenditure	Continuous	kcal/kg/day
Fruits and Vegetable Consumption	Categorical	Less than 5 times per day; 5-10 times per day; more than 10 times per day
Employment	Categorical	Full-time; Other
Diabetes	Categorical	Has diabetes; No diabetes
Thyroid	Categorical	Has thyroid; No thyroid
High Blood Pressure	Categorical	Has high blood pressure; No high blood pressure
Anxiety-Mood Disorder	Categorical	Has an anxiety/mood disorder; No disorder
Arthritis/Rheumatism	Categorical	Has arthritis/rheumatism; No arthritis/rheumatism
Income	Categorical	Less than $20,000; 20,000-39,999; 40,000-59,999; 60,000-79,999; More than 80,000
Income Adequacy	Categorical	Low adequacy; Medium adequacy; High adequacy
Household size	Continuous	Number of people in the household
Home Ownership	Categorical	Owner; Other
Education	Categorical	Less than secondary; Secondary; More than secondary
Member of a Voluntary Organisation	Categorical	Member; Non-member

Seven built-environment variables were constructed: land-use mix, street network connectivity, residential density, density of fast-food restaurants, density of convenience stores, density of grocery stores and supermarkets and density of recreational activities facilities. Brief operational definitions for each appear below.

Land-use mix. Land-use mix was operationalised using the method provided by Frank and Engelke (2001), which provides a measure of the evenness of distribution of several land-use types (i.e., residential, commercial, industrial, institutional and open space) within the study's geographic area and can be described by LUM = $-\sum_{i=1}^{5}\frac{p_i \ln(p_i)}{\ln(5)}$. In this study, data for five land-use types are available (i.e. residential, commercial, industrial, institutional and open space). Therefore, the proportion for the residential land use type will be estimated as follows:

$$p_{residential} = \frac{\text{square footage of residential land - use}}{\text{total square footage of residential, commercial, industrial, institutional and open space}}$$

In general, values of LUM vary on a continuous scale between 0 and 1, with one indicating even distribution of all land-use categories (heterogeneity) and zero implying a single type of land-use (homogeneity). An illustration of the development of the LUM is shown in Figure 1.

Figure 1: Illustration of the development of land-use distribution

Street network connectivity. The number of street intersections divided by area in square kilometers.

Residential density. number of occupied households per residential land-use in square kilometers

Density of fast-food restaurants. The number of fast-food restaurants divided by area in square kilometers.

Density of convenience stores. The number of stores divided by area in square kilometers.

Density of grocery stores and supermarkets. The number of grocery stores and supermarkets divided by area in square kilometers.

Density of recreational activities facilities. The number of recreational activities facilities (i.e. bowling, dance studios, gyms, youth organizations) divided by area in square kilometers.

Measures of the built environment could be correlated. That is, areas with higher residential density are characterized by mixed landuses and an interconnected street network (Frank et al., 2006). The degree of correlation may also create model estimation problems associated with multicollinearity (i.e. two or more of the independent variables are correlated) (Anselin, 1995; Gatrell and Bailey, 1996). To avoid this issue, a walkability index was derived by taking the sum of z-scores for the residential density, street network connectivity and landuse mix variables. Higher values of the walkability index indicate a walkable built environment.

3.3.3 Statistical analyses

Descriptive and multivariate techniques were applied to examine the potential association between overweight/obesity and a number of individual and socio-environmental determinants in Toronto and Vancouver CMAs using the SAS software.

Spatial data analysis and GIS techniques were first employed to assess the contribution of the built environment. The process involved three steps: 1) geocoding participants' residential addresses; 2) creating "buffers," (i.e. bounded areas of a specific dimension, around each residence location in which built environment features are subsequently quantified; and 3) linking built environment data sources (e.g., land-uses) to geocoded participants' buffers to measure the built environment near the participant's residence (e.g., land-use mix). Arcview 3.3 (ESRI, 2002) software was used to geocode participant addresses and create 1-km buffers, with distances based on the street network. Along these lines, measures of the built environment could be assessed in order to better understand the potential contribution of the built environment in the development of overweight/obesity in Toronto and Vancouver CMAs.

Bivariate analysis was first incorporated to identify explanatory variables with the strongest influence on overweight and obesity variations. In this study, in order to model the relationship between BMI and a number of individual, socio-demographic and environmental (e.g. land-use mix, number of fast-food outlets) variables, we applied multivariate linear regression based on a stepwise variable selection procedure. The goodness of fit for linear regression is represented by the coefficient of variation or R^2, which is defined as one minus the ratio of residual sum of squares divided by the total sum of squares. The value of R^2 is a fraction between 0.0 and 1.0, and has no units. An R^2 value of 0.0 means that there is no linear relationship between the dependent and independent variables while a value of 1, indicates that all points lie exactly on a straight line (Younger, 1985).

3.4 Results

Table 2 presents a demographic and socio-economic profile of the sample from the CCHS, and summarizes the data for respondents. Men and women were almost equally likely to be included in the sample for both Toronto and Vancouver (50.12 percent females and 49.37 percent respectively) and the median age was similar for both sample groups (44 years for Toronto, 45 years for Vancouver). Average BMI of respondents was also similar for both study sites (25.03 for Toronto and 24.47 for Vancouver); however there were differences in individuals classified as overweight (31.29 percent in Toronto and 28.88 percent in Vancouver) and obese (12.55 percent of the Toronto sample and 9.25 percent of the Vancouver sample). The Toronto sample had a higher percentage of Black (4.79 percent) and a lower percentage of Asian individuals (23.21 percent) compared to the Vancouver sample (0.5 and 30.21 respectively) (Table 2). Finally, in the Toronto sample, there were fewer individuals with low income (8.36 percent) and more individuals with income more than 80,000 (40.06 percent) compared to the Vancouver sample (13.16 and 33.19 percent respectively).

Table 2: Descriptive statistics (weighted sample)

Sample Characteristics	Toronto, CMA	Vancouver, CMA
N*	3787244	1630974
Female, (%)	1898355 (50.12)	805132 (49.37)
Age, mean, (years)	44.10	45.02
Ethnicity, (%)		
White	2313051 (63.21)	1015944 (63.23)
Black	175115 (4.79)	7965 (0.50)
Asian	849425 (23.21)	485324 (30.21)
Other ethnicity	321898 (8.80)	105366 (6.56)
Marital Status, (%)		
Single	1005296 (26.57)	403725 (24.84)
Married	2351493 (62.15)	1017974 (62.64)
Other (Seperated/Divorced/Widowed)	427041 (11.29)	203456 (12.52)
Education, (%)		
Less than high school	558422 (15.03)	192683 (12.22)
High school completed	764949 (20.59)	331422 (21.02)
Diploma	1361312 (36.65)	643830 (40.83)
University degree or higher	1029655 (27.72)	409037 (25.94)
Household Income, (%), (CN$)		
<20,000	274586 (8.36)	169685 (13.16)
20,000 - 40,000	543638 (16.54)	229373 (17.79)
40,001 - 60,000	5999901 (18.26)	247210 (19.18)
60,001 - 80,000	551545 (16.78)	215079 (16.68)
>80,000	1316557 (40.06)	427806 (33.19)
Employment, (%)		
Full-time	2348498 (64.56)	956527 (59.93)
Part-time	405680 (11.15)	210809 (13.21)
Not employed/not in labour force	883505 (24.29)	428715 (26.86)
Length of time in Canada since immigration, mean, (years)	21.16	19.97
Immigrants	1871938 (51.21)	678909 (42.41)
More than 10 years in Canada since immigration, (%)	1338215 (71.49)	461268 (67.94)
Household size, mean, (individuals)	3.34	3.10
Own Dwelling, (%)	2805048 (74.15)	1173555 (73.26)
Urban, (%)	3654479 (96.49)	1578915 (96.81)
Body Mass Index, mean, (kg/m^2)	25.03	24.47
Underweight, (%)	147769 (3.9)	68296 (4.19)
Normal weight, (%)	1979245 (52.26)	940892 (57.69)
Overweight, (%)	1185079 (31.29)	471050 (28.88)
Obese, (%)	475152 (12.55)	150736 (9.25)

*N may vary due to missing values on some variables

The final multivariate models capturing relationships between various individual-level environmental characteristics with BMI are presented in Tables 3 and 4. As shown in Tables 3 and 4, three models were run. Model 1 included only the demographic, individual and socio-economic variables, Model 2 incorporated the walkability index and in Model 3 regression coefficients were expanded using interaction terms. All results are presented as β estimates, and may be interpreted as the absolute change in BMI associated with a one-unit change in the independent variable.

As expected, age and sex were found to be statistically significant. In general, it was found that age was positively associated with BMI for both Toronto (Table 3) and Vancouver (Table 4). However, we included the age-squared effect to account for the non-linear association between age and BMI. Additionally, the relationship found between sex and the outcome variable was also significant, indicating that males have larger average BMI's than their female counterparts by 1.54 kg/m^2 (Table 3) for Toronto and 1.75 kg/m^2 for Vancouver (Table 4).

In addition, Tables 3 and 4 reference health disparities with respect to diagnosed chronic conditions that have been found to be associated with overweight and obesity. In particular, individuals with rheumatoid/ arthritis, high blood pressure, diabetes and/or anxiety/mood disorder have higher BMI values by 0.84, 2.02, 1.86 and 0.62 kg/m^2 respectively for Toronto (Table 3). Similarly for Vancouver, based on Model 1, individuals with chronic conditions including rheumatoid/ arthritis, high blood pressure, diabetes, thyroid and/or anxiety/mood disorder have higher BMI values compared to those not having a chronic condition (Table 4).

