

**NEIGHBOURHOOD BUILT AND SOCIAL ENVIRONMENTS AND
INDIVIDUAL PHYSICAL ACTIVITY AND BODY MASS INDEX:
A MULTI-METHOD ASSESSMENT**

By

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**Thesis submitted to the Faculty of Graduate and Postdoctoral Studies
in partial fulfillment of the requirements for the PhD degree in Population Health**

**University of Ottawa
Ottawa, Ontario, Canada
February 2012**

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ABSTRACT

Background: Obesity and physical inactivity rates have reached epidemic levels in Canada, but differ based on whether they are self-reported or directly measured.

Canadian research examining the combined and independent effects of social and built environments on adult physical activity (PA) and body mass index (BMI) is limited.

Furthermore there is a lack of Canadian studies to assess these relationships using directly measured PA and BMI.

Objectives: The objectives of this thesis were to systematically compare self-reported and directly measured PA and to examine associations between neighbourhood built and social environmental factors with both self-reported and directly measured PA and overweight/obesity in adults living in Ottawa, Canada.

Methods: A systematic review was conducted to identify observational and experimental studies of adult populations that used both self-report and direct measures of PA and to assess the agreement between the measures. Associations between objectively measured neighbourhood-level built recreation and social environmental factors and self-reported individual-level data including total and leisure-time PA (LTPA) and overweight/obesity were examined in the adult population of Ottawa, Canada using multilevel models.

Neighbourhood differences in directly measured BMI and PA (using accelerometry) were evaluated in a convenience sample of adults from four City of Ottawa neighbourhoods with contrasting socioeconomic (SES) and built recreation (REC) environments.

Results: Results from the review generally indicate a poor level of agreement between self-report and direct measures of PA, with trends differing based on the measures of PA, the level of PA examined and the sex of the participants. Results of the multilevel analyses identified that very few of the built and social environmental variables were

significantly associated with PA or overweight/obesity. Greater park area was significantly associated with total PA in females. Greater green space was shown to be associated with lower odds of male LTPA. Factors from the social environment were generally more strongly related to male outcomes. Further to the recreation and social environment, factors in the food landscape were significantly associated with male and female PA and overweight/obesity. Results of the directly measured PA and BMI investigation showed significant neighbourhood-group effects for light intensity PA and sedentary time. Post-hoc tests identified that the low REC/high SES neighbourhood had significantly more minutes of light PA than the low REC/low SES. BMI differed between the four neighbourhoods, but the differences were not significant after controlling for age, sex and household income.

Conclusions: Results of this dissertation show that the quantity of PA can differ based on its method of measurement (i.e. between self-report and direct methods) with implications for the interpretation of study findings. It also identifies that PA and BMI can differ by neighbourhood and recognizes that the relationships between neighbourhood environments and PA and body composition are complex, may be differ between males and females, and may not always follow intuitive relationships. Furthermore it suggests that other factors in the environment not examined in this dissertation may influence adult PA and BMI and that longitudinal and intervention studies are needed.

CO-AUTHORSHIP STATEMENT

This thesis presents the research of Stephanie Prince in collaboration with her thesis supervisors Dr. Denis Prud'homme and Dr. Mark Tremblay and manuscript co-authors: Dr. Kristi Adamo, Ms. Meghan Hamel, Ms. Jill Hardt, Dr. Sarah Connor Gorber, Dr. Elizabeth Kristjansson, Ms. Katherine Russell, Ms. Amira Ali, Dr. Jean-Michel Billette, Dr. Michael Sawada, and Dr. Rachel Colley.

Manuscript 1: *A population health approach to obesity in Canada – putting the problem back into context.* S. Prince conceived the topic of this discussion paper and wrote and edited the manuscript as the sole author.

Manuscript 2: *A comparison of direct versus self-report measures for assessing physical activity in adults: a systematic review.* Dr. Tremblay conceived of the study. S. Prince carried out the design, bibliographic search, article screening, data abstraction and synthesis and drafted and edited the manuscript. Dr. Adamo participated in its design and coordination and helped edit the manuscript. M. Hamel participated in article screening, data abstraction and editing of the manuscript. J. Hardt participated in data abstraction, data synthesis and helped edit the manuscript. Dr. Connor Gorber participated in the design of the study, provided methodological input, and assisted in the editing of the manuscript. All authors read and approved the final manuscript.

Manuscript 3: *Relationships between neighbourhoods, physical activity and obesity: A multilevel analysis of a large Canadian City.* S. Prince conceived the study, carried out the design, performed the analyses, and drafted and edited the manuscript. Dr. Kristjansson is a principal investigator with the ONS and was responsible for the environmental data; she participated in this study's design and coordination, provided analytical input and helped draft and edit the manuscript. K. Russell participated in the

study's design, abstraction of data, provided analytical input and aided with the editing of the manuscript. Dr. Billette provided analytical advice and interpretation and helped edit the manuscript. Dr. Sawada is also a principal investigator with the ONS and was responsible for the environmental data, specifically the GIS components, provided methodological input, and assisted in the editing of the manuscript. A. Ali participated in the study's design and coordination of data acquisition and edited the manuscript. Drs. Tremblay and Prud'homme participated in the design of the study, provided methodological input, and assisted in the editing of the manuscript. All authors read and approved the final manuscript.

Manuscript 4: *A multilevel analysis of neighbourhood built and social environments and adult self-reported physical activity and body mass index in Ottawa, Canada.* S. Prince conceived the study, carried out the design, performed the analyses, and drafted and edited the manuscript. Dr. Kristjansson participated in this study's design and coordination, provided analytical input and helped draft and edit the manuscript. K. Russell participated in the study's design, abstraction of data, provided analytical input and aided with the editing of the manuscript. Dr. Billette provided analytical advice and interpretation and helped edit the manuscript. Dr. Sawada participated in the design of the study, provided methodological input, and assisted in the editing of the manuscript. A. Ali participated in the study's design and coordination of data acquisition and edited the manuscript. Drs. Prud'homme and Tremblay participated in the design of the study, provided methodological input, and assisted in the editing of the manuscript. All authors read and approved the final manuscript.

Manuscript 5: *Neighbourhood differences in objectively measured physical activity, sedentary time and body mass index.* S. Prince conceived the study, carried out data

collection, performed the analyses, and drafted and edited the manuscript. Drs. Tremblay and Prud'homme provided resources and support for data collection, provided analytical guidance, helped to interpret the findings and edited the manuscript. Dr. Colley provided support for the use of accelerometers and the analysis and interpretation of the data. Drs. Sawada and Kristjansson participated in the selection of the four study neighbourhoods and helped to edit the manuscript. All authors read and approved the final manuscript.

The other components of this thesis (i.e. Introduction, Literature Review, General Discussion, and Appendices) are all original work of S. Prince with editorial changes provided by Dr's Prud'homme and Tremblay.

ACKNOWLEDGEMENTS

To Tom and Evan Ware, who deserve this degree as much as I do. Thank you guys for your support, patience, cups of tea during late nights working, support in high and low times, ‘nose kisses’ and ‘hug sandwiches’, and most importantly your endless love. You are the reason I was able to complete this degree and I dedicate this thesis to you. xoxo

To mom, Kris and Sarah, thank you for being there to support me, listening to me vent, providing babysitting, and most importantly, a personal cheering squad.

To dad, although you are not physically here, your spirit gave me inspiration. This is for you.

This dissertation is truly a collaboration of many minds. I have had the privilege to work with some very generous, intelligent and kind individuals. I would like to sincerely thank my thesis supervisors Dr. Denis Prud’homme and Dr. Mark Tremblay who allowed me to identify a research project that combined several of my interests and the support to see it through. Denis, you were always incredibly supportive throughout the process and gave me confidence in my work. Mark, you provided fantastic feedback, several opportunities that opened doors and an incredible work atmosphere at HALO for which I am grateful.

I would like to thank Drs. Elizabeth Kristjansson and Mike Sawada for providing access to the Ottawa Neighbourhood Study data and allowing me to take part in such a fantastic initiative. To Amira Ali and Katherine Russell from Ottawa Public Health, thank you for providing support for this project. Dr. Kristi Adamo, Dr. Sarah Connor Gorber, Dr. Rachel Colley, Ms. Meghan Hamel, Dr. Jean-Michel Billette, Mr. Travis Saunders, and Ms. Megan Carter, thank you for all of your help in the many ‘projects’ that compose this thesis. To all the HALOites and residents of ‘R242’, thank you for being such an amazing group of people to work with, you enriched my grad student experience.

And finally, to all those who encouraged me to pursue this degree and who were with me throughout the journey, there are far too many of you to ever mention, thank you from the bottom of my heart.

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LIST OF ABBREVIATIONS

BMI	Body mass index
CCHS	Canadian Community Health Survey
CHMS	Canadian Health Measures Survey
CI	Confidence interval
DLW	Doubly labelled water
GIS	Geographical Information Systems
ICC	Intraclass correlation coefficient
IPAQ	International Physical Activity Questionnaire
KKD	Kilocalorie per kilogram per day
LTPA	Leisure-time physical activity
MPA	Moderate physical activity
MVPA	Moderate-to-vigorous physical activity
NAICS	North American Industry Classification System
NCC	National Capital Commission
ONS	Ottawa Neighbourhood Study
OR	Odds ratio
PA	Physical activity
PAI	Physical Activity Index
REC	Recreation environment
RRFSS	Rapid Risk Factor Surveillance System
SD	Standard deviation
SES	Socio-economic status
VPA	Vigorous physical activity

CHAPTER 1: INTRODUCTION

1.1 General introduction

Obesity and physical inactivity have reached epidemic levels in Canada and are associated with several chronic diseases, premature mortality and a high economic burden (1-3). Canadian physical activity (PA) levels range depending on whether they are self-reported or directly measured. In the 2009 Canadian Community Health Survey (CCHS), 49% of females and 56% of males self-reported that they were moderately active during their leisure time (4) as compared to 14% of females and 17% of males who met current PA Guidelines (5) using directly measured accelerometry data from the 2009 Canadian Health Measures Survey (CHMS) (6). Furthermore obesity rates differ depending on whether weight and height (used to determine body mass index (BMI) as $\text{kg}\cdot\text{m}^2$) are self-reported or directly measured. In 2009, 19% of males and 17% of females were considered obese using self-reported height and weight from the CCHS (7), while measured height and weight from the CHMS identified that 24% of men and women were obese (8).