Table 3: Multivariate regression results - Toronto, CMA

Variable	Model 1	Model 2	Model 3
Intercept	16.81134 (16.0367, 17.5860) ***	16.85054 (16.0745, 17.6265) ***	16.98843 (16.1915, 17.7854) ***
Age	0.27078 (0.2393, 0.3022) ***	0.26955 (0.2381, 0.3010) ***	0.27023 (0.2388, 0.3017) ***
Age^2	-0.0027 (-0.0031, - 0024) ***	-0.00272 (-0.0030, -0.0024) ***	-0.00273 (-0.0030, -0.0024) ***
Female (ref.)	---	---	---
Male	1.54092 (1.3381, 1.7437) ***	1.53707 (1.3343, 1.7399) ***	1.20132 (0.7559, 1.6467) ***
Arthritis - Rheutism	0.83924 (0.5503, 1,1282) ***	0.83666 (0.5477, 1.1256) ***	0.82435 (0.5357, 1.1130) ***
High Blood Pressure	2.02399 (1.7278, 2.3202) ***	2.02623 (1.7301, 2.3224) ***	2.02431 (1.7286, 2.3200) ***
Diabetes	1.86108 (1.3856, 2.3366) ***	1.87199 (1.3964, 2.3476) ***	1.8213 (1.3460, 2.2966) ***
Anxiety - Mood Disorder	0.61613 (0.2245, 1.0077) *	0.62163 (0.2300, 1.0132) *	1.00219 (0.5229, 1.4814) ***
Energy Expenditure	-0.15055 (-0.2009, - 0.1002)***	-0.15178 (-0.2022, -0.1014) ***	-0.1521 (-0.2024, -0.1018) ***
Regular Smoker	-0.49429 (-0.7440, -0.2445) ***	-0.48371 (-0.7338, -0.2337) ***	-0.46065 (-0.7109, -0.2104) ***
Race - White	1.75787 (1.5060, 2.0097) ***	1.73903 (1.4863, 1.9918) ***	1.34638 (1.0013, 1.6915) ***
Race - Asian (ref.)	---	---	---
Race - Other	1.535 (1.1032, 1.9668) ***	1.53368 (1.1019, 1.9655) ***	1.38653 (0.7887, 1.9844) ***
Less than Secondary	0.58565 (0.2827, 0.8886) ***	0.58496 (0.2821, 0.8879) ***	1.01858 (0.6182, 1.4189) ***
Secondary	0.3547 (0.0986, 0.6107) *	0.3423 (0.0858, 0.5988) **	0.4713 (0.1271, 0.8155)
More than Secondary (ref.)	---	---	---
Walkability Index		-0.03941 (-0.0864, 0.0076)	-0.03885 (-0.0858, 0.0081)
Anxiety - Mood Disorder * Males			-1.07579 (-1.8977, -0.2539) *
Race - White *Males			0.81691 (0.3282, 1.3056) **
Race - Asian * Males (ref.)			---
Race - Other * Males			0.2965 (-0.5649, 1.1579)
Less than Secondary *Males			-0.93515 (-1.5055, -0.3648) **
Secondary * Males			-0.27212 (-0.7803, 0.2361)
More than Secondary * Males (ref.)			---
R^2 (Adjusted R^2)	0.1492 (0.1476)	0.1495 (0.1478)	0.1528 (0.1515)

p<0.001 *; p<0.01 **; p<0.05 ***

ref: reference category

Table 4: Multivariate regression results - Vancouver, CMA

Variable	Model 1	Model 2	Model 3
Intercept	17.18927 (16.3220, 18.0566) ***	17.25968 (16.3908, 18.1285)***	16.86947 (15.9742, 17.7647) ***
Age	0.19018 (0.1540, 0.2263) ***	0.18753 (0.1513, 0.2237) ***	0.1891 (0.1529, 0.2253) ***
Age^2	-0.00181 (-0.0022, -0.0014) ***	-0.00178 (-0.0021, -0.0014) ***	-0.00181 (-0.0022, -0.0014) ***
Male	1.75142 (1.5115, 1.9914) ***	1.74713 (1.5073, 1.9870) ****	2.5267 (2.0171, 3.0363) ***
Female (ref.)	---	---	---
Arthritis - Rheutism	0.87753 (0.5405, 1.2146) ***	0.88174 (0.5448, 0.2186) ***	0.8773 (0.5410, 1.2136) ***
High Blood Pressure	1.40389 (1.0542, 1.7536) ***	1.40253 (1.0530, 1.7521) ***	1.34717 (0.9978, 1.6965) ***
Diabetes	1.83117 (1.2961, 2.3663) ***	1.81308 (1.2780, 2.3481) ***	1.85319 (1.3194, 2.3870) ***
Thyroid	1.06668 (0.5387, 1.5947) ***	1.07162 (0.5439, 1.5994) ***	1.01846 (0.4918, 1.5451) ***
Anxiety - Mood Disorder	0.58648 (0.1627, 1.0103) **	0.60625 (0.1823, 1.0302) **	1.07237 (0.5668, 1.5780) ***
Energy Expenditure	-0.11322 (-0.1666, -0.0598) ***	-0.1137 (-0.1671, -0.0603) ***	-0.10835 (-0.1616, -0.0551) ***
Regular Smoker	-0.72105 (-1.0263, -0.4158) ***	-0.70075 (-1.0063, -0.3952) ***	-0.68167 (-0.9873, -0.3761) ***
Employed - Full Time	0.38065 (0.1002, 0.6611) **	0.38648 (0.1062, 0.6668) **	0.37104 (0.0912, 0.6509) **
Race - White	2.35701 (2.0718, 2.6422) ***	2.3359 (2.0502, 2.6216) ***	2.58321 (2.1987, 2.9677) ***
Race - Asian (ref.)	---	---	---
Race - Other	2.12913 (1.6113, 2.6470)***	2.15466 (1.6367, 2.6727) ***	2.41632 (1.7187, 3.1139) ***
Less than Secondary	0.50603 (0.1324, 0.8797) **	0.50569 (0.1322, 0.8792) **	1.17872 (0.6879, 1.6695) **
Secondary	0.1868 (-0.1036, 0.4772)	0.16089 (-0.1302, 0.4519)	0.45109 (0.0599, 0.8422) *
More than Secondary (ref.)	---	---	---
Walkability Index		-0.06131 (-0.1122, -0.0104) *	-0.06007 (-0.1109, -0.0093) *
Anxiety - Mood Disorder * Males			-1.50053 (-2.4016, -0.5995) ***
Race - White *Males			-0.47991 (-1.0323, 0.0724)
Race - Asian * Males (ref.)			---
Race - Other * Males			-0.55608 (-1.5890, 0.4769)
Less than Secondary *Males			-1.41478 (-2.1241, -0.7055) ***
Secondary * Males			-0.62043 (-1.1994, 0.0415) *
More than Secondary * Males (ref.)			---
R^2	0.1649 (0.1623)	0.1658 (0.1631)	0.1714 (0.1679)

p<0.001 *; p<0.01 **; p<0.05 ***

ref: reference category

Individual-level behavioural characteristics have been well established in the literature as important risk factors for overweight and obesity. Variables related to diet (e.g. fruits and vegetable consumption) were not included in the final models presented here, as they were not found to be significant. However, variables representing individual physical activity and smoking status were both included. Energy expenditure was a very important predictor of BMI. Specifically, energy expenditure was negatively associated with BMI indicating that individuals with higher energy expenditure values had lower BMIs by 0.15 kg/m^2 for Toronto (Table 3) and 0.11 kg/m^2 for Vancouver (Table 4). Finally, self-reported smoking status (i.e. regular smoker) was found to be inversely associated with BMI. Specifically, being a smoker predicted a lower BMI by 0.49 kg/m^2 for Toronto, on average, after controlling for all other individual-level covariates (Table 3). For Vancouver the effect of smoking was also significant and pointing to an even lower BMI value of 0.72 kg/m^2 for smokers (Table 4).

Race was also found to be significantly associated with BMI. As expected, for Toronto whites or individuals from any other than Asian race had higher BMI values by 1.76 and 1.54 kg/m^2 respectively, compared to Asians (reference category) (Table 3). However, the effect of race on BMI was stronger in Vancouver with whites and individuals from any other than Asian race having higher BMI values by 2.36 and 2.13 kg/m^2 respectively, compared to Asians (Table 4). High school education was a very strong socio-economic covariate of overweight and obesity. This relationship emerged as a much stronger indicator than any measure of socio-economic status (e.g., average family income or income adequacy). In particular, based on the basic model (Model 1), individuals who have not completed a high school education have a higher BMI value by 0.59 kg/m^2 for Toronto and by 0.51 kg/m^2 for Vancouver. Similarly, the coefficients from the individuals that have completed a high school education but do not have a diploma and/or university degree (reference category) have higher BMIs by 0.35 kg/m^2 (Table3) for Toronto and 0.19 kg/m^2 for Vancouver (Table 4).

In Model 2, the walkability index was included into the model. Based on Tables 3 and 4, individuals living in more walkable areas had lower BMI's on average by 0.04 kg/m^2 for Toronto and 0.06 kg/m^2 for Vancouver than those living in the least walkable areas. However, the relationship between BMI and the walkability index was not significant for Toronto and marginally significant for Vancouver, indicating that the results need to be interpreted with caution.

Finally, in Model 3, significant gender differences have been found in terms of the psychological and socio-economic characteristics of the individuals. In particular, based on Model 3, females with an anxiety/mood disorder have higher BMI values compared to their counterpart males. In addition, as mentioned earlier, individuals with low levels of education (less than high school, high school) had higher BMI's compared to those with higher levels of education. However, the strength of this relationship tended to be slightly stronger for females than for males. Also, white and other than Asian males had lower BMI's compared to white and other than Asian females.

The overall performance of the models in terms of the percentage of the variation of the dependent variables explained by the variation of the independent variables (R^2) was good. The highest Adjusted R^2 obtained was 0.1505 (Toronto) indicating that 15.05

percent of the variation of the BMI values is explained by the variation of the independent variables included in the model. For Vancouver, the highest Adjusted R^2 obtained was 0.1679 indicating that 16.79 percent of the BMI variation is explained by the variation of the independent variables. Nevertheless, the large size of the sample ensured the robustness of the relationships established.

3.5 Discussion

The central aim of this research was to understand and quantify the potential individual, socio-economic and environmental determinants of overweight and obesity in Toronto and Vancouver, CMAs. The results of the analyses support the existing literature, underscoring the evidence for an association between BMI and age, gender, chronic diseases, energy expenditure, race, educational level and the walkability index.

In addition, this study provided further evidence on the application of GIS methods to develop environmental variables as well as the association between BMI and the built environment. In particular, a key aspect of this study is that the method for deriving a walkability index, though developed in the USA (Frank et al., 2004) appears to be highly applicable in Canada as well. The index may therefore be generalizable to other countries, but the requirement for detailed land use and census data can limit the ability for others to directly apply it to the degree that was possible in the current study. Further, it is worthwhile noting that, to our knowledge, this is the first study in Canada that utilized GIS methods to develop built environment characteristics and model the variability of BMI.

In addition, while the relationship between the built environment and obesity has been examined in many studies, there is a lack of a clear rationale for choosing built environment measures. For example, while many have used measures of urban form and landuse mix (Frank and Engelke, 2001; Ewing et al., 2003), others have explored the potential association between weight status and the built environment using measures of accessibility (Scott et al., 2007; Powell et al., 2007). Nevertheless, no existing studies have explored the association between weight status and the built environment using both the neighbourhood-level (i.e. walkability index) as well as various accessibility measures (i.e. density of fast-food restaurants). The findings of this study indicated though, that compared to accessibility measures, the walkability index generally performed as a better indicator of the built environment for both Toronto and Vancouver. Employing a more sensitive estimate of the built environment could be therefore used to better assess the environmental determinants of overweight and obesity.