A variety of factors can influence energy balance and contribute to the development of obesity, these include biological, behavioural, environmental, economical, and social influences (9). The social and built environments that individuals inhabit have recently gained much attention as possible contributors to the development of healthy behaviours including PA. As a result of increasingly sedentary jobs and a greater dependence on motorized transport in North America, leisure time PA (LTPA) provides an important means for achieving recommended PA targets. Research investigating the relationships among factors in the built and social environments related to recreation-based PA (i.e. LTPA) and overweight/obesity has become more prevalent in

recent years. Canadian research examining these relationships in adults is limited. The majority of Canadian studies examining factors in the recreation environment have focused on parks (10-14) and proximity to facilities (10;12;15-17), while most social-environment research has involved the use of area-level socioeconomic status (i.e. income/education levels) or deprivation (15;18-23) as they relate to self-reported PA and/or BMI. Further research is needed to identify whether specific recreation venues (e.g. parks, green spaces, bike/walk paths, season specific, etc.) or other factors in the social environment (e.g. social capital or crime) are more or less important than others in their relationship with PA or BMI. In addition, there continues to be a paucity of Canadian research linking directly measured individual-level PA and overweight/obesity data to objectively assessed neighbourhood recreation built and social environments within an analysis.

This dissertation systematically compares self-report and directly measured PA and examines the associations between built and social environmental factors with both self-report and directly measured PA and overweight/obesity in adults living in City of Ottawa neighbourhoods. Neighbourhood-level information pertaining to the recreation and social environments are extracted from data captured by the Ottawa Neighbourhood Study (ONS), the CCHS, the City of Ottawa, and the 2006 Canadian census. Three samples are used to examine the relationships of the neighbourhood-level factors with PA and BMI outcomes. The first involves individual-level data including self-reported height, weight, total PA, and demographics obtained from the 2003-2007 years of the Rapid Risk Factor Surveillance System (RRFSS) (See: www.rfss.on.ca). The second sample includes similar individual-level data including LTPA derived from the 2001/03/05/07 cycles of the CCHS (24). The third sample is primary data collected for

the specific use of this dissertation and provides smaller-scale pilot data from four contrasting (based on SES and recreation environment) Ottawa neighbourhoods and includes directly measured PA and sedentary time using accelerometers and measured height and weight for BMI.

Both self-reported and directly measured PA data are examined as it is hypothesized that they do not capture the same parameters of PA and therefore, the strength and direction of association with the environmental factors may differ. Accurate monitoring of PA is important to establish current levels, to monitor changes, and to inform intervention effectiveness and public policy. Most PA research in Canada has used self-report methods and prior to this thesis no attempt had been made to synthesize the literature to determine the validity of these methods. As a result, this thesis also systematically reviews the literature to compare self-report methods with direct methods for assessing PA in adult populations. The review helps to inform the interpretation of results used to examine PA as an outcome in both this dissertation and in future PA research.

This research is timely and important due to the high prevalence of physical inactivity and overweight/obesity in Canada. Given that physical inactivity is a known risk factor for obesity, the promotion of an active lifestyle remains an important public health goal (25). From an intervention perspective, it is essential to incorporate socio-ecological and policy approaches to create supportive environments to reach large segments of the population and to support delivery of individual-level interventions. Results from this thesis inform current gaps in the literature and provide for recommendations for the design of future research projects and the creation of policies to encourage and promote PA participation in adults.

1.2 Conceptual Framework

The thesis explores the relationships between the built and social environments, PA and overweight/obesity. A modified and simple conceptual model (26;27) for overweight/obesity and its development, specifically through PA (energy expenditure) is shown in **Figure 1.1**. It is hypothesized that the built and social environments have the capacity to influence individual behaviour and inhibit or enable regular PA leading to conservative changes in body fat and body weight. For example, a lack of recreation facilities and resources may hinder an individual's ability to be physically active in a way that is appealing to them and their abilities. The conceptual model shows the potential reciprocal relationships between the environment, behaviour and the onset of obesity. Important to note is that although this thesis uses cross-sectional data, longitudinal data are needed to demonstrate a cause-effect relationship.

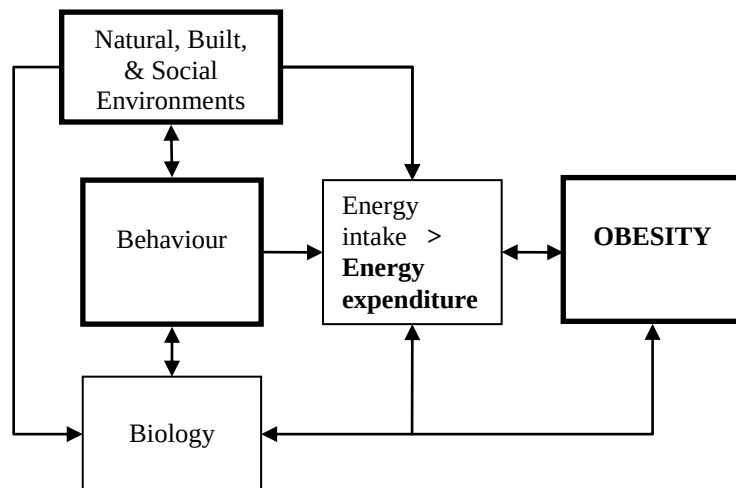


Figure 1.1 Modified conceptual model for the development of obesity (26;27)

This thesis uses a socio-ecological approach to investigate the environmental influences associated with PA and identify the existence of relationships that can be

investigated further using longitudinal study designs. The modified socio-ecological framework of PA and obesity (**Figure 1.2**) recognizes that individual behaviours may be dependent on the dynamic relationships between the structure and function of the environment and an individual's interaction with these features (28). Individuals are influenced by multiple health determinants including environments (i.e. socio-cultural, policy, natural, and built) across multiple levels of interaction (intrapersonal, interpersonal, community, etc.) over the lifespan. The problems of physical inactivity and obesity in Canada must be addressed at these multiple levels and interventions must be designed in recognition of the interactions between individuals and multiple determinants across various levels. The goal should therefore be to create healthy community environments that provide health promoting opportunities and the social support needed to enable Canadians to achieve healthy lifestyles – in essence, ideal environments will make “the healthy choice the easy choice”. This framework provides a means for understanding the multilevel determinants of individual behaviours such as PA and the transdisciplinary approach required to study its determinants. This thesis uses this socio-ecological framework to explore the relationships among built and social environmental determinants (distal), individual behavior (e.g. PA/proximal) and related outcomes (obesity).

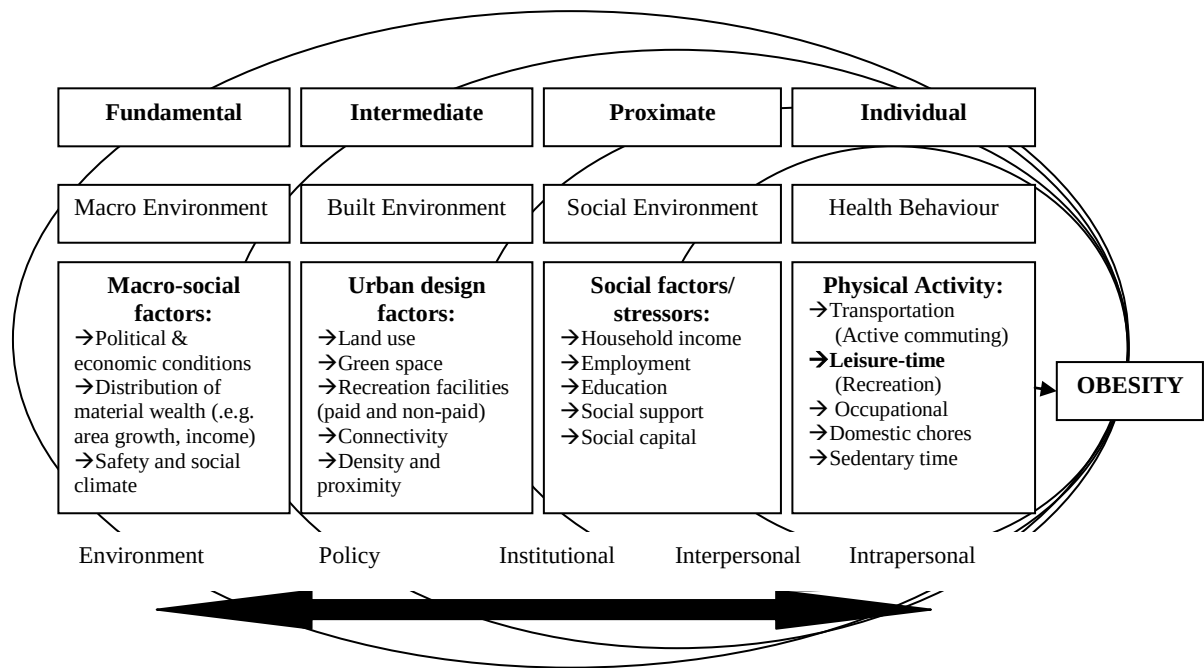


Figure 1.2 Modified socio-ecological framework for the study of physical activity and obesity (28)

1.3 Objectives

The purposes of this thesis are to compare self-reported and directly measured PA and to examine the associations between neighbourhood built and social environmental factors with both self-reported and directly measured PA and overweight/obesity in adults living in Ottawa, Canada. The specific objectives of this thesis were as follows:

- 1) To perform a *systematic review* of the literature to compare the agreement between *self-report and direct measures* in assessing PA in adult populations;
- 2) to determine the associations between the built and social environments and *self-reported total PA and BMI* in the City of Ottawa adult population;
- 3) to determine the associations between the built and social environments and *self-reported LTPA and BMI* in the City of Ottawa adult population;

- 4) to determine whether adult *directly-measured PA levels, sedentary time and BMIs* were different across four neighbourhoods with contrasting socioeconomic and recreation environments in the City of Ottawa; and
- 5) to determine whether any difference in these relationships existed between males and females.