Also interesting are the variables that were not found to be significant in the models. For example, income was not significantly associated with BMI, although it has been traditionally and widely used as an indicator of individual socio-economic status in health-related studies (Diez Roux, 2000; Sundquist et al., 1999). This study demonstrated that education might act as a more sensitive determinant of overweight and obesity in a Canadian context compared to similar studies in US (Swinburn et al., 1999) indicating a potential difference in SES measures between the US and Canada. Nevertheless, the relationship must not be discounted and further analysis examining alternative measures of SES should be considered. The social environment indicators (i.e. member of a voluntary organization and sense of belonging in the local community) were also not significantly associated with weight status. This suggests the following possible explanations: the variables used are not adequate measures of the social environment; there is a mismatch between the scale of analysis and the scale of the underlying process; or more simply, that the social environment does not equate with the weight status of individuals in urban Canada. This last explanation seems unlikely given that Cohen et al. (2006) found that that trust between neighbours was negatively associated with obesity.

Through this study, it became clear that the use of interaction terms could demonstrate potential differences on the determinants of overweight and obesity among genders. The difference could potentially be due to differences in the social constructs of gender (Diamond, 2000). For example, findings suggested that overweight and obese females are more likely to be diagnosed with a psychosocial disorder (e.g., anxiety, mood disorder) than males, confirming existing research on the association between obesity and psychosocial characteristics (Steptoe et al., 2000). In addition, results extend previous findings on overweight and obese females being less likely than males to have a university degree (Crosnoe, 2007). A possible explanation for this is that many studies have demonstrated the importance of educational level in predicting weight-related behaviours (diet and physical activity) and have suggested that knowledge might play an important role in a range of health-related behaviours (Lahti-Koski et al., 2000).

Examining the adjusted R^2 statistics suggested that only a proportion of the variation (15 to 16 percent) in BMI could be explained by the individual-level covariates. From this, built environment variables explained only six percent of the variance in BMI.

However, this amount of variance could have public health significance, because environmental variables affect all people exposed, and the exposure occurs over a long period of time. Therefore, the present study is an early investigation of a complex phenomenon that requires continued examination.

There were few limitations of this study that need to be addressed. First, the study is based on a cross-sectional design, which does not allow us to account for potential changes over time. However, the relationships discovered throughout this study are well established in the literature, and the direction of the relationships is well known. Second, the overweight/obesity data used were based on self-reported information. Yet, given that individuals tend to over-report their stature and under-report their weight (Katzmarzyk, 2002a) the prevalence's of overweight/obesity reported in this study should be considered conservative. Third, determining the optimal buffer size for measuring environmental characteristics needs further consideration. While we presented results using a 1 kilometre buffer, we also conducted initial analyses with a 500m and 1.5 kilometres buffer but found even fewer associations with BMI. Other aspects of the buffers such as whether access to recreational facilities in the buffers varied based on obstacles (e.g., a freeway) or restrictions (e.g., for adults only, fees) could also be considered. Assessing other buffer sizes and characteristics may help to better delineate the relationship between the environment and BMI. Finally, although additional built environment correlates such as sidewalks, trees, traffic speed and volume, and intersection design were found to be correlated to overweight/obesity (Frank and Engelke, 2001; Frank et al., 2004), only variables available in the DMTI database could be examined and therefore included in the present study. Further studies are thus needed to evaluate associations between BMI and a greater range of built environment variables. Yet, the variations in the BMI established in this study verify the contribution of the built environment on overweight and obesity in urban Canada.

3.6 Conclusions

The findings established in this study strengthen previous studies' results by confirming that individual, socio-economic as well as environmental characteristics appear to play a substantial role in explaining the variation of BMI. In addition, the incorporation of both the neighbourhood-level (i.e. walkability index) as well as various accessibility measures (i.e. density of fast-food restaurants) of the built environment demonstrated the effectiveness of GIS applications and offered new evidence with regard to the contribution of the built environment. Employing different measures of the built environment could be therefore modifying their potential association with weight status. Further, embracing of the population health perspective provided the opportunity for addressing the complexity of the obesity problem by deconstructing aspects of obesogenic environments as well as better framing of the relationship between weight status and a number of individual, socio-economic and environmental factors. Finally, the inclusion of the interaction terms allowed for different determinants of overweight and obesity between male and female participants to be explored. Research findings revealed that not only is gender significant to overweight and obesity, but that the effects of socio-economic status on weight status differ between genders.

Overall, this study added to growing evidence suggesting that targeting high-risk individuals will only address a portion of the overweight/obesity problem, and that it is also important to address the places that compel individuals to make unhealthy choices. Yet, in order to increase awareness and potentially alleviate obesity prevalence as well as prevent the growing rate of various diseases compounded by the obesity problem, city planners and public health professionals need to combine forces and guide short-term and long-term public health policy towards less obesogenic environments.

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CHAPTER FOUR

Building obesity in Canada: understanding the individual- and neighbourhood-level determinants using a multi-level approach

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Abstract

Overweight/obesity represent a significant public health problem in Canada and abroad. The literature around the determinants of overweight/obesity focuses mainly on temporal trends as well as demographic and socio-economic determinants. However, individuals are embedded within social and physical environments that play a significant role in shaping health. The objective of this paper is to identify heterogeneities associated with the relationships between overweight/obesity and individual as well as socio-environmental determinants at the individual- and neighbourhood-levels.

The data sources used are: 1) the 2003 Canadian Community Health Survey, 2) the 2001 Canadian Census and 3) the Desktop Mapping Technologies Incorporated database. Geographical Information Systems are first employed to create neighbourhood-level variables such as residential density and land-use mix, as well as accessibility to fast food outlets and recreational centres. Multi-level analysis (MLA) is then applied to estimate the relative effects of individual- and neighbourhood-level risk-factors of overweight/obesity.

Results indicate marked geographical variability in risk factors for overweight/obesity between the two urban centres (Toronto, Vancouver). MLA demonstrates the important role of the built-environment after adjusting for demographic, socio-economic and behavioural characteristics.

Findings support the rationale that reversing current trends will require a multifaceted public health approach where interventions are developed from the

individual- to the neighbourhood-level, with a specific focus on altering obesogenic environments.

Keywords: Obesity, health determinants, built environment, walkability index, Canada, ANGELO framework

4.1 Introduction

Overweight and obesity are now widely recognized as not only a major public health problem but literally an epidemic (World Health Organization, 2006). While it is well-known that excess weight has significant health consequences, we nevertheless see the population gaining weight to a dangerous degree and at an alarming rate (World Health Organization, 2000). Over the past two decades, the prevalence of obesity has risen with the most substantial increases observed in economically developed countries In particular, in developed countries, between ten and twenty percent of people are obese, and the problem is not unknown in less developed countries (Katzmarzyk, 2002). Within the Canadian context, the problem of excess adiposity was recognized almost 50 years ago and was the stimulus for the 1953 Canadian Weight-Height Survey (CWHS)(Katzmarzyk, 2002a). Since then, Survey data indicate that the national prevalence of obesity in adults consistently increased from 5.6 percent in 1985 to almost 15 percent in 1998 (Katzmarzyk, 2002). More recent self-reported data from the 2005 Canadian Community Health Survey (CCHS) identified that approximately 4 million adults (17.55 percent) were obese and an additional 8 million adults (33.77 percent) were overweight.

Overweight and obesity has been associated to various health outcomes such as type II diabetes, heart disease and hypertension as well as psychosocial outcomes such as mood disorder and depression (Raine, 2004). Further, overweight/obesity have been associated with increased prevalence of primary-care visits, exacerbating the load on an already overburdened health-care system (Bertakis and Azari, 2005). According to

Katzmarzyk and Janssen (2004), the direct and indirect medical costs associated with overweight and obesity in Canada in 2001 were estimated at $1.6 billion (CAD), and $2.7 billion (CAD) respectively, representing 2.2 percent of the total health-care costs.

Yet, in spite of the magnitude of the problem, little is known about the factors contributing to the obesity epidemic. Current literature has primarily been focusing on the individual physiologic, demographic and socio-economic risks for overweight/obesity. This provides us with a limited explanation of the prevalence and trends of this important public health issue. In addition, the short-time frame in which the overweight/obesity prevalence has increased to epidemic scales signals that this could be due to changes in the physical/built environments. Studies that consider the relation between BMI and the environment tend to focus on two broad aspects: socio-demographic characteristics of neighbourhoods and overall urban form (density, land-use mix, and street connectivity). Nevertheless, researchers have only recently attempted to examine the relation between neighbourhood socio-economic conditions, urban form, and body weight (Gordon-Larsen et al., 2006; Ross et al., 2007; Nelson et al., 2006).

Further, most of the current studies have focused on either neighbourhood socio-demographics or the built environment, making it very difficult to illustrate potential interactions between them and overweight/obesity. A notable exception is a study by Ross and colleagues (2007), which studied the influence of neighbourhood and metropolitan area characteristics on body mass index (BMI) in urban Canada. In an attempt to capture the potential contribution of the built and social environments on overweight and obesity, an urban sprawl index for Canadian Metropolitan Areas was estimated. After controlling for individual socio-demographic characteristics and behaviours, the average BMIs of residents of neighbourhoods in which a large proportion of individuals had less than a high school education were higher than those BMIs of residents in neighbourhoods with small proportions of such individuals. Metropolitan sprawl was also associated with higher BMI for Canadian men. However, Ross et al. (2007) measured the built environment at the metropolitan area level, suggesting that the urban sprawl index in some metropolitan areas might not have captured the unique urban form stimuli experienced by each person at their place of residence.

Therefore, we felt that it would be worthwhile to examine the individual as well as neighbourhood determinants of overweight/obesity taking into account both the built environment and neighbourhood social-economic characteristics. In particular, the main objective of this research is to identify heterogeneities associated with the relationships between individual and socio-environmental determinants and overweight and obesity at the individual- and community-levels.

4.2 Dissecting obesogenic environments

This research employed the "analysis grid for environments linked to obesity" (ANGELO) framework (Swinburn et al., 1999), to effectively identify and categorize elements of the local neighbourhood that could potentially be driving the obesity epidemic in Canada. The ANGELO framework divides the environment into two dimensions: the size (micro and macro) and the type of environment (e.g., physical, socio-cultural, economic and political environments). Microenvironments are environmental settings where groups of people meet and gather (e.g. homes, schools, restaurants and neighbourhoods). Such settings are often geographically distinct and allow direct mutual influences between individuals and the environment. Macro-environments include the broader infrastructure that may support or hinder health behaviours (e.g. town planning, transport infrastructure, the health system and the media).