1.4 Hypotheses

The hypotheses of this thesis were as follows:

- 1) Self-report and direct methods for measuring PA would not agree;
- 2) inactivity and overweight/obesity rates would be highest in neighbourhoods with built recreation environments that are not conducive to PA (i.e. low density of facilities, walk/bike paths, green space area, and park area);
- 3) inactivity and obesity rates would be highest in neighbourhoods with social environments that do not facilitate or promote healthy behaviours; specifically PA (i.e. areas with low SES, high crime rates, low voting rates, and low sense of community belonging);
- 4) the built and social environmental factors associated with PA and overweight/obesity and the strengths of the associations may differ when the outcomes are self-reported versus directly measured; and
- 5) the relationships between the built and social environments with PA and overweight/obesity would differ between males and females.

1.5 Thesis Organization and Outline

This thesis is organized according to the *Guide for Doctoral Thesis* as stipulated by the Faculty of Graduate and Postdoctoral Studies at the University of Ottawa and the Population Health PhD Program. The next chapter of this thesis presents a literature

review of the exposure and outcomes under study, and the associations between factors in the built environment specific to the recreation and social environment and possible sex differences as they relate to the outcomes of interest (PA and body composition) in adults. Chapter three is the first manuscript entitled: *A population health approach to Obesity in Canada – putting the problem back into context*, published in the journal *Transdisciplinary Studies in Population Health Series* (29). This chapter discusses population health frameworks for obesity used to identify gaps in the literature and proposes directions for future research that served as a primer for the analyses that follow in subsequent chapters. Chapter four is the second manuscript entitled: *A comparison of direct versus self-report measures for assessing physical activity in adults: a systematic review* and was published in the *International Journal of Behavioural Nutrition and Physical Activity* (30). Chapter five is the third manuscript and is entitled: *A multilevel analysis of neighbourhood built and social environments and adult self-reported physical activity and body mass index in Ottawa, Canada*. This manuscript has been published in the *International Journal of Environmental Research and Public Health*. The sixth chapter presents the fourth manuscript entitled: *Relationships between neighbourhoods, physical activity and obesity: A multilevel analysis of a large Canadian City* that was published in the journal *Obesity*. Chapter seven houses the final manuscript of the thesis entitled: *Neighbourhood differences in objectively measured physical activity, sedentary time and body mass index* and was published in the *Open Journal of Preventive Medicine*. Finally, chapter eight presents a general discussion including a summary and conclusions, including strengths, limitations, and future implications of the study and its results.

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CHAPTER 2: LITERATURE REVIEW

2.1 Introduction

The literature review is organized in accordance with the objectives of this thesis. Following this organizational introduction, the second section provides definitions for and a summary of self-reported and directly measured PA and BMI and perceived and objectively measured built recreation and social environments. The third and fourth sections of the literature review examine the associations between the built recreation and social environments and self-reported or directly-measured PA and BMI. The fifth section of the review focuses on the synergistic effects of the recreation and social environments while the next section focuses on possible sex differences. Finally, the review concludes with a summary and rationale for the study.

2.2 Definitions of Outcomes and Exposures

2.2.1 *Physical activity*

PA refers to “any bodily movement produced by the skeletal muscle that results in energy expenditure” (1). The *Canadian Physical Activity Guidelines for Adults* suggest that “...adults aged 18-64 years should accumulate at least 150 minutes of moderate- to vigorous-intensity aerobic PA per week, in bouts of 10 minutes or more” (2).

Unfortunately, the majority of Canadians are not meeting current PA recommendations. Data from the 2009 CHMS identified that only 14% of females and 17% of males met current PA Guidelines using directly measured accelerometer data and are therefore, not accruing the associated health benefits of regular PA (3). Furthermore, overweight and obese Canadians have lower measured PA levels than their normal weight counterparts (3). In 2001, the economic costs of physical inactivity in Canada were estimated at \$5.3

billion or 2.6% of the total direct health care expenditures and \$3.7 billion in indirect costs (4). This thesis uses both self-reported and directly measured PA.

2.2.1.1 Self-reported vs. directly measured physical activity

To date the majority of Canadian health behaviour and outcome data has been self-reported, but Canada has recently undertaken national, objective PA surveillance using accelerometry (5;6) as part of the CHMS. Accurate assessment of PA is required to identify current levels and monitor changes within the population, to improve the precision of determining the relationships between PA and health indicators, and to assess the effectiveness of interventions designed to increase activity levels. In a laboratory or field setting, PA can be measured with greater accuracy using direct measures (e.g. doubly-labeled water, pedometer, accelerometer, etc.) (7;8). However, when collecting data at the population level, self-reported measures of PA (e.g. surveys, questionnaires, etc.) are largely used due to their practicality, low cost, low respondent burden, and general acceptance (7). Although self-reports are useful for gaining insight into the population PA levels, they have the capacity to over- or under-estimate true energy expenditure and rates of inactivity and are often wrought with issues of recall and response bias (e.g. social desirability, inaccurate memory) and the inability to capture absolute levels of PA.

As self-report methods possess several limitations in terms of their reliability and validity (9), direct measures of PA are often used to increase precision and accuracy and to validate self-report measures. Direct measures offer more precise estimates of energy expenditure and reduce the issues of recall and response bias. Despite the advantages to using direct methods, these types of measures are often too intrusive and time consuming

for the participant and expensive rendering them challenging to apply to large epidemiologic settings. These measures also require specialized training and close geographic proximity of the participant for data collection, and each direct measure tool possesses its own limitations (7).

The feasibility and the type of PA measurement method to use depends on factors such as the number of individuals to be monitored, the time period of measurements and available funding (10). Activity monitors such as accelerometers are able to measure multiple forms of PA including smaller intermittent bouts of low- to moderate-intensity activities and sedentary time that are presumably not accurately captured by self-report methods (5). It is likely that self-report and direct methods do not totally measure the same parameter of PA. Results from studies have been conflicting and there has yet to be a synthesis of the evidence to assess the extent of agreement between self-report and direct methods for assessing PA. Chapter 4 of this dissertation presents a systematic review that compares directly measured and self-reported PA in adult populations.

2.2.2 Body mass index and overweight/obesity

Overweight and obesity are conditions of excessive body fat that are associated with an increased risk for mortality and morbidity (11-14). In epidemiologic research, BMI, waist-to-hip ratio, and waist circumference are the most often used indices to define body composition and body fat distribution. Canadian adult BMI cut-offs are: 25.0-29.9 kg/m² and ≥ 30 kg/m² to define overweight and obesity, respectively (15;16).

Unfortunately, the majority of Canadians are considered overweight or obese and are subsequently at a greater risk for developing several chronic diseases and premature

mortality (17). Data from the 2009 CHMS identified that 53% of females and 68% of males were either overweight or obese using directly measured height and weight (18). Recently, the indirect and direct economic costs associated with obesity in Canada were estimated at \$4.6 billion annually (17). This thesis reports on data using both self-report and direct measures of BMI.

2.2.2.1 Self-reported and directly measured body mass index and overweight/obesity

In a laboratory setting, obesity can be measured accurately using sophisticated techniques such as magnetic resonance imagery, computed tomography, or dual-energy x-ray absorptiometry technology (19;20). In an epidemiological setting, the common measure of obesity is BMI, which is a proxy measure for total body fat. BMI is generally collected by two methods: self-report and technician/physician measured. In large population-based studies, objective measurements are often not feasible and as a result researchers often rely on self-reported information. The validity of self-reported height and weight has been examined under various contexts and using different protocols. Results generally suggest that self-reported height and weight are not highly accurate for calculating and interpreting BMI due to a general trend in underreporting of weight and over reporting of height among adults; however, in the case of epidemiologic monitoring, self-report measures may be valid for identifying possible relationships and as a practical means for obtaining data on large samples, but objective measures still remain the gold standard (21-23).

2.2.3 Built recreation environment

The built environment describes structural features of the environment that are created and modified by human beings (24). These features include homes, schools, park/recreation areas, workplaces, businesses and roads and have the capacity to impact health and quality of life (25). Within this thesis the built environment primarily conducive to the adoption of recreational PA (e.g., parks, green spaces, facilities, and bike/walking paths) is evaluated using objectively measured per-capita density of these features.

2.2.3.1 Perceived and objectively measured built recreation environment

One of the key challenges surrounding research of the built environment is its measurement. Data on the built environment can be *perceived* using tools such as surveys and questionnaires or *objectively measured* using systematic audits or geographically linkable datasets such as a city's resource database or the Yellow Pages® that can in-turn be layered and analyzed using Geographical Information Systems (GIS) (26). Individual perceptions of the built environment are likely affected by previous experiences, preferences and individual circumstances (e.g. health status, personality, behaviours, family size, etc.), whereby, two individuals living in the exact same environment can perceive it differently (26). Furthermore the methods used to obtain perceived data may also have issues of response bias that can affect the overall measure's validity (26). Objective measures remove these issues and provide unbiased assessments of the built environment. They do however, also possesses drawbacks including the time to undertake audit assessments (e.g. data collection, raining and testing), problems with existing datasets such as accuracy and completeness, and possible issues with temporality

between environmental measures and the outcomes under study (26). Studies examining the agreement between perceived and objectively measured built environments have shown poor to fair agreement (kappas ranging from 0 to 0.4) identifying that these two methods of measurement are likely not capturing the same parameters of the environment (26). It has also been shown that agreement can be affected by whether an individual interacts with that specific environment (e.g. parks) for its specific purpose (e.g. park-based PA) (27).

2.2.4 Social environment

The social environment includes “the groups to which we belong, the neighbourhoods in which we live, the organization of our workplaces, and the policies we create to order our lives” (28). Supportive social environments have shown positive associations with PA and health status (28-31). Measures of the social environment can include such things as social inequality (related to socioeconomic status (SES)), crime or safety, social support, social capital, social cohesion, policies, and culture. This thesis examines features of the social environment using proxy or aggregate measures including: community SES measured using a neighbourhood socioeconomic index, safety evaluated using crime rates and social capital examined using voting rates and sense of belonging to the local community.

2.2.4.1 Perceived and objectively measured social environments

Data on the social environment as is the case with the built environment, can be *perceived* using tools such as surveys and questionnaires or *objectively measured* using geographically linkable datasets such as the Census (SES data), police databases (crime,

traffic, incivilities), area voting rates, or group membership lists that can be layered and analyzed using GIS. It is hypothesized that individual perceptions of the social environment are also likely affected by previous experiences, preferences and individual circumstances and subject to issues of response bias. Similar to the discussion surrounding the built environment, objective measures remove these issues and provide unbiased assessments, but also have their own set of issues. There has been less work comparing the agreement between these two type of measures, it is important however, to realize that especially with regard to the social environment perceived and objective measures are not likely capturing the same parameters of the environment. Perceiving that there is a great amount of crime for instance (regardless of actual crime rates) will likely impact individual health and health behaviours differently than objective measures as this will likely lead an individual to not feel safe in their environment. Studies examining the agreement between perceived and objectively measured social environments have supported this by showing poor to fair agreement between the measures and their different associations with PA (32-34).

2.2.5 Neighbourhoods

Neighbourhoods are “geographical constructs of place, defined around home and everyday activities, centered around schools, community centres, parks, or retail services. Neighbourhood evokes socio-physical homogeneity, a shared sense of place, connections, and access” (35). Within this thesis, neighbourhoods in the City of Ottawa were defined by the ONS using physical function and properties, as well as homogeneity amongst socio-physical factors (e.g. median household incomes, percent of dwellings owned, percent visible minorities, etc.) (36).

2.3 Built recreation environment and physical activity and body mass index

Studies investigating the association between the built recreation environment and PA and BMI have provided conflicting results and appear to be dependent on whether the environmental variables are perceived or objectively measured and whether PA and BMI are self-reported or directly assessed. The built environment presents a potentially unique opportunity to increase PA through urban planning with a focus on access to opportunities to be active. The built recreation environment as it applies to PA refers to the access and availability of opportunities to be physically active in leisure and includes such things as neighbourhood recreation facilities and surroundings (e.g. bike/walk paths, green spaces, facilities, etc.).

2.3.1 *Perceived built recreation environments and self-reported physical activity and body mass index*

Key studies investigating the relationships between the perceived built recreation environment and self-reported PA or BMI in adults are presented in **Table 2.1**. Findings are mixed and are possibly attributable to the different questions/survey methods used to quantify perceived recreation environments and in self-reporting of PA and BMI.

In adults, both significant positive associations and absence of associations have been reported between PA and density or proximity of resources in the built recreation environment. Positive associations indicate that greater perceived access to a recreation resource is associated with higher levels of PA or lower perceived access is associated with lower levels of PA. Significant positive associations have been reported between PA and greater density, accessibility/convenience or satisfaction of walking/bike paths

(37-48), public recreation/fitness facilities (43;49-65), private recreation facilities (pay for use) (55;66;67), and parks or green spaces (38;46;52;53;55;57;62;68-75). Fewer studies have reported a lack of a significant association with PA and greater density or shorter distance of walking/bike paths (76-78), public recreation facilities (77;79-86), private recreation facilities (52), and parks or green spaces (27;58). Only one known study has reported findings indicating that poorer perceptions of the built recreation environment are linked to higher PA participation (87). An analysis of data from the Canada Fitness Survey showed that females who reported a lack of facilities nearby had higher amounts of weekly PA than those who reported no constraint (87). Additionally, both males and females who indicated that available facilities were inadequate also had greater amounts of weekly PA (87).

Increased use of, or a membership for private recreation facilities has been associated with self-reported PA (88;89). Furthermore, placing an importance on living near parks has been shown to be associated with greater odds of park-based activity (90). Cross-sectional findings are mixed, but generally show that higher perceived access (including density and proximity) to built recreation environment resources is associated with an increased likelihood of being physically active. Only one known longitudinal study has looked at the effects of recreational resources and changes in PA. Sallis *et al.* looked at changes in vigorous exercise patterns after a 24-month follow-up in a cohort of randomly selected adults from California (91). They found that self-reported convenience of recreation facilities at baseline was not associated with changes in vigorous exercise (91).

Fewer studies have looked at the associations between recreation resources and self-reported BMI. In general, studies have found either significant negative association

or lack of association between self-reported BMI and density or proximity of resources. Negative associations indicate that greater accessibility of resources is associated with lower BMI or lower odds of overweight/obesity. Greater perceived access to public recreation facilities has been shown to be either negatively (51;92) or not significantly (60;93-95) associated with BMI or overweight/obesity. Similarly, though in fewer studies, the association between parks and green spaces with BMI or overweight/obesity has either been negative (74;96) or non-significant (60). Overall, the cross-sectional evidence is weak and only two known studies have examined changes in BMI over time (77;97). Berry and colleagues showed that whether an individual moves may interact with their rated importance of proximity to recreational resources and subsequent weight change. In their Canadian-based study, participants who rated being close to outdoor recreation resources as important and who moved over a 6 year follow-up had greater increases in their BMIs than movers who placed low importance on proximity (97). In those who did not move over the 6 years the relationship was in the opposite direction (97). In this same dataset, no significant associations were shown between perceptions of cycling and recreation facilities and BMI (77).

2.3.2 *Perceived built recreation environments and directly measured PA or body mass index*

Key studies investigating the relationships between the *perceived* built recreation environment and *directly measured* PA in adults are presented in **Table 2.2**. Fewer studies reported on the use of directly measured PA with perceived environments and only one known study has examined directly measured body composition. This is likely due to the nature of data collection methods as most studies investigating environmental

perceptions did so using a questionnaire where self-reported PA/BMI could be obtained using the same method. Additionally, several perceived environmental studies were conducted using secondary health data surveys.

Significant positive associations have been reported between directly measured PA (pedometer and accelerometer) and greater perceived density, proximity or accessibility of walking/bike paths (78), public recreation/fitness facilities (58;64;92) and parks (78). Studies have also reported a lack of significant association with directly measured PA and a greater density of walking/bike paths (98), public recreation facilities (76) and parks (58). Only one study has examined the associations between access to leisure facilities and the odds of being obese and found good access was associated with a lower likelihood of being obese (OR=0.84, 95% CI: 0.75, 0.94) (64). The level of evidence for the perceived built recreation environment and directly measured PA or BMI is weak with no clear trend in association. Furthermore, no known Canadian or longitudinal studies have examined this relationship.

2.3.3 Objectively measured recreation built environments and self-reported physical activity or body mass index or overweight/obesity

Several studies have looked at the associations between *objectively measured* built recreation environments through GIS linked databases with *self-reported* PA and BMI (see **Table 2.3**). Adult studies involving the use of objectively measured built recreation environment factors have found positive associations between PA and greater proximity, density and accessibility of walking and bicycle paths (99); public/free recreation facilities (100-104); private/pay-for-use recreation facilities (52;100;105;106); parks

(73;99;107;108), green spaces (100;109-113), swimming pools (114), and tennis courts (100).

Several studies have also reported no significant associations exist between self-reported PA and objectively measured proximity, density and accessibility of public or free recreation facilities (52;100;105;108;115;116), private recreation facilities (100;101); parks (100;116-122), green spaces (74;100;113;114;123-126), swimming pools (100), and tennis courts (100). One known study reported a greater likelihood of meeting PA recommendations with greater distances to parks (127) possibly attributed to more travel-related PA.

Within some of the same studies, the degree of association varies depending on the type of PA outcome such as walking, vigorous PA, sports, or cycling (100;113). Furthermore, within the same study, fee-based facilities show positive associations with PA whereas free facilities do not (105;106). There have also been several studies to report on the availability of facilities and their specific use. For instance, shorter distance to a green space (123;124;128), park (73), bike path (48), or recreation facility (115) and greater park area (90;129;130) have been shown to be associated with an increased likelihood of their use. The vast majority of the evidence is cross-sectional, but prospective cohort studies have demonstrated that residential self-selection (131) or whether or not an individual moves (117) may interact with the relationship between the objectively measured built environment and self-reported PA.

Interestingly, most adult research looking at the effect of objectively measured built recreation environments on self-reported PA has been conducted in the United States, Europe, and Australia, with only six known studies to have reported on Canadian data. The majority of Canadian research looking at the effect of objectively measured

built recreation environments on self-reported PA has involved parks, with five of these papers reporting on findings from the same Ontario-based dataset (27;90;107;118;132). The other looked at facility density per 1,000 residents and did not find any significant associations with use of the facilities (133).

A further subset of adult studies has examined self-reported BMI in relation to the objectively measured built recreation environment. Similar to the PA studies, findings are mixed; with one known study having shown that lower access to environmental supports was associated with normal weight (93), six studies showed the opposite that lower access to environmental supports was related to higher BMI or obesity (or inversely higher supports associated with lower obesity risk) (74;110;123;134-136), and five studies reported no significant association with BMI (95;103;121) or overweight/obesity (136;137). No longitudinal evidence exists and only one known Canadian study, using data from the 2003 CCHS, found no significant association between density of recreation facilities and overweight/obesity (137).