1. The physical environment refers to the availability of opportunities for healthy and unhealthy choices, for instance the availability and accessibility of healthy and unhealthy foods.
2. The socio-cultural environment refers to the social and cultural subjective and descriptive norms and other social influences such as parental influences and peer pressure.
3. The economic environment refers to the costs related to healthy and unhealthy behaviours, for instance costs of fruit and vegetables and household income.
4. The political environment refers to the rules and regulations that may influence food choice or availability, for example, bans on snack vending machines in schools.

Though the application of the ANGELO grid as a framework for guiding neighbourhood and obesity research has been limited, it has been applied to a systematic review of the environmental determinants of physical activity (Wendel-Vos et al., 2007), which was used as a guide for deconstructing aspects of neighbourhood for this study. This broader framework on the elements of obesogenic environments may improve our understanding on the determinants of overweight/obesity, allowing us to point in a useful policy direction vis-à-vis response.

Much research on the determinants of overweight and obesity has primarily focused on exploring and identifying individual risk factors. In particular, several studies have found overweight and obesity to be associated with genetic, physiological and behavioural characteristics such as age, gender, diet and physical activity (Tjepkema, 2005; Bouchard, 1994; Trakas et al., 1999; Raine, 2004; Hill et al., 2003). While these studies have had some success in informing intervention approaches for overweight and obesity, they were not successful into fully explaining and/or reversing the rapid growth in overweight and obesity.

Within recent literature, overweight and obesity are framed as being functions of individual characteristics operating within social and physical environments that may also play a significant role in shaping health (Macintyre et al., 2002; Duncan et al., 1998; Curtis and Taket, 1996). In particular, a number of studies have examined the effects of area-level socio-economic status (SES) on obesity and have found strong associations between obesity and income inequality as well as neighbourhood deprivation, even after accounting for individual-level effects such as age, gender, and level of education (Ellaway et al., 1997; Sundquist et al., 1999). According to Reidpath et al. (2002), a potential explanation for the association between area-level SES and overweight/obesity is that the physical and social environments of low-SES areas might promote poor diets and sedentary lifestyles. Yet, the actual mechanism by which such factors may affect weight gain is still at the level of speculation and requires further investigation.

In addition, there is a growing consensus among the scientific community that aspects of the built environment serve as potential determinants of overweight and obesity. In general, we have seen that existing literature demonstrates that aspects of the built environment contribute to the unexplained variation for a range of health-related issues (Macintyre et al., 2002). However, research examining the influence of the built environment on overweight and obesity has been limited by two factors. First, there is a need for theories or conceptual models articulating how aspects of the built environment may influence weight status. Second, limitations mainly in the availability of geographic data have made it difficult to empirically test hypotheses. Until recently, most studies have relied on perceived rather than objective measures of the built environment (Saelens et al., 2003). Yet, the use of objective measures of the built environment is important to better understand how land use may influence walking and in general healthier behaviours (Leslie et al., 2007).

Ewing et al., (2003) were the first to demonstrate an association between obesity and the built environment, using an objective measure; the urban sprawl index. More recently, Frank et al. (2004) applied geographic information systems (GIS) techniques to develop measures of walkability at the neighbourhood level based on landuse mix, street connectivity and residential density. In particular, Frank et al (2004) demonstrated that the likelihood of obesity decreased by 4.8 percent with each additional kilometer walked per day and by 12.2 percent for every quartile increase in land-use mix. Although Frank et al. (2004) adjusted for socio-demographic covariates including age, gender, income, education and race/ethnicity, they did not take into consideration the potential contribution of the dietary habits and exercise practices of the participants (other than walking), as well as potential contribution of area-level effects. Lately, GIS and spatial analysis have been also used to explore the accessibility to various opportunities for eating and physical activity, including access to fast-food restaurants, supermarkets as well as walking paths, trails and recreational facilities (Scott et al., 2007; Powell et al., 2007). For example, a recent study of US metropolitan areas has demonstrated that a greater diversity of business establishments in a neighbourhood increases walking (Boer et al., 2007).

Yet, to assess potential relations between the local environments and overweight/obesity, it is necessary to define a spatial unit that best represents a respondent's local environment. A number of studies have used pre-defined spatial units such as census tracts to define spatial units to measure aspects of the built environment (Ross et al., 2007; Boer et al., 2007; Leslie et al., 2007). Yet, pre-defined areas may not correspond to areas individuals walk. Some studies have begun to use locational information (e.g. addresses, postal codes) to establish a circular buffer around respondent's geocoded location at a given radius (Frank et al., 2004). While providing a more representative assessment of the built environment, a shortcoming is that a circle may not accurately represent the spatial area that influences walking. Circular buffers are likely to be inaccurate in areas with natural features such as rivers, lakes and cliffs or built features such as railways or suburbs. In such cases, areas within the buffer may be inaccessible by the respondent but still used to calculate built environment measures. Despite major improvements in the modeling of the built environment, more research is required on the evaluation of these methods. No studies we are aware of have defined unique areas for each individual based on the distance traveled by the respondents.

What is therefore apparent is that while the volume of literature exploring the determinants of overweight and obesity is expanding, the field offers important opportunities for further study. In particular, this brief review of literature revealed the general lack of a theoretical framework that underpins the broader individual as well as environmental (physical and social) determinants of overweight and obesity. Further, current research findings suggest that the social context of the determinants of overweight and obesity are generally not well explored and require further investigation. In addition, no existing studies have assessed the extent to which a circular or distance traveled buffers influence walking patterns and therefore potentially the association between weight status and the built environment. This research will thus contribute to the existing literature by (1) applying the ANGELO framework towards an empirical exploration of the individual as well as environmental determinants of overweight and obesity, using a nationally representative health-related database in Canada (2) exploring the potential contribution of the social environment and (3) building upon the relatively limited number of studies on assessing as well as comparing the extent to which the selection of circular or distance-traveled based buffers affect the results of analysis and therefore influence the association between overweight and obesity and the built environment.

4.3 Methods

This research explores the determinants of overweight and obesity with particular emphasis on social and environmental risk factors, incorporating both individual- and neighbourhood-level indicators. Spatial data analysis and GIS techniques are employed to assess the contribution of the built environment. Further, based on postal code information, a direct record linkage with the 2001 Canadian census data was conducted to add neighbourhood-level measures such as income, employment and education level.

For the purposes of this study we chose Canada's two largest metropolitan areas (Toronto and Vancouver) for several reasons. First, approximately one-third of all Canadians live in these metropolitan areas. Second, choosing Canada's largest CMAs is likely to capture the socio-cultural diversity of Canada's population. Finally, both CMAs are characterized by various neighbourhood designs ranging from high to low on a continuum of walkability and density. Thus, Toronto and Vancouver CMAs provide a useful case study for the individual and socio-environmental determinants of overweight/obesity in Canada.

4.3.1 Data

The data sources for this study were: 1) 2003 Canadian Community Health Survey (CCHS), Cycle 2.1, master file and 2) 2001 Canadian Census of Population and 3) the CanMap RouteLogistics (CMRL) spatial information database on land-uses as well as the enhanced points of interest (EPOI) file from the Desktop Mapping Technologies

Incorporation (DMTI). These data sources were matched based on postal code residential information available in the master files of the CCHS database.

The CCHS provides cross-sectional health and social indicator data on a large representative sample of Canadians and is intended to provide reliable estimates of health outcomes and health determinants at sub-provincial scales of analyses. The target population of the CCHS is individuals 12 years of age and over living in private dwellings, excluding those living on Indian Reserves or Crown lands, clientele of institutions, full-time members of the Canadian Armed Forces, and residents of certain remote regions. Using a multistage stratified cluster design approach a total of 134,072 individuals participated in the survey, with a response rate of 80.7%. A detailed description of the CCHS design and questionnaire is available elsewhere (Statistics Canada, 2005). The use of the micro-data file allowed for access to a sub-national disaggregation of the data (postal codes are available only in the CCHS master files) as well as linkage with the DMTI spatial database and the 2001 Canadian Census of Population, using the Statistics Canada's postal code conversion file.

To effectively analyze potential contextual determinants of overweight and obesity the individual-level data were linked to the 2001 Canadian census profiles using the postal codes recorded for each respondent in the CCHS at the dissemination area (DA) level. DA was selected as an appropriate boundary for neighbourhood since it was the smallest possible geographical level to link the data – thereby representing the most homogeneous population possible for this study – that satisfied the assumptions of the multilevel model.

4.3.2 Variables of Interest

Outcome Variable

BMI is the standard unit of measure for weight and obesity in populations and is calculated by dividing a person's weight in kilograms by their height in meters squared. BMI was calculated for CCHS respondents according to self-reported height and weight (N-weighted=23,243,098). Individuals with missing BMI records due to invalid data were excluded from the analysis (N-weighted=783,526). Therefore, the total sample size for all individuals aged 20 and older and with no missing BMI records was 115,548. All data were weighted using the combined weight provided by Statistics Canada as part of the public use micro-data file. This has the effect of generating estimates relevant to the Canadian population under study. Further, as mentioned earlier, we included only those individuals residing in the Toronto and Vancouver CMAs. Therefore, the final sample included in the analysis was based on 5,418,218 (N weighted) participants 20 years and older.

Independent variables

Multiple independent variables were used to account for individual, socio-economic and built and social environmental characteristics. Based on a review of the literature, demographic, health status, lifestyle, and socioeconomic features were drawn from the CCHS data set. The determinants of health included within this analysis may be divided into four categories, including health status, demographic, socio-economic, and lifestyle variables. Health status variables included chronic disease status, such as cardiovascular diseases, rheumatoid/arthritis and anxiety-mood disorders. Socio-economic variables included income adequacy (based upon income and household size), employment status, home ownership, and education level. Demographic variables included age, gender, martial status, period of arrival in Canada, race/ethnicity, while smoking, drinking, and physical activity and fruits and vegetable consumption defined the lifestyle variables. Characteristics of the social environment of the individuals was also acquired from the CCHS data and included information on whether the individual was a member of a voluntary organization as well as their sense of belonging to the local community. Categorical representations of these explanatory variables were included within the models based upon a priori expectations, with one value of each variable used as the reference category, typically representative or linked to poorer states of health (i.e., regular smokers, heavy drinkers, suffering from a chronic disease).