2.3.4 Objectively measured built recreation environments and directly measured physical activity and BMI or overweight/obesity

Very few studies have examined the associations between *objectively measured* built recreation environments and *directly measured* PA or BMI (see **Table 2.4**). There is no known study to have assessed these relationships in a Canadian sample. Two studies reported a lack of significant association between parks and pedometer (78) and accelerometer (58) measured PA. Interestingly, living within walking distance of a golf course has been shown to be associated with greater pedometer assessed steps per day (78). It is possible that golf courses, which usually involve participation and equipment

fees, may act as a proxy for higher area SES. The only other known study reported an counter-intuitive finding with greater green space area associated with lower accelerometer measured MVPA (48).

Similar to PA, very few studies have looked at directly measured BMI. Three studies reported a lack of association between recreation facilities and BMI (138-140) and one reported a significant negative association between a greater density of recreation facilities and BMI (141).

2.3.5 *Summary*

The majority of research examining relationships between the built recreation environment and PA or BMI has involved perceived access to recreation facilities. Perceived access to facilities has generally been associated with higher PA levels, but several studies have also shown no clear associations. The longitudinal evidence for the perceived built environment is very weak, with only one known study to date. Findings identified no significant associations between perceived convenience of recreation facilities and changes in vigorous PA. Fewer studies have examined the perceived built environment and self-reported BMI. The evidence is very mixed and weak, but does suggest that the importance an individual places in accessibility of recreation resources may interact with changes in BMI.

Very few studies have looked at the relationship between the perceived built recreation environment and directly measured PA or BMI, likely due to the mixed nature of data collection. Findings for PA are weak with no clear trend. Furthermore, no longitudinal or Canadian studies have been conducted. Only one known study

investigated the associations with measured BMI and showed that greater access to resources was associated with a lower odds of obesity (64).

Findings from studies investigating the relationships between objectively measured built recreation environments and self-reported PA or BMI are mixed between significant and non-significant associations. It is possible that the relationship between objectively measured built recreation environments and self-reported PA depend on whether the resources are fee-based rather than free and on the type or intensity of PA. Additionally, longitudinal evidence suggests that self-selection may play a role in the relationship. The evidence for objectively measured built recreation environments and self-reported BMI is also mixed with only one known Canadian study and no longitudinal evidence.

Finally, very few studies have been found that report on the association between objectively measured built recreation environments and directly measured PA or BMI. The majority have reported non-significant findings and no Canadian or longitudinal studies have been identified.

Table 2.1 Characteristics and main findings of studies examining relationships between perceived built recreation environments and self-reported physical activity and body mass index or obesity among adults (alphabetical order based on first author)

Reference	Sample	Environmental variable	Setting	Physical activity or weight status	Associations with outcome
Abildso 2007 (37)	N=788 ≥18 years 66% F	Distance perception to trail	United States Morgantown	Local trail use	↓ distance to trail sig. assoc. with more use
Adams 2011 (92)	N=2,199 20-65 years 48% F	Low walkable/transit and recreationally sparse Low walkable/recreationally sparse Moderately walkable/ recreationally dense High walkable/recreationally dense	United States Seattle-King County, WA Baltimore, MD Washington, DC	IPAQ minutes/week of walking for transportation and leisure Self-reported BMI	High-walkable recreationally-dense NBs had sig. more minutes of walking for transportation and minutes of LTPA vs. other NB types. In Seattle, BMI was lowest in the high-walkable recreationally-dense NB and highest in the low walkable/ recreationally sparse profiles
Addy 2004 (88)	N=1,194 ≥18 years 56% F	Perceived supports & barriers to PA in the NB (public recreation facilities, pleasant NB for walking)	United States Rural	Active, insufficiently active, inactive (no activity)	Use of private rec. facilities, parks, playgrounds, sports fields assoc. with ↑ PA
Atkinson 2005 (76)	N=102 48 ±12 years 52% F	NEWS scale (environmental index) Recreational facilities	United States 2 walkably different NBs	Self-reported PA (MPA, VPA and total)	NS correlations with recreational variables or MPA
Ball 2001 (46)	N=3,392 ≥18 years 54% F	NB convenience (shops, park or beach, and cycle path within walking distance)	Australia	Walking for exercise (walking/not walking)	Low and moderate convenience assoc. with lower odds of walking for exercise (OR=0.64; 95% CI: 0.54-0.77)
Bengoechea 2005 (49)	N=1,209 ≥18 years 50% F	Sex differences in perceived access to PA locations and bike facilities	Alberta, Canada	LTPA (Godin Leisure-Time Exercise Questionnaire)	↑ easy access to places for PA assoc with ↑ LTPA in men only . NS assoc. between bike facilities and LTPA.

Reference	Sample	Environmental variable	Setting	Physical activity or weight status	Associations with outcome
Bergman 2009 (50)	N=2,500 18-74years 53% F	Presence and maintenance of foot and bike paths and recreational facilities, walking distance to shops, services, and public transportation, access to motorised vehicles.	Sweden	IPAQ short form <u>Physically active</u> : ≥ 600 MET minutes·week <u>Walking</u> : low (<80 mins), moderate (80-300 mins) & high (>300 mins)	NS assoc. between environmental factors and odds of moderate PA. Lowest tertile for opportunities assoc. with $\downarrow$ odds of upper tertile of walking. Sig. positive trend between the highly PA category and opportunities and aesthetics
Berry 2010a (97)	N=572 (PCS) & 1164 (C-S) ≥ 18 years	Importance of being near to outdoor recreation and easy of walking	Edmonton, Alberta C-S survey and PCS (6 years)	BMI Change in BMI	<u>Cross-sectional</u> : $\uparrow$ importance placed on ease of walking when choosing a NB assoc. with $\downarrow$ BMIs. <u>Longitudinal</u> : Rated ease of walking as low priority had greater $\uparrow$ in BMI vs. rated important. Movers who rated being close to outdoor recreation important had greater $\uparrow$ s in BMI vs. those rated as low importance. Opposite for non-movers.
Berry 2010b (77)	N=500 18-90 years 48% F PCS	Perceptions of NB: Cycling trails Recreation facilities	Edmonton, Alberta	BMI and change in BMI	NS assoc. between perceptions of cycling and recreation facilities and BMI
Blanchard 2005 (51)	N=5,996 M+F	Access to facilities for PA	United States Market sample	<u>3 BMI groups analyzed</u> : Normal weight Overweight Obese (≥ 30 kg/m ²) Total # of days in MVPA	Obese report access to fewer facilities. Main effect of BMI group for PA and access to facilities $p < .01$. Access to facilities in the NB sig. predictor of PA for normal weight and overweight.
Boehmer 2007 (93)	N=1,032 ≥ 18 years 65% F	Recreational facilities	United States Randomly selected urban	IPAQ: Meeting PA recs. Obese vs. normal (BMI) Obese/inactive vs. normal/active	Perceived indicators of facility access NS assoc. with obesity. Obese/inactive more likely to strongly disagree 'many places' for PA vs. normal/active (aOR = 5.0, 95% CI: 1.5-15.9).

Reference	Sample	Environmental variable	Setting	Physical activity or weight status	Associations with outcome
Bolivar 2010 (68)	N=13,193 ≥16 years 51% F	Perception of sufficient green spaces	Spain	Self-reported PA during free time: some PA vs. sedentary	↓ green space in the NB less likely to exercise (OR=1.26; 95% CI:1.13-1.41) Perceiving no green spaces in NB more likely to be sedentary vs. those perceive green space (OR _{men} = 1.37; 95% CI = 1.24, 1.52 and OR _{women} = 1.19; 95% CI = 1.08, 1.32).
Boone-Heinonen 2010 (52)	N=449 ≥60 years 55% F	Environment (access to): recreation center, cycle track, golf course, gym, park, swimming pool, tennis court, bowling green	Australia Census Collectors' Districts	Sufficiently active (≥800 kcal/kg/week) vs. insufficiently active	Sig. greater % active vs. inadequately active reported access to recreation cycle track center, golf course, park, and pool. NS assoc. for access to exercise hall, gym, tennis courts, or bowl greens with PA. Access to park sig. assoc. with being PA.
Booth 2000 (69)	N=449 ≥60 years 55% F	Access to various PA facilities: gym, exercise hall, recreation center, cycle path, golf course, park, swimming pool, tennis court, or bowling green	Australia	Sufficiently active and inactive based on energy expenditure estimates	Access to local park assoc. with being active (OR=1.14, 95% CI: 1.03-1.26)
Brownson 2001 (53)	N=1,818 ≥18 years 67% F	Perceived environment: -general access -specific access -NB characteristics	United States	1) MPA (5 x 30 mins) or VPA (3 x 20 mins) 2) Insufficiently active 3) Inactive	Access to parks (OR=1.95; 1.52-2.52) Indoor gyms (OR=1.94; 1.45-2.60) Places to exercise indoor & outdoor (OR=1.85, 95% CI: 1.39-2.47) Outdoor only (OR=2.05; 1.32-3.19)
Catlin 2003 (94)	N=2,370 ≥18 years 52% F	Community infrastructure: sidewalks, walking or bike trails, parks, public outdoor facilities, public indoor facilities	United States	Overweight (BMI ≥25 kg/m ²) LTPA (not an outcome)	Absence of outdoor facilities (33.5% vs. 26.5%) and indoor facilities (59.9% vs. 57.0%) higher in overweight, but NS. OR for outdoor OR=1.21(1.00-1.45) OR for indoor OR=0.96 (0.81-1.13)

Reference	Sample	Environmental variable	Setting	Physical activity or weight status	Associations with outcome
Cerin 2008 (54)	N =2,650 20-65 years 64% F	Perceived access to facilities and home equipment for LTPA: beach/river/lake; public open space; indoor and outdoor team-sport facilities; indoor/outdoor individual sport/fitness facilities.	Australia	Long IPAQ: 1) weekly MET-minutes of walking for recreation and exercise; (2) weekly MET-minutes of any other moderate and vigorous LTPA.	Access to outdoor team-sports and indoor and outdoor individual sport/fitness facilities assoc. with sig more MET-minutes of moderate-to-vigorous LTPA. Access to recreational facilities independently related to LTPA after accounting for self-selection.
Christensen 2010 (142)	N=4,947 18-64 years	Use of facilities: private or membership; walking trails, parks, playgrounds, and sports fields; public recreation facilities; and schools open for public recreation.	United States Texas	Meeting PA recommendations vs. not.	Reported use of private recreation facilities, trails, parks, playgrounds, or sports fields sig. more likely to report LTPA vs. reporting no use.
Christian 2011 (95)	N=1151 40 ±12 years 59% F	Perceived PA destination within a 10–15 min walk from home.	Australia	BMI	BMI NS assoc. with perceived PA destinations.
De Bourdeaudhuij 2003 (56)	N=521 18-65 years 48% F	NEWS scale: Sidewalks Convenience of PA facilities	Belgium Local NB	IPAQ: Walking MPA VPA	Convenience of PA facilities sig. assoc. with ↑ VPA. ↑ availability of sidewalks positively assoc. with an ↑ likelihood of walking in males only. NS assoc. with MPA.
De Bourdeaudhuij 2005 (143)	N=526 35±12 years 65-66% F	Availability of sidewalks Availability of bike lanes Access to PA facilities	Belgium & Portugal	Long IPAQ: active transportation, walking for leisure, MPA-VPA in leisure time	Portuguese: ↑ availability of sidewalks Sig. assoc. with walking for leisure. NS assoc. with MPA or VPA in leisure.
Duncan 2005 (127)	N=1,215 ≥18 years 52% F	Perceived opportunities for PA	Australia	Sufficient ≥150 min in previous week Self-reported recreational walking in previous week	NOT agreeing that NB footpaths were in good condition, 38% more likely to walk for recreation

Reference	Sample	Environmental variable	Setting	Physical activity or weight status	Associations with outcome
Dunton 2009 (89)	N=7700 ≥21 years 46% F	Self-reported places individuals were active: outdoors, home, work, gym/health club, and other	United States	Sport & exercise for recreation only, MPA, VPA	VPA sig. more likely to occur when at a gym/health club and at home vs. outdoors.
Eyler 2003a (47)	≥18 years	Locations used in walking for PA & characteristics Environmental barriers	United States	Never walkers vs. occasional walkers vs. regular walkers (met recommendations by walking)	Regular walkers reported using parks, trails & NB streets more often vs. occasional walkers. Never walkers more likely vs. regular walkers to report lack of sidewalks and walking/jogging trails.
Eyler 2003b (82)	N=350 20-50 years F only C-S & Qual.	<u>Built Environment:</u> Presence of sidewalks Places to exercise	United States Native American	Inactive: no MPA or any PA Insufficiently active Sufficiently active: meets PA recommendations	No physical environment factors assoc. with PA status. Qualitative responses identified not enough rec. facilities (14%) and bad weather (8%) as barriers.
Foster 2004 (70)	N= 4157 16–74 years 57% F	Access to leisure centres, parks, cycle paths, and traffic density	England	(a) any reported walking in past four weeks, (b) reported walking >150 minutes per week in the past four weeks	Women: No environmental variables assoc. with walking >150 minutes per week. Men: Having a park/open space within walking distance sig. assoc. with walking >150 min/week (OR=2.22; 95% CI: 1.18-4.35)
Giles-Corti & Donovan 2002 (100)	N=1,773 18-59 years	Stratified by social advantage index <u>Perceived NB access:</u> Sidewalks available Public transport, a park or shop within walking distance	Australia	High vigorous (>1680 METs-mins/week) Sufficiently active (≥30 mins/day of MPA) Walking as recommended (≥6 x 30 mins per week)	<i>Low vs. high SES:</i> Agree that sidewalks are available (OR=1.88, p=.001) & park within walking distance (OR=0.47, p=.025)

Reference	Sample	Environmental variable	Setting	Physical activity or weight status	Associations with outcome
Granner 2007 (38)	N= 1,806 ≥18 years	Access to convenient indoor walking facility # known mapped out walking routes # of known mapped out bicycling routes # of parks, trails, and other recreation facilities	United States	Meeting guidelines (≥ 5 times/week MPA ≥30 min/day or VPA ≥ 3 times/week, ≥ 20 min/day) Insufficiently active Inactive (no PA reported) Walker vs. irregular/non-walker	Meeting PA recommendations sig. and positively assoc. with knowing of 1-2 parks, trails, or other recreational areas available for use. Walking sig. positive assoc. with knowing of 3+ walking routes and knowing of any available parks, trails, or other recreational areas.
Harrison 2007 (144)	N=15,461 50±18years 55% F	Placement of home for leisure facilities	England	Participation in ≥5 sessions per week of MVPA with each session lasting ≥15 mins	Linear trend between how well people thought their NB was for leisure facilities and prevalence of being physically active.
Hoehner 2005 (57)	N=1,068 18-96 years M+F	Recreation facilities (many places to exercise, any park, any trail, any private fitness facilities, # rec facilities) Transportation environment (presence of: sidewalks, bike lane)	United States High vs. low walkability	IPAQ-Long Past 30 days # times used the nearest park, trail for walking or biking, and indoor fitness center	SR of many places to exercise in community and more facilities within 5 minute walk more likely to meet recommendations. Living closer to a park or trail more likely to use facilities.
Humpel 2004 (39)	N=800 18-71 years 50% F	Perceived environment: Distance to park or beach Accessibility of path or cycleway Convenience of walking in NB	Australia University	IPAQ: overall estimate of total PA performed in a week (min/week) NB walking	Men: Convenience and access assoc. with ↑ NB walking and total PA. High access assoc. with greater total walking. Women: Moderate convenience more likely to walk in NB.
Huston 2003 (40)	N=1,796 ≥18 years	Sidewalks Presence of trails Places to be physically active	United States	Any activity Recommended activity (moderate LTPA for at ≥30 mins on ≥5 days/week) Place of LTPA	NB trails & streetlights positively assoc. with engaging in any activity. Access to places for PA & NB trails assoc. with meeting recommendations. Access to places for PA assoc. with any PA.

Reference	Sample	Environmental variable	Setting	Physical activity or weight status	Associations with outcome
Inoue 2009 (41)	N=492 20-74years 39% F	IPAQ environment module: Presence of bike lanes Presence of sidewalks Access to recreation facilities	Japan	Short IPAQ Walking: active (walk ≥ 150 min/week) vs. inactive MVPA: ≥ 950 MET*min/week vs. < 950	Presence of sidewalks (OR=1.65) sig. assoc with walking ≥ 150 mins/week. Presence of bike lanes (OR=1.57), related to high levels of MVPA (≥ 950 MET*min/week)
Kaczynski 2011 (90)	N=585 ≥ 18 years 55% F	Importance of living near a park Park space	Waterloo, Ontario 4 NBs	7-day PA recall: some vs. no park-based PA	Importance of park space sig. assoc. with $\uparrow$ odds of park PA (OR=2.34, 95% CI= 1.55–3.53). Living in NB with $\uparrow$ amount of park space sig. more likely to engage in park-based PA regardless of importance placed on living near a park.
King 2003 (78)	N=149 74 $\pm$ 4 years F only	Proximity to park Proximity to trail	United States	Walking LTPA	Living within walking distance of a trail or park NS assoc. with PA
Kondo 2009 (71)	30-69 years	NEWS: accessibility to gymnasiums/fitness facilities and amusement facilities	Japan 500m radius from home	Total number of steps/day via accelerometer IPAQ: walking & Cycling time	Women: Cycling time for transport longer for those who perceive accessibility to gyms/fitness and amusement facilities in their NB Men: Walking time for leisure longer for those who perceived accessibility to parks.
Kruger 2007 (66)	N= 27894 ≥ 18 years 51% F	Perceived access to health clubs, wellness programs, or fitness facilities	United States	Participation in LTPA Active = meeting PA recommendations	$\uparrow$ perceived access assoc. with higher PA and use . Women sig. more likely than men to report cost was too high or lacked transportation.

Reference	Sample	Environmental variable	Setting	Physical activity or weight status	Associations with outcome
Lackey 2009 (27)	N=574 18-88 years 55% F	Self-reported distance to closest park	Ontario, Canada	Some vs. no NB-based PA Some vs. no park-based PA	Perceived access to a park NS assoc. with park-based PA
Lee 2009 (62)	N=14,767 19-64 years 57% F	Satisfaction with parks and recreation facilities	Korea	Presence or absence of VPA	Women satisfied with park and recreation facilities more likely to engage in VPA.
Li 2005 (72)	N=577 65-94 years 64% F	Proximity to local recreational facilities # of nearby recreational facilities	United States Portland, Oregon	NB walking activity	Area of green & open spaces sig. related to walking at the NB level. # of recreational facilities sig. related to walking at the level of the resident.
MacDougall 1997 (63)	N=960 ≥17 years 57% F	Satisfaction with recreation facilities, sport, meeting places, and parks in local community	Australia	Low activity Moderate activity Vigorous activity	Dissatisfaction with facilities & environment assoc. with inactivity OR = 1.60, 95% CI: 1.20-2.13
McNeill 2006 (59)	N=910 67% F	Perceived access to facilities for PA	United States	Total mins/week of walking, MPA and VPA	Perceived BE had direct effects on PA
Mowen 2007 (73)	N=1,515 50-99 years 66% F	Perceived park proximity	United States	Park visitation frequency Park visitation duration 1-question on PA	Perceived park walking proximity related to PA and health through park use frequency.
Nielsen 2007 (96)	N~1,200 18-80 years	Self-reported distance to green areas (0-50m, 50-100m, 300m-1km, 1-2km, 2-5km, 5-20km, and >20km) Use of green areas	Danish	BMI (overweight/obesity)	Access to garden or green area less likely to be overweight/obese. Among youngest respondents, ↑ distances to green areas assoc. with ↑ obesity odds.
Pan 2009 (79)	N=5167 15-79 years	Facility availability	Canada Physical Activity Monitor	Short IPAQ: MET-hours per week and sufficiently vs. insufficiently active	PA facility availability NS assoc. with PA Facility availability more strongly assoc. with PA among people with a university degree vs. lower education level