The spatial databases (CanMap RouteLogistics) provided by the DMTI maintains a current street address database as well as many other layers (e.g., boundary files, street networks and land-use information) from which the characteristics of the built-environment were derived. Seven built-environment variables were constructed: land-use mix, street network connectivity, residential density, density of fast-food restaurants, density of convenience stores, density of grocery stores and supermarkets, and density of recreational activities facilities. Brief operational definitions for each appear below.

Land-use mix. Land-use mix was operationalized using the method provided by Frank and Engelke (2001), which provides a measure of the evenness of distribution of several land-use types (i.e., residential, commercial, industrial, institutional and open space) within the study's geographic area and can be described by LUM $= -\sum_{i=1}^{5} \frac{p_i \ln(p_i)}{\ln(5)}$. In this study, data for five land-use types are available (i.e. residential, commercial, industrial, institutional and open space). Therefore, the proportion for the residential land use type is estimated as follows:

$$p_{residential} = \frac{\text{square footage of residential land - use}}{\text{total square footage of residential, commercial, industrial, institutional and open space}}$$

In general, values of LUM vary on a continuous scale between 0 and 1, with one indicating even distribution of all land-use categories (heterogeneity) and zero implying a single type of land-use (homogeneity). An illustration of the development of the LUM is shown in Figure 1.

Figure 1: Illustration of development of the land-use mix based on land-use distribution

Street network connectivity. The number of street intersections divided by area in square kilometers.

Residential density. The number of occupied households per residential land-use in square kilometers

Densities of opportunities. The number of opportunities such as fast-food restaurants, convenience stores, grocery store and recreational activities divided by area in square kilometers (each measured separately).

Dissemination area-level variables

By the definitions advocated by Swinburn et al. (1999), neighbourhood is defined as a micro-environmental setting, rather than a macro-environmental sector; therefore, only the top row of the ANGELO grid was necessary. Variables from the census were grouped within the environment types specified by the ANGELO framework (Table 1). However, no measures of the political environment were available in the census profiles and therefore could be taken into consideration in the analysis.

For the physical environment, older homes were those built prior to 1946, which have been used as proxies for neighbourhood characteristics which may influence physical activity (Berrigan and Troiano, 2002), and homes in need of major/minor repairs were selected as indicators of neighbourhood aesthetics.

For socio-cultural variables, proportion of homeowners vs. rental homes was calculated as a proxy for neighbourhood social cohesion. It was expected that homeowners are more inclined to invest in their direct surroundings and be more attached to their neighbourhood than a more transient, rental-based neighbourhood (Brown, Perkins, & Brown, 2003). Finally proportion of the neighbourhood with their high school education, was included as socio-cultural environmental factors. Since education can be used as a proxy for health literacy (Crosnoe, 2007) it may be more likely to represent a neighbourhood's attitudes and beliefs about obesity, rather than to represent measures of the costs related with obesity, as with the economic environmental factors (Swinburn et al., 1999).

For the economic environment, we included variables such as average/median household income, average dwelling value, proportion of households below the low-income cut-off (Statistics Canada, 2008), and unemployment rate (Lahti-Koski et al., 2000).

Table 1: Classification of variables based on the ANGELO framework

	Micro-settings **Dissemination Area**
Physical environment	Homes built pre-1946 (%) Home in need of major repairs (%) Homes in need of minor repairs (%)
Socio-cultural environment	Homes Rented (%) High school education (%)
Economic environment	Average household income Median household income Average dwelling value Low income families (%) Unemployment rate (%)
Political environment	Not available

4.3.3 Statistical analyses

Descriptive and bivariate techniques were applied to examine the potential association between overweight/obesity and a number of individual and socio-environmental determinants in Toronto and Vancouver CMAs using the SAS 9.2 software. A number of outliers were excluded from the analysis as we deemed their BMI values to be inaccurate (i.e. cases were excluded if the reported BMI was more than 100 kg/m^2 and could not be justified by all other characteristics of the individual).

Spatial data analysis and GIS techniques were first employed to assess the contribution of the built environment. The process involved three steps: 1) geocoding participants' residential addresses; 2) creating "buffers," (i.e. bounded areas of a specific dimension, around each residence location in which built environment features are subsequently quantified); and 3) linking built environment data sources (e.g., land-uses) to geocoded participants' buffers to measure the built environment near the participant's residence (e.g., land-use mix). Arcview 3.3 (ESRI, 2002) software was used to geocode participant addresses and create 1-km buffers, with distances based on the street network.

Circular and travel-distance-based buffers were created for the purposes of this study. The circular buffers had a radius of 1 km around each respondent's postal code in the CCHS sample. The radius of the travel-distance-based buffer was estimated according to the model developed by Morency et al. (2009) for Toronto. The model estimated the distance-traveled based on demographic (i.e., age), socio-economic (i.e., income, household structure, and occupation), mobility (i.e., drivers license, vehicle ownership, and proximity to transit facilities) and urban form characteristics (i.e., population density). For the purposes of this study though, we applied the Morency et al. (2009) model to estimate the distance-traveled by all individuals included in the CCHS sample for Toronto. We only used demographic and socio-economic data from the CCHS dataset, since mobility information was not available in the CCHS dataset. Buffers were created around each respondent's postal code based on the travel-distance that resulted from the model (range of values = 1.2 – 6.5 km). Also, for comparison purposes, buffers equal to the median travel distance (=3.94 km) were constructed for both Toronto and Vancouver.

All variables found to be statistically significant in bivariate models were included in multivariate models. A type II analysis of variance test followed to test the significance of each variable to the overall fit of the model. Multicollinearity was assessed using the variance inflation factor for each estimator (for both individual- and area-levels of analysis). All variables found to be statistically significant after this stage were included as the individual-level basis for the multilevel regression analyses.

Multilevel models are statistical models that specify and estimate the relationship between variables observed at different levels of hierarchical structures (Rasbash et al., 2004). This type of modelling has been considered an important alternative modeling approach that addresses the limitations of multiple regression analysis as it captures variations in differences between individuals and between places that regression analysis fails to consider (Duncan and Jones, 2000). The multilevel models used to assess the potential influence of area-level variables were computed using MLwiN v.2.01. In particular, the deviance statistic was computed for the null model, which includes only the intercept, to test for significant area-level variation. Secondly, the deviance was computed for the model that included individual-level independent variables, as selected by the multivariable regression procedure. An intra-class (neighbourhood) correlation coefficient was used to determine the proportion of the total variability that is accounted for by the differences among areas/neighbourhoods (Snijders and Bosker, 1999). Generally, a decline in the intra-class correlation coefficient indicates that the differences between neighbourhoods have been reduced by the inclusion of explanatory variables.

4.4 Results

The final multilevel models are presented in Tables 2 and 3. The coefficients may be interpreted as the absolute change in the outcome variable associated with a one-unit increase in the independent variable for continuous variables (e.g., energy expenditure). For categorical variables, these coefficients can be interpreted as the difference between mean BMI and levels of that categorical variable (e.g. not having completed a high school education) and the reference group (e.g. completed high school education), while controlling for all other variables in the model.

As expected, age and sex were highly statistically significant in each model. In particular, individuals less than 35 years of age as well as those more than 65 years of age had lower BMI's than individuals 36 to 50 years old. Also, individuals 51 to 64 years old had higher BMI's compared to those in the 36 to 50-age category. Additionally, the relationship between sex and the outcome variable was also significant, indicating that males have larger average BMI's than their female counterparts for both Vancouver and Toronto. However, the magnitude of the effect differed between models ranging from

0.93 kg/m^2 to 1.9 kg/m^2 for Toronto (Table 2) and between 2.52 kg/m^2 and 2.73 kg/m^2 for Vancouver (Table 3).

In addition, Tables 2 and 3 reference health disparities with respect to diagnosed chronic conditions that have been found to be associated with overweight and obesity. In particular, individuals with rheumatoid arthritis, high blood pressure, diabetes and/or anxiety/mood disorder have higher BMI values compared to those not having a chronic condition for both Toronto and Vancouver. In addition, the magnitude of the effect was stronger for individuals with high blood pressure and diabetes with values ranging between 1.33 and 2.04 kg/m^2 and between 1.81 and 2.1 kg/m^2 respectively (Tables 2 and 3).

Individual-level behavioural characteristics such as diet and physical activity have been well established in the literature as important risk factors for overweight and obesity. According to Tables 2 and 3, energy expenditure and smoking were significantly associated with BMI. Diet-related variables (e.g. fruits and vegetable consumption) were also tested but were not included the final models presented here, as they were not found to be significant. Specifically, energy expenditure was negatively associated with BMI indicating that individuals with higher energy expenditure values had lower BMIs by 0.13 kg/m^2 (Table 2 - Models 1 and 2) and 0.14 kg/m^2 (Table 2 - Models 2) for Toronto and 0.16 kg/m^2 (Table 3 - Models 1) and 0.10 kg/m^2 (Table 3– Model 2) for Vancouver. Further, self-reported smoking status (i.e. regular smoker) was also found to be inversely associated with BMI. Specifically, being a smoker predicted on average a lower BMI with values ranging between 0.46 to 0.52 kg/m^2 for Toronto (Table 2) and between 0.65

to 0.67 kg/m^2 for Vancouver (Table 3), even after controlling for all other individual-level covariates. Diet-related variables (e.g. fruits and vegetable consumption) were tested but were not included the final models presented here, as they were not significant.

Table 2: Multilevel model results - Toronto, CMA

Variable	Model 1 (distance-traveled)	Model 2 (median distance-traveled)	Model 3 (1km buffer)
Intercept	13.47 (10.64, 16.30) ***	19.51 (17.09, 21.93) ***	16.88 (16.06, 17.70) ***
Age			
Less than 20 years of age	-2.20 (-3.12, -1.28) ***	-2.22 (-3.14, -1.30) ***	-2.61 (-3.11 -2.11) ***
20 to 35 years of age	-1.04 (-1.48, -0.60) ***	-1.07 (-1.51, -0.63) ***	-0.61 (-0.04, 0.56)
36 to 50 years of age (ref)	---	---	---
51 to 64 years of age	0.30 (-0.20, 0.80)	0.27 (-0.23, 0.77)	0.26 (-1.62, -0.84) ***
More than 65 years of age	-1.18 (-0.65, -0.53) **	-1.16 (-0.62, -0.54) *	-1.23 (-1.62, -0.84) ***
Female (ref.)	---	---	---
Male	1.08 (0.43, 1.73) **	0.93 (0.28, 1.55) **	1.19 (0.74, 1.64) ***
Arthritis - Rheutism	0.96 (0.50, 1,42) ***	0.94 (0.48, 1.41) ***	0.83 (0.53, 1.12) ***
High Blood Pressure	2.00 (1.52, 2.48) ***	1.97 (1.49, 2.45) ***	2.04 (1.74, 2.34) ***
Diabetes	2.10 (1.35, 2.85) ***	2.07 (1.34, 2.84) ***	1.92 (1.44, 2.40) ***
Anxiety - Mood Disorder	0.58 (-0.07, 1.23)	0.62 (-0.03, 1.27)	1.02 (0.54, 1.51) ***
Energy Expenditure	-0.13 (-0.22, - 0.05)***	-0.13 (-0.22, -0.05) ***	-0.14 (-0.19, -0.09) ***
Regular Smoker	-0.49 (-0.90, -0.08) ***	-0.52 (-0.90, -0.11) ***	-0.46 (-0.72, -0.21) ***
Race - White	1.45 (0.91, 1.99) ***	1.49 (0.94, 2.03) ***	1.34 (0.99, 1.69) ***
Race - Asian (ref.)	---	---	---
Race - Other	1.67 (0.79, 2.55) ***	1.68 (0.80, 2.48) ***	1.41 (0.80, 2.01) ***
Less than Secondary	0.05 (0.02, 0.08) *	0.02 (0.018, 0.022) *	0.99 (0.58, 1.39) ***
Secondary	0.03 (0.00, 0.06) *	0.01 (0.002, 0.018) *	0.54 (0.19, 0.89) **
More than Secondary (ref.)	---	---	---
Land-use mix	-5.81 (-8.96, -2.65) ***	-6.12 (-9.12, -3.12) ***	-0.22 (-0.30, 0.04)
Street Connectivity	-0.002 (-0.0035, 0.0031)	-0.04 (-0.01, 0.04)	-0.001 (0.00, 0.00)
Residential density	-0.04 (-0.11, 0.16)	-0.001 (-0.10, 0.02)	-0.06 (-0.11, 0.01)
Anxiety - Mood Disorder * Males	0.55 (0.30, 0.80) *	0.60 (0.27, 0.93) *	-0.99 (-1.82, -0.16) **
Race - White *Males	0.90 (0.15, 1.65) **	0.88 (0.13, 1.63) **	0.80 (0.31, 1.30) **
Race - Asian * Males (ref.)	---	---	---
Race - Other * Males	0.08 (-1.19, 1.35)	0.11 (-1.17, 1.38)	0.26 (-1.41,-0.26)
Less than Secondary *Males	-0.03 (-0.72, 0.66)	-0.03 (-0.69, 0.63)	-0.84 (-2.85, -0.41) *
Secondary * Males	-0.21 (-0.87, 0.45)	-0.20 (-0.86, 0.46)	-0.39 (-1.48, -0.09) **
More than Secondary * Males (ref.)	---	---	---
Average Value of Dwelling	-0.11 (-0.23, -0.01) **	-0.04 (-0.06, -0.02) *	-0.03 (-0.04,-0.02) *
Level 1 Variance	18.45 (0.54)***	18.63 (0.62) ***	17.69 (0.32) **
Level 2 Variance	0.59 (0.25)**	0.43 (0.38) *	0.22 (0.18) *
Intraclass Correlation	3.08%	2,24%	1.23%

p<0.001 *; p<0.01 **; p<0.05 ***
ref: reference category

Table 3: Multilevel model results - Vancouver, CMA

Variable	Model 1 (distance-traveled)	Model 2 (median distance-traveled)	Model 3 (1km buffer)
Intercept		19.51 (17.09, 21.93) ***	21.7 (21.12, 22.27) ***
Age			
Less than 20 years of age		-2.14 (-3.14, -1.30) ***	-2.03 (-2.59, -7.14)***
20 to 35 years of age		-1.17 (-1.51, -0.63) ***	-0.25 (-1.52, -0.57) **
36 to 50 years of age (ref)		---	---
51 to 64 years of age		0.98 (0.23, 1.77) **	0.53 (0.19, 0.87) **
More than 65 years of age		-1.34 (-2.62, -0.54) **	-0.43 (-0.85, 0.01)
Female (ref.)		---	---
Male		2.73 (0.28, 3.55) **	2.52 (2.01, 3.03) ***
Arthritis - Rheutism		0.94 (0.49, 1.39) ***	0.83 (0.50, 1.17) ***
High Blood Pressure		2.04 (1.49, 2.45) ***	1.33 (0.97, 1.68) ***
Diabetes		2.07 (1.34, 2.72) ***	1.81 (1.28, 2.35) ***
Anxiety - Mood Disorder		0.54 (-0.03, 1.65)	1.12 (0.61, 1.62) ***
Energy Expenditure		-0.16 (-0.19, -0.05) ***	-0.10 (-3.72, -0.15) ***
Regular Smoker		-0.65 (-0.89, -0.21) ***	-0.67 (-4.3, -0.98) ***
Race - White		2.62 (1.94, 3.02) ***	2.51 (2.12, 12.73) ***
Race - Asian (ref.)		---	---
Race - Other		1.68 (0.80, 2.01) ***	2.34 (1.64, 6.56) ***
Less than Secondary		1.18 (0.58, 1.73) ***	1.11 (0.62, 1.60) ***
Secondary		0.01 (-0.04, 0.018)	0.47 (0.08, 2.34) **
More than Secondary (ref.)		---	---
Land-use mix		-6.24 (-7.35, -3.18) ***	-2.22 (-1.28, -0.55) *
Street Connectivity		-0.04 (-0.01, 0.04)	0.002 (-1.52, 0.001)
Residential density		-0.22 (-0.34, -0.02)**	-0.18 (-0.87, -0.03) *
Anxiety - Mood Disorder * Males		-0.64 (-0.99, -0.27) *	-1.43 (-3.11, -2.34) **
Race - White *Males		0.85 (0.23, 1.64) **	-0.45 (-1.58, -1.00) *
Race - Asian * Males (ref.)		---	---
Race - Other * Males		0.11 (-1.17, 1.38)	-0.51 (-1.55, -0.97)
Less than Secondary *Males		-1.68 (-2.35, -1.11) **	-1.32 (-3.63, -2.03) **
Secondary * Males		-0.20 (-0.86, -0.16)*	-0.62 (-2.09, -1.20) **
More than Secondary * Males (ref.)		---	---
House in need of minor repairs		-0.03 (-0.04,-0.02) *	0.02 (0.01, 0.03) *
Level 1 Variance		19.12 (0.65) ***	16.44 (0.35) **
Level 2 Variance		0.90 (0.48) **	0.71 (0.53) **
Intraclass Correlation		4.5%	4.14%

p<0.001 *; p<0.01 **; p<0.05 ***
ref: reference category

Race was also found to be significantly associated with BMI. As expected, for both Toronto and Vancouver, whites or individuals from non-Asian race had higher BMI values by 1.76 and 1.54 kg/m^2 respectively, compared to Asians (reference category) (Tables 2 and 3). However, the effect of race on BMI was stronger in Vancouver with whites and individuals from non-Asian race having higher BMI values compared to Asians (Table 3). High school education was also found to be positively associated with BMI, indicating that individuals with more than secondary education had lower BMIs compared to those with less than secondary and secondary education. This relationship, although marginally significant in Models 1 and 2 for Toronto (Table 2) and Model 2 for Vancouver (Table 3) emerged as a much stronger indicator than any measure of socio-economic status (e.g., average family income or income adequacy).

With regard to the built environment, three variables were included in the models; landuse mix, residential density and street connectivity. However, measures of the built environment could be correlated. That is, areas with higher residential density could be characterized by mixed landuses and an interconnected street network (Frank et al., 2006). The degree of correlation may also create model estimation problems associated with multicollinearity (i.e. two or more of the independent variables are correlated) (Bailey and Gatrell, 1995). To avoid this issue, the variance inflation factor between BMI and the built environment variables was estimated and presented in Table 4. According to Table 4, the values of the variance inflation factor are very low (close to one) indicating that there is no issue of multicollinearity between the built environment variables.

Based on Tables 2 and 3, individuals living in areas with mixed landuses have lower BMI's for both Toronto and Vancouver than those living in areas with a single or few landuse types. Residential density was also negatively associated with BMI for Vancouver, but not for Toronto. In addition, street connectivity was not found to be significantly associated with BMI for both Toronto and Vancouver. Further, the relationship between BMI and landuse mix was significant in Model 1 and 2 in Toronto but not in Model 3, indicating that the selection of buffer size might result in different outcomes and therefore the results need to be interpreted with caution.

Table 4: Variance Inflation Factor for the built environment variables for Toronto and Vancouver

Toronto					
Variable	**Parameter Estimate**	**Standard Error**	**t Value**	**Pr > |t|**	**Variance Inflation**
1 km buffer					
Intercept	25.2202	0.1351	18.69	<.0001	0.00
Landuse mix	-0.1638	0.2428	-0.67	0.5000	1.00
Residential Density	-0.0829	0.0274	-3.03	0.0024	1.01
Street connectivity	-0.0012	0.0010	-2.09	0.0400	1.01
Median distance-traveled buffer					
Intercept	20.7200	1.1422	18.14	<.0001	0.00
Landuse mix	-5.7246	1.5308	3.74	0.0002	1.16
Residential Density	-0.0013	0.0016	-0.80	0.0387	1.09
Street connectivity	-0.0070	0.0032	-2.22	0.0266	1.11
Distance-traveled buffer					
Intercept	20.9106	1.1510	18.17	<.0001	0.00
Landuse mix	-5.7196	1.5312	3.74	0.0002	1.00
Residential Density	-0.0665	0.0318	-2.09	0.0368	1.01
Street connectivity	-0.0012	0.0016	-0.73	0.4674	1.01

Vancouver

Variable	**Parameter Estimate**	**Standard Error**	**t Value**	**Pr > |t|**	**Variance Inflation**
1 km buffer					
Intercept	25.4542	0.1873	135.94	<.0001	0.00
Landuse mix	-2.7545	0.3622	-2.08	0.0373	1.31
Residential Density	0.2380	0.1762	0.13	0.0027	1.27
Street connectivity	-0.0040	0.0013	-3.08	0.0021	1.18
Median distance-traveled buffer					
Intercept	24.6382	0.0612	402.69	<.0001	0.00
Landuse mix	-4.0434	1.2981	3.11	0.0019	1.06
Residential Density	-0.2997	0.1564	-1.92	0.0300	1.07
Street connectivity	-0.0049	0.0012	-4.15	<.0001	1.19

Further, significant gender differences have been found in terms of the psychological and socio-economic characteristics of the individuals. In particular, based on Tables 2 and 3, females with an anxiety/mood disorder have higher BMI values compared to their counterpart males. Also, white and other than Asian males had higher BMI's compared to white and other than Asian females. In addition, females with low levels of education (high school or less) had higher BMI's compared to those with higher levels of education. However, the association was marginally significant in Model 3 for Toronto and Models 2 and 3 for Vancouver and therefore the results need to be interpreted with caution.