Reference	Sample	Environmental variable	Setting	Physical activity or weight status	Associations with outcome
Poortinga 2006 (64)	N= 14,836 ≥16 years 56% F	Access to amenities	England	Overall activity Sports	Access to leisure things sig. assoc. with more sports and overall PA.
Powell 2003 (42)	N=3,949 ≥18 years M+F	Safe and convenient places to walk: public park, school track, gym or fitness center, trail, shopping mall, NB streets or roads, NB sidewalk, treadmill at home	United States Georgia	Meeting PA recommendations	Reporting a place to walk sig. more likely to meet current PA recs. (42% vs. 27%).
Rhodes 2007 (86)	N=358 ≥18 years 49% F PCS (2 months)	NEWS: Proximity to NB recreation facilities	British Columbia	Leisure-time walking over past 2 months (Godin Leisure Time Exercise Questionnaire)	Intention for walking was moderated by conscientiousness and proximity to NB recreation facilities. Proximity to recreation facilities NS assoc. with walking.
Rutten 2001 (145)	N= 3343 ≥18 years 57% F	Opportunities to be physically active (actual facility type not specified)	Belgium, Finland, East/West Germany, Netherlands Spain, Switzerland	Participation in gymnastics	All active groups report sig. more opportunities than the groups with no PA
Sallis 1989 (80)	N=1,789 M+F	Convenience of facilities (# of facilities perceived as convenient)	United States San Diego	Vigorous exercise	Home equipment assoc. with vigorous PA NB environment and convenience of facilities NS assoc. with VPA
Sallis 1992 (91)	N=1,719 18-90 years 42% F PCS	Convenience of facilities (# of facilities perceived as convenient)	United States San Diego	Change in vigorous exercise (24-month)	NB convenience of facilities was NS assoc. with change in exercise.

Reference	Sample	Environmental variable	Setting	Physical activity or weight status	Associations with outcome
Sallis 1997 (43)	N=110 21 ± 2 years 75% F	Convenient facilities: courts, bike lanes, gyms	United States College students	Strength exercise Vigorous exercise Time spent walking for exercise	Home equipment assoc. with strength exercise and VPA (p<0.001) Convenient facilities assoc with strength exercise (p<0.05), VPA (r=0.19, p<0.05)
Sallis 2009 (44)	N=11,451 18-65 years 56% F	PA NB Environment Survey: Presence of sidewalks & bike paths Free or low-cost recreation facilities NB = area within a 10- to 15min walk from home	Belgium, Brazil, Canada , Colombia, China, Japan, Lithuania, New Zealand, Norway, Sweden, U.S.	Short IPAQ: Meeting guidelines for moderate amounts of PA	Assoc. with meeting PA guidelines: Sidewalks on most streets (OR=1.47, 95% CI:1.32, 1.65) Bicycle facilities (OR=1.21, 95% CI:1.10, 1.33) Low-cost recreational facilities (OR=1.16, 95% CI: 1.05, 1.27).
Salmon 2003 (81)	N=1,332 ≥18 years 55% F	Lack of sidewalks No access to facilities	Australia	LTPA: walking, MPA, VPA Time in sedentary activities	NS assoc. between access to facilities and LTPA or sedentary activities.
Santana 2009 (60)	N=7,669 ≥18 years 54% F	Green parks Gymnasiums Swimming pools	Portugal	Overweight (BMI ≥ 25) Planned PA (MPA and VPA)	Overweight NS assoc. with parks or facilities ↑ VPA assoc. with ↑ # of gyms and pools. VPA was NS assoc. with parks.
Sharpe 2004 (45)	N=1,936 ≥18 years 60% F	Use of public trail, track, pathway or mapped-out route, public park or other outdoor recreation area # of known walking, jogging or bicycling routes # of different public parks, trails or other outdoor recreation areas	United States South Carolina	Meeting recommendations (MPA ≥5 x week, ≥30 mins/day or VPA ≥3 x week, ≥20 mins/day) Insufficiently active Inactive	↑ odds of meeting PA recommendations: Well maintained sidewalks in NB for walking and jogging (aOR = 2.04; 95% CI: 1.25- 3.35) Knowledge of routes for bicycling (aOR = 1.39; 95% CI: 1.10-1.76) or walking & jogging (aOR=1.33; 95% CI: 1.09-1.62). ↑ # of known routes for walking and jogging or bicycling ↑ use of public track, trail, pathway or mapped-out route, public park or other outdoor recreation area.

Reference	Sample	Environmental variable	Setting	Physical activity or weight status	Associations with outcome
Shaw 1991 (87)	N=14,674 18-69 years	No facilities nearby Available facilities are inadequate	Canada Fitness Survey	<u>Recreational PA</u> : vigorous sport, moderate recreation, walking or cycling exercise	Reporting no nearby facilities assoc. with ↑ PA participation in women only Inadequate facilities assoc. with ↑ PA participation in men & women
Shibata 2009 (84)	N=1,932 50% F	NB provides facilities for engaging in PA	Japan	Short IPAQ: meeting vs. not meeting recommendations for PA	NS adjusted assoc. between access to facilities and meeting recommendations.
Stahl 2001(146)	N=3,342 ≥18 years 57% F	Area offers many opportunities to be active Local sports clubs and other providers in community offer many opportunities to be active Awareness of opportunities	Belgium, Finland, Germany, Netherlands, Spain, Switzerland	One yes/no PA question (active/inactive)	Low support from BE ↑ odds of inactivity (OR=1.31; 1.06-1.61) Poorly informed of programs for PA ↑ odds of inactivity (OR=1.77; 1.44-2.18) ***Assoc. of built environment no longer sig. after controlling for country**
Sternfeld 1999 (65)	N=2,636 20-65 years F only	Perceived barriers including external obstacles (lack of facilities, lack of equipment, lack of skill/knowledge)	United States	Sport and exercise Active living Total PA	Reporting external obstacles less likely to play sports or exercise (aOR=0.55; 95% CI: 0.43-0.71)
Sugiyama 2009 (61)	N=2194 64% F	NEWS: Foot paths or sidewalks Perceived distances to the nearest outdoor recreational facilities	Australia	NB street use for PA	Access within 20-minute walk for outdoor recreation facilities sig. assoc. with ↑odds of NB street use for PA.
Tilt 2007 (74)	N=494 57% F	Subjective greenness Importance of destinations	United States	Self-reported destinations, walking trips, and BMI.	Walking trips per month were related to subjective greenness, but not OM of actual greenness.
Troped 2001 (147)	N=413 52±17 years 60% F	Perception of distance to bikeway	United States Arlington, Massachusetts	Use or nonuse of bikeway	↑ in distance from trail assoc with ↓ likelihood of bikeway use

Reference	Sample	Environmental variable	Setting	Physical activity or weight status	Associations with outcome
Velasquez 2009 (67)	N= 6,317 18-64 years 51% F	Use of recreation facilities in NB Sidewalks in NB Private membership to a recreation facility	United States Texas	Reporting LTPA Meeting recommended PA guidelines	Women: ↑ odds of LTPA assoc. with private membership and use of recreation facilities ↑ odds of meeting guidelines assoc. use of recreation facilities in NB. Men ↑ odds of LTPA assoc. with sidewalks in NB, private membership to a recreation facility, use of recreation facilities in NB NS assoc. with NB characteristics and meeting MVPA recommendations.
Wen 2007 (75)	N= 41545 51% F	Presence of a park, playground, or open space within walking distance of home	United States Census tracts	Walking at recommended levels: ≥ 5 sessions of walking (for transportation or leisure) in the previous week totalling ≥ 150 minutes.	Access to a park, playground, or open space (OR=1.26; 95% CI=1.16, 1.36) sig. assoc. with walking at recommended levels, after adjusting for demographics and NB SES.
Wilcox 2000 (83)	N=2338 ≥40 years F only	<u>NB environment:</u> Sidewalks Easy access to walking trails, swimming pool Lack a safe place to exercise	United States Urban vs. rural	Sedentary Under-active Active Underactive & active vs. sedentary	Access to facilities higher in urban vs. rural (84% vs. 64%, p<.001) NS odds of increased or decreased PA for recreation characteristics

Assoc. – association, BMI – body mass index, CI – confidence interval, C-S – cross-sectional study design, F – females, IPAQ – International Physical Activity Questionnaire, kcal – kilocalories, km – kilometers, LTPA – leisure-time physical activity, MPA – moderate physical activity, MVPA – moderate-to-vigorous physical activity, N – study sample size, NB – neighbourhood, NEWS – Neighborhood Environment Walkability Scale, NS – not significant, PA – physical activity, NQLS – Neighborhood Quality of Life Study, NS – non significant, OM – objective measure, OR – odds ratio, PAQ – physical activity questionnaire, PCS – prospective cohort study design, sig. – significant, U.S. – United States, VPA – vigorous physical activity, yrs – years

Table 2.2 Characteristics and main findings of studies examining relationships between perceived built recreation environments and objectively measured physical activity and body mass index or obesity among adults (alphabetical order based on first author)