The intraclass correlation coefficients (ICC) from the multilevel models were used to quantify the amount of variation in BMI and WC resulting from differences between areas. In each of the three BMI models, the ICC's indicated that substantial proportions of the variation occurring at the neighbourhood-level in adult BMI with values ranging between 1.23 and 3.08 percent for Toronto and 4.14 and 4.5 percent for Vancouver. Only one area-level measure emerged as significant in the models after controlling for all other individual-level covariates, with the inclusion of average dwelling value [ADV] producing an inverse gradient relationship. That is, individuals living in areas with low average dwelling value had higher BMI's than those living in areas with high average dwelling value. The relationship was significant for all models and for both Toronto and Vancouver with coefficients ranging between 0.02 and 0.11 kg/m^2.

4.5 Discussion and conclusions

The central aim of this research was to understand and quantify the potential individual, socio-economic environmental determinants of overweight and obesity at the individual and neighbourhood levels in Toronto and Vancouver, CMAs. The results of the analyses support the existing literature, underscoring the evidence for an association between BMI and age, gender, chronic diseases, energy expenditure, race, educational level and landuse mix, residential density and average value of dwellings. The majority of the variation in these outcomes was found to be due to individual-level differences rather than area-level differences. However, this study did show significant differences at the area-level of analysis, supporting related research that has suggested that individual-level factors alone cannot explain variation in obesity rates across space (Duncan et al., 1993; Macintyre et al., 2002; Reidpath et al., 2002).

In addition, this study provided further evidence on the application of GIS methods to develop environmental variables and therefore explore the potential association between BMI and the built environment. In particular, a key aspect of this study is construction of a travel-distance-based buffer that may better assess the landuses that influence walking and potentially the BMI of individuals. In particular, this buffer size presented a vast improvement over the commonly used 1km circular buffer (Frank et al., 2004), because it takes into account the area of a local neighbourhood, which may differ depending on location. That is, estimates of distance traveled might be lower near the city centre and higher toward the suburban settings. In addition, consideration of various demographic and socio-economic characteristics may be more appropriate since the elderly populations tend to travel shorter distances and therefore have a shorter buffer size, while younger populations travel more and therefore have a larger buffer size.

Comparing the results of utilizing the travel-distance-based, the median-travel-distance-based and the 1km buffers revealed that the travel-distance-based buffers performed better, resulting in a greater association between the local built environments and BMI. Findings are particularly important because they demonstrate that relations between the built environment and BMI are sensitive to the choice of the buffer measure. In addition, while the relationship between the built environment and obesity has been examined in many studies, there is a lack of a clear rationale for choosing built environment measures. For example, while many have used measures of urban form (Ewing et al., 2003; Ross et al., 2007), others have explored the potential association between weight status and the built environment using measures of walkability and accessibility (Powell et al., 2007; Frank et al., 2004). Nevertheless, no existing studies have explored the association between weight status and the built environment using measures of landuse, residential density and street network connectivity as well as measure of accessibility (e.g., density of fast-food restaurants). Findings from this study indicated though that, compared to accessibility, measures of landuse and residential density generally performed as better indicators of the built environment for both Toronto and Vancouver. Employing a more sensitive estimate of the built environment could be therefore used to better assess the environmental determinants of overweight and obesity.

Average dwelling value was related to BMI independently of individual-level characteristics. There is a growing understanding that average dwelling value is a expression of individual-level SES (Dunn, 2002) and that aggregate measures of average dwelling values may be sensitive measures of neighbourhood socio-economic position (Cozier et al., 2007).

The social environment indicators (i.e. member of a voluntary organization and sense of belonging in the local community) were also not significantly associated with weight status. This suggests the following two possible explanations: the variables used are not adequate measures of the social environment; or more simply, that the social environment, as measured by these indicators, does not equate with the weight status of individuals in urban Canada. However, the last explanation seems unlikely given that studies have found that these social environment indicators are significantly associated with weight status (Cohen et al., 2006; King et al., 2006).

Through this study, it became clear that the use of interaction terms could demonstrate potential differences on the determinants of overweight and obesity among genders. In general, findings of this study are consistent with current literature. The gender differences on the determinants of overweight and obesity could potentially be due to differences in the social constructs of gender (Diamond, 2000). For example, research findings from related studies have suggested that overweight and obese females are more likely to be diagnosed with a psychosocial disorder (e.g., anxiety, mood disorder) than males (Steptoe et al., 2000). Gender differences on the relationship between educational attainment and BMI, could result from a number of mediating factors such as social perceptions/norms and availability of resources (Crosnoe, 2007).

There were four limitations of this study that need to be addressed. First, the study is based on a cross-sectional design, which does not allow us to account for potential changes over time. However, the relationships discovered throughout this study are well established in the literature, and the direction of the relationships is well known. Second, the overweight/obesity data used were based on self-reported information. However, given that individuals tend to over-report their stature and under-report their weight (Katzmarzyk, 2002a), the prevalence of overweight/obesity reported in this study should be considered conservative. Third, determining the optimal buffer size for measuring environmental characteristics needs further consideration. While we presented results using an 1-kilometre, a travel-distance-based and a median travel-distance-based buffers, further research could also be considered. Finally, although additional built environment correlates such as sidewalks, trees, traffic speed and volume, and intersection design were found to be correlated to overweight/obesity (Frank and Engelke, 2001; Frank et al., 2004), only variables available in the DMTI database could be examined and therefore included in the present study. Further studies are thus needed to evaluate associations between BMI and a greater range of built environment variables. Yet, the variations in the BMI established in this study verify the contribution of the individual and area-level factors on overweight and obesity in urban Canada.

The findings established in this study strengthen previous studies' results by confirming that individual, socio-economic as well as environmental characteristics both at the individual and area-level of analysis play a significant role in explaining the variation of BMI. In addition, the incorporation of built environment measures demonstrated the effectiveness of GIS applications and offered new evidence with regard to the relative contribution of the built environment. Employing different measures of the built environment could be therefore modifying their potential association with weight status. Although the overwhelming amount of variation in BMI occurred at the individual level, we found incremental effects at the area-level of analysis as well. That is, this study added to growing evidence suggesting that targeting high-risk individuals will only address a portion of the overweight/obesity problem, and that it is also important to address the places that compel individuals to make unhealthy choices.

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CHAPTER FIVE

Discussion and Conclusions

5.1 Introduction

The goal of this thesis was to gain a better understanding of the determinants of the critical public health issue of overweight and obesity in Canada. Over the past two decades, the prevalence of overweight and obesity has risen with the most substantial increases observed in economically developed countries (Katzmarzyk, 2002).

For many years and in the most recent past, overweight and obesity have been studied as important risk factors for cardiovascular and other chronic diseases with grave implications for individuals as well as populations (National Institute of Health, 2004). It has been recognised that overweight and/or obesity increase the risk of diabetes, heart disease, stroke, gallbladder disease and some cancers, contribute to greater risk for hypertension, dyslipidaemia and insulin resistance as well as impacts the psychosocial state and quality of life of individuals. Recently, however, overweight/obesity has been seen to be a public health issue in and of itself.

To address the emerging epidemic, this study examined the individual- and neighbourhood-level determinants of overweight and obesity for two major urban centres in Canada, Vancouver and Toronto using a nationally representative database. In so doing, integrated data from the 2003 Canadian Community Health Survey, the 2001 Canadian Census Profiles and the spatial databases of the Desktop Mapping Technologies Incorporated were analysed. The specific objectives of this study were to:

1. Examine the sex-specific spatial patterns of overweight/obesity in Canada as well as investigates the presence of spatial clusters;
2. Explore the relative contribution of built environment measures to the development of overweight and obesity using spatial analysis and geographical information systems (GIS).
3. Identify heterogeneities associated with the relationships between individual and socio-environmental determinants and overweight and obesity at the individual- and community-levels.

This final chapter presents a summary of key findings, as well as contributions and policy implications of this research. Study limitations and future directions are also addressed.

5.2 Summary of key findings

The Body Mass Index (BMI) is a standard unit of measure for weight and obesity in populations and is calculated by dividing a person's weight in kilograms by their height in meters squared. The independent variables were selected based on the literature and the determinants of health outlined by the population health perspective (Evans et al., 1994).

This study illustrates the marked variability of overweight/obesity prevalence in Canada at the health region level. In addition, the significant positive spatial autocorrelation identified by Moran's I for both males and females as well as the significant local clusters identified by LISA confirm the presence of spatial heterogeneity

(Anselin, 1994). This study demonstrates also that in the Northwest Territories/Yukon/Nunavut and the Atlantic health regions, age-standardized rates of overweight/obesity are much higher than the national average.

The results of the analyses support the existing literature, underscoring the evidence for an association between BMI and age, gender, chronic diseases, energy expenditure, race, educational level. With regard to the built environment measures, landuse mix and residential density were found to be significantly associated with BMI.

Further, with regard to the potential influence of the built environment on overweight and obesity, the variables included into the models were: landuse mix, residential density and street connectivity. Findings revealed that landuse mix and residential density were significantly associated with BMI for Vancouver, but not for Toronto. In addition, estimation of the walkability index based on residential density, street connectivity and landuse mix allowed the comparison with similar studies in the United States. The relationship between BMI and the walkability index was not significant for Toronto and marginally significant for Vancouver, indicating that the results need to be interpreted with caution.

In addition, findings of this study indicated that the walkability index generally performed as a better indicator of the built environment compared to accessibility measures. Employing a more sensitive estimate of the built environment could be therefore used to better assess the environmental determinants of overweight and obesity.

High school education was a very strong socio-economic covariate of overweight and obesity. This relationship emerged as a much stronger indicator than any measure of socio-economic status (e.g., average family income or income adequacy). The social environment indicators (i.e. member of a voluntary organization and sense of belonging in the local community) were also not significantly associated with weight status.

Through this study, it became clear that the use of interaction terms could demonstrate potential differences on the determinants of overweight and obesity among genders. For example, findings suggested that overweight and obese females are more likely to be diagnosed with a psychosocial disorder (e.g., anxiety, mood disorder) than males, confirming existing research on the association between obesity and psychosocial characteristics (Steptoe et al., 2000).

Average dwelling value was related to BMI independently of individual-level characteristics. There is a growing understanding that average dwelling value is a expression of individual-level SES (Dunn, 2002) and that aggregate measures of average dwelling values may be sensitive measures of neighbourhood socio-economic position (Cozier et al., 2007).

The overall performance of the multivariate models in terms of the percentage of the variation of the dependent variables explained by the variation of the independent variables (R^2) was good. The highest Adjusted R^2 obtained was 0.1505 (Toronto) indicating that 15.05 percent of the variation of the BMI values is explained by the variation of the independent variables included in the model. For Vancouver, the highest Adjusted R^2 obtained was 0.1679 indicating that 16.79 percent of the BMI variation is explained by the variation of the independent variables. Nevertheless, the large size of the sample ensured the robustness of the relationships established.

This study also demonstrated significant differences at the area-level of analysis, supporting related research that has suggested that individual-level factors alone cannot explain variation in obesity rates across space (Duncan et al., 1993; Macintyre et al., 2002; Reidpath et al., 2002). The ICC's indicated that substantial proportions of the variation occurring at the neighbourhood-level in adult BMI with values ranging between 1.23 and 3.08 percent for Toronto and 4.14 and 4.5 percent for Vancouver.

Overall, research findings are consistent with current understanding in health geography, that characteristics of the built and social environments have an independent influence on health (Evans and Kantrowitz, 2002; Duncan et al., 1999).

5.3 Contributions and Policy Implications

5.3.1 Theoretical Contributions

Theoretically, this research was informed by the population health perspective (Evans et al., 1994). Embracing of the population health perspective allows for the consideration of the broader determinants of health including individual characteristics (i.e., human biology and behaviour), availability of health services as well as aspects of the social, economic and physical environments (Edwards, 1999), therefore, providing the opportunity for addressing the complexity of the overweight and obesity. In general, the results of this study demonstrated the effectiveness of the population health framework in identifying the determinants of overweight and obesity given the range of explanatory variables that emerged as significant in the models. Further, results from the regression models demonstrate that adopting a population health approach offered new evidence with regard to relative contribution of the social and built environments on overweight and obesity. In general, research findings constitute additional empirical evidence for the importance of considering broad range of health determinants in the study of health and illness.

Secondly, through the "analysis grid for environments linked to obesity" (ANGELO) framework (Swinburn et al., 1999), this study dissects the broad array of environmental factors influencing obesity into concrete elements, which are amenable to measurement and intervention. Focus on the environmental elements further underscores the importance of prioritizing research needs as well as the settings/sectors for intervention.

5.3.2 Methodological Contributions

The methodological contributions of this study stem from the application of GIS and spatial analysis techniques to examine the spatial patterns of overweight and obesity as well as investigate the potential contribution of various environmental factors on current rates.

In particular, this research employed GIS and spatial analysis techniques to explore sex-specific spatial patterns of overweight/obesity in Canada as well as investigate the presence of spatial clusters. Until recently, these techniques have been sparingly used in the field of health geography, despite the geographical nature of the data. The results of this study, however, verify the effectiveness of spatial data analysis methods and in particular cluster analysis as a helpful tool for public health professionals and policy makers to identify areas of elevated risk and therefore enable regionally focused prevention and health promotion strategies as well as the effective allocation of resources and services. The use of such methods remains relatively uncommon in health geography and should be encouraged.

The application of GIS techniques to develop environmental variables and therefore explore the potential association between BMI and the built environment represents a further contribution. In particular, a key aspect of this study is the construction of standard-distance (radius of 1km) and travel-distance-based (radius based on Morency et al., 2009 model) buffers were created in order to better assess the landuses that influence walking and potentially the BMI of individuals. Further, comparison of the buffers revealed that the travel-distance-based buffers performed better, resulting into a greater association between the local built environments on BMI. In particular, the construction of land-use mix, street network connectivity, residential density, density to various opportunities (e.g., fast-food restaurants, convenience stores, grocery stores and recreational centres) as well as the walkability index demonstrate that relations between the built environment and BMI are sensitive to the choice of the built environment measure.

In addition, this is the first study to our knowledge to explore the association between weight status and the built environment using measures of urban form (i.e., landuse, residential density and street network connectivity) as well as accessibility (e.g., density of fast-food restaurants). Findings indicated though, that compared to accessibility, measures of landuse and residential density, generally performed as a better indicator of the built environment for both Toronto and Vancouver. Employing a more sensitive estimate of the built environment could be therefore used to better assess the environmental determinants of overweight and obesity.

A third methodological contribution of this thesis lies in the use of interaction terms. Typically, studies separate the sample by sex to examine for differences in the determinants of overweight and obesity between males and females. However, the effects of some independent variables may differ across males and females. Conducting such analysis will not allow comparing coefficient estimates across the sub-samples (males and females). Therefore, the inclusion of the interaction terms allowed for different determinants of overweight and obesity between male and female participants to be explored. Research findings revealed that not only is gender significant to overweight and obesity, but that the effects of socio-economic status on weight status differ between genders.

A final significant methodological contribution of this study comes form the application of multilevel statistical techniques to identify heterogeneities associated with the relationships between individual and socio-environmental determinants and overweight and obesity at the individual- and community-levels. While interest in such multilevel analysis is growing, relatively few studies have been conducted, particularly within the Canadian context (Harrington and Elliott, 2009; Ross et al., 2007). The analysis conducted in the study builds upon the relatively small number of multilevel obesity-related studies conducted in a Canadian context and provides further evidence on the environmental determinants of overweight and obesity at the area-level of analysis.

5.3.3 Substantial Contributions

This thesis makes several substantive contributions relevant to the development of public health and health care programs and policies. First, this study illustrates that spatial analysis can provide a better understanding of the geographical variability of overweight and obesity in Canada. In addition, the identification of spatial clusters provides a great potential to uncover region-specific risk factors of overweight/obesity as well as be an evidence-based tool for public health professionals and policy makers to effectively direct scarce public health resources and services based on regional and population specific demands.

Secondly, this study has identified a number of demographic, socio-economic, behavioural risk factors to be associated with overweight and obesity. In particular, the demographic relationships (e.g., age, sex and race) reported in this thesis have been reproduced elsewhere in numerous contexts (Sundquist and Johansson, 1998; Tremblay et al., 2005). Similarly, the association between BMI and various chronic conditions has been exhibited in numerous studies throughout the literature (Reeder et al., 1997; Falkner et al., 2001). Further, indicators of physical activity have been found to be significantly associated with BMI in the literature (Nelson et al., 2006a; Gordon-Larsen et al., 2005; Janssen et al., 2004; Frank et al., 2004). However, the findings with respect to individual-level socio-economic status indicate some novel relationships. In particular, income-related measures have been found to be significantly associated with overweight and obesity in many studies (Pickett et al., 2005; Macdonald et al., 1997). Findings of this thesis however, pinpoint education as a significant SES predictor of overweight and obesity. This finding is noteworthy as it suggests that education at the individual-level is an important indicator of SES in a Canadian context (Ross et al., 2000). Results provide further evidence that in order to reverse current overweight and obesity trends, a multi-sectoral approach involving various sectors will be necessary. For example, implementing public awareness or offering incentives for adults to complete high school could prove to be useful in fighting increasing prevalence rates.

Another substantive contribution surfaced through the multilevel analyses, with respect to the area-level covariates of overweight and obesity. In the Toronto models, average dwelling value emerged as a significant covariate of BMI, while dwelling in need of minor repairs emerged in the Vancouver models. The Vancouver model results are of particular importance to the contributions of this thesis, since these results have not been reproduced (to our knowledge) elsewhere in the literature. In particular, there is an emerging consensus in the housing and health inequalities literature that housing characteristics are a manifestation of socio-economic status (Dunn, 2002). Therefore, since average dwelling value as well as dwelling in need of minor repairs had the expected relationships with BMI, it is reasonable to assume that these variables are acting as proxies for area-level SES (Crosnoe, 2007). Yet, the actual mechanism by which such factors may affect weight gain is still at the level of speculation and requires further investigation. According to Reidpath et al. (2002), a potential explanation for the association between area-level SES and overweight/obesity is the physical and social environments of low-SES areas might promote poor diets and sedentary lifestyles.

Further, while the majority of variation in BMI was occurring at the individual level, this study did show significant differences at the area-level of analysis, supporting related research that has suggested that individual-level factors alone cannot explain variation in obesity rates across space (Macintyre et al., 2002). The results of this thesis can therefore help guide policy interventions targeting overweight and obesity in Canada by providing further evidence that the local social and built environments can influence individual weight status, above and beyond the effects of individual characteristics and behaviours (Nelson et al., 2006b; King et al., 2006). Population-level interventions have the power to shift the obesity distribution curve in a direction that would benefit the entire population by removing or modifying these underlying forces. Indeed, major gains in altering other health behaviours, such as reducing smoking-related inequalities in health, have been realized by developing interventions focused on modifying population-level determinants in combination with individual-level interventions.

5.4 Future Directions

This study has significantly improved our understanding of the spatial patterns and determinants of overweigh and obesity in urban Canada. However, through conducting this research, new questions have emerged and the need for further research has become apparent.

First, overweight and obesity are not static conditions; rather, these are chronic conditions that develop over time with varying degrees of severity. Thus, it would be useful to conduct a longitudinal study of weight status to determine any changes in the magnitude and direction of the relationships exhibited in this research over time.

Secondly, incorporating bootstrapping into the multi-level models to estimate the variance for the estimates would be important to account for the complex sampling design of the CCHS. In particular, the lack of accounting for the non-random sampling design of the survey could affect the validation of the estimates and need to be interpreted with caution. Future work should therefore incorporate bootstrapping into the models.

Thirdly, a deeper exploration of the area-level determinants of overweight and obesity would be important to fully understand the contribution of area-level characteristics to the development of such a chronic condition. Specifically, more attention should be paid to measures of the social environment such as social support or collective efficacy. Broadening the scope of the area-level variables to include more contextual factors could provide important information that may contribute to a more comprehensive interpretation of existing trends.

In addition, while this research has examined a number of built environment measures, it would be important to consider a wider range of environmental aspects that may influence overweight and obesity such as presence or absence and quality of sidewalks, traffic and road conditions and safety.

Finally, this research has focused on the individual-level and dissemination area level. It could be useful to explore other geographical units, as this may provide a deeper understanding of the relationship between weight status and area-level characteristics. Additionally, it could be useful to incorporate higher level of geography into the multilevel models, in order to assess higher-level variation in the outcome variables (e.g. inter-provincial disparities).

Ultimately, this research has demonstrated that Canadian urban environments play a small but significant role in shaping the distribution of BMI. They also provide support for altering the contexts in which health improvement behaviour occurs and for informing urban sustainability and design policy with human health research.

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