Reference	Sample	Environmental variable	Setting	Physical activity or weight status	Associations with outcome
Adams 2011 (92)	N=2,199 20-65 years 48% F	Low walkable/transit and recreationally sparse Low walkable/recreationally sparse Moderately walkable/recreationally dense High walkable/recreationally dense	United States Seattle-King County, WA Baltimore, MD Washington, DC	Accelerometer MVPA minutes/day	High walkable/recreationally dense NB had the highest amount of MVPA.
Atkinson 2005 (76)	N=102 48 ±12 years 52% F	NEWS scale (environmental index) Recreational facilities Home equipment	United States Two 'walkability' different NBs	Accelerometer (MPA, VPA and Total)	VPA positively and sig. correlated with residential density, connectivity and total index. NS correlations with recreational variables and MPA.
Jilcott 2007 (148)	N=123 53±7 years F only	Perceived proximity to PA resources (e.g., parks, gyms, schools)	United States North Carolina	Accelerometer-measured MVPA (minutes per day)	Lower perceived distance to gyms was assoc. with more MVPA.
King 2003 (78)	N=149 74 ± 4 years F only	Convenience of destinations: Proximity to park Proximity to trail	United States	Pedometer-measured PA	Living within walking distance of a trail, retail store, or park more likely to have ↑ pedometer scores vs. those not living within walking distance.
Poortinga 2006 (64)	N= 14,836 ≥16 years 56% F	Access to leisure things (i.e. recreation and leisure centres)	England	Obese (BMI >30 kg/m ²)	Access to good leisure things assoc. with lower likelihood of being obese (OR=0.84, 95% CI: 0.75–0.94).
Sigmundova 2011 (98)	N=1,653 18-69 years 58% F	NEWS: Places for walking/cycling Distance to sports facilities	Czech Republic 8 towns	7-day pedometer: meeting 10,000 steps/day	NS correlation between sports facilities and locations for walking and cycling with pedometer steps.

Assoc. – association, BMI – body mass index, F – female, MPA – moderate physical activity, MVPA – moderate to vigorous physical activity, NEWS – Neighbourhood Environment Walkability Scale, NS – non significant, OR – odds ratio, PA – physical activity, VPA – vigorous physical activity

Table 2.3 Characteristics and main findings of studies examining relationships between objectively measured built recreation environments and self-reported physical activity, body mass index or obesity among adults (alphabetical order based on first author)

Reference	Sample	Environmental variable	Setting	Physical activity or weight status	Associations with outcome
Black 2010a (134)	N=9,916 ≥18 years	PA facilities per 100,000	United States New York	Obesity (BMI≥30 kg/m ²)	Fitness facilities independently assoc. with ↓ obesity.
Black 2010b (135)	N=48,506 ≥18 years	PA facilities per 100,000 used in NB amenities score	United States New York	Obesity (BMI≥30 kg/m ²) (aggregated 5 yrs)	↑ NB amenities score assoc. with sig. lower prevalence of obesity.
Boehmer 2007 (93)	N=1,032 ≥18 years 65% F	Recreational facilities	United States Urban	Obese vs. normal (BMI)	Fewer observed recreational facilities (0-1) within close proximity assoc. with <u>lower</u> odds of obesity in women only vs. several (6-17).
Boone-Heinonen 2010 (131)	N=12,701 11-22 years to adulthood 18-26 years PCS	GIS-derived using NB buffer sizes: 1k for street connectivity and 3k for PA facilities Pay and public PA facilities counts per 10,000 population	United States	Weekly frequency (bouts) of leisure-time MVPA (skating & cycling, exercise, and active sports)	More pay facilities in the NB assoc. with greater MVPA in males . Public facility availability unrelated to MVPA. Public facility availability positively assoc. with MVPA in female movers .
Christian 2011 (95)	N=1,151 40± 12 years 59% F	PA destination index Greenness index	Australia	BMI	NS assoc. between BMI and PA destinations or greenness.
Cochrane 2009 (149)	N=761 ≥15 years 55% F	Proximity of PA spaces and facilities (using both Euclidean and network distances)	England Deprived areas	Long IPAQ: sum of active transport, garden and domestic, and leisure	Accessibility of recreational green space made a negative contribution to PA during sunnier weather and a positive contribution in wetter weather.
Coogan 2009 (117)	N=18,525 21-69 years F only PCS	Presence of sidewalks Distance to parks	United States	Utilitarian walking Exercise walking	Miles to nearest park and sidewalk coverage NS assoc. with utilitarian walking or walking for exercise

Reference	Sample	Environmental variable	Setting	Physical activity or weight status	Associations with outcome
Coombes 2010 (123)	N=6,803 59% F	Distance by road to the nearest green space: 1) Formal (organised layout and structured path network, generally well maintained) 2) Informal 3) Natural (ex. woodland) 4) Young People (used by children or teenagers) 5) Sports (e.g. fields & courts)	England Bristol Quality of Life in your Neighbourhood Survey	Frequency of green space use Participation in sport Meeting PA recommendations Overweight/obese (BMI $\geq$ 25)	$\uparrow$ distance to all green spaces except young people's assoc. with sig. $\downarrow$ odds of visiting green space. $\uparrow$ distance to all green spaces sig. assoc. with $\downarrow$ odds of overweight/obesity. $\uparrow$ distance to formal green space sig. assoc. with $\uparrow$ odds of overweight/obesity and $\downarrow$ odds of meeting PA recommendations.
Diez-Roux 2007 (105)	N = 2,723 45-84 years M+F	Density of private and public facilities Resources within 0.5, 1, 2, and 5 miles from residence	United States	PA: team sports, dual sports, individual activities, moderate or heavy effort conditioning	Highest tertile of density of resources sig. more likely to report engaging in PA vs. lowest tertile from 1-5 miles. PA assoc. with <u>few</u> resources only. Assocs. stronger among low income.
Duncan 2005 (127)	N=1,215 $\geq$ 18 years 52%F	Geocoded environment: Street network distance to nearest parkland ($\leq$ 600m vs. $>$ 600m) Distance to nearest footpath ($\leq$ 400m vs. $>$ 400m)	Australia NBs	Active Australia PAQ <u>2 outcomes:</u> 1) Sufficient = 150 min in previous week 2) Any self-reported recreational walking in previous week	<u>Sufficient PA:</u> $\uparrow$ network distance to parkland assoc. with $\uparrow$ likelihood of being sufficiently active (OR=1.41, 95% CI: 1.01-1.97). <u>Recreational walking:</u> $\uparrow$ distance to footpath assoc. with $\downarrow$ likelihood of walking for recreation (OR = 0.31, 95% CI: 0.18-0.55).
Ellaway 2005 (110)	N=6,919 C-S	Immediate residential environment for amount of greenery & vegetation	Europe	BMI (overweight/obesity $\geq$ 25 kg/m ²) PA (never/seldom vs. often)	Dose-response relationship between $\uparrow$ levels of greenery and $\downarrow$ likelihood of being overweight/obese and $\uparrow$ likelihood of PA.
Fisher 2004 (99)	N=582 64-94 years 69% F	Park & trail density (per NB acre)	United States Portland, Oregon	NB walking activity	$\uparrow$ park and trail density sig. assoc. with $\uparrow$ NB walking.

Reference	Sample	Environmental variable	Setting	Physical activity or weight status	Associations with outcome
Foster 2009 (114)	N= 13,927 45-74 years 56% F	Proximity to nearest swimming pools Proximity to nearest sports centers and facilities Proximity to nearest public open/green space	England	Facility based PAs (e.g., aerobics, exercise with weights, badminton, and yoga), plus swimming, walking, and cycling for recreation	NS assoc. between access to green space and walking for recreation. Distance to facilities had either no or only a small effect on the uptake of different activities. For women, ↑ distance to swimming pool assoc. with ↓ swimming.
Giles-Corti & Donovan 2002a (115)	N=1,803 18-59 years M+F	Total spatial access to a range of purpose built recreational facilities including golf courses, gym/health club/exercise centres; sport and recreational centres; swimming pools; tennis courts and public open space.	Australia Community open space	Meeting PA recommendations Use of facilities	NS assoc. with recreation facilities and meeting PA recs. NS assoc. between access to gym/health club/exercise centres, sport and recreational centres and their use. ↓ access to public open space and swimming pool assoc. with ↓ likelihood of use. Individual determinants stronger than social and built environment.
Giles-Corti & Donovan 2002b (100)	N=1,773 18-59 years	Stratified by social advantage <u>Distance</u> to golf course, gym/health club/exercise centres, sport & recreation centers, pools, tennis courts, public open spa	Australia	VPA (>1680 METs-mins/week) Walking as recommended (≥6 x 30 mins per week)	<u>Top vs. other quartiles of access:</u> Access to beach more likely to walk for rec (OR=1.49, p=.003) and access to public open space more likely to walk as recommended (OR=1.43, p=.015). NS assoc. with VPA.
Giles-Corti & Donovan 2003 (109)	N=1,773 15-59 years	Functional environment (sidewalks, shops), appeal (type of street, tree coverage), overall spatial access to public open space, river, beach & golf courses	Australia	Walking as recommended: ≥12 sessions in previous 2 weeks or total of 360 minutes	Top quartile of access to attractive public open space sig. higher odds of walking vs. bottom quartile OR=1.47. High BE score vs. low 2.13 times more likely to meet recommendations.
Giles-Corti 2003 (136)	N=1,755 18-59 years M+F	GIS surveying of NBs Measure of poor spatial access to recreational facilities & public open spaces	Australia	BMI: non-overweight ≤25 kg/m ² overweight >25 kg/m ² obese >30 kg/m ²	<u>Overweight</u> NS assoc. with poor spatial access to recreational facilities <u>Obese</u> sig. assoc. with poor access to ≥ 4 recreational facilities (OR=1.68).

Reference	Sample	Environmental variable	Setting	Physical activity or weight status	Associations with outcome
Giles-Corti 2005 (124)	N=1,803 18-59 years	Public open space	Australia Collection districts	Use of public open spaces Sufficient PA (≥ 30 mins of MPA most days of the week) Walking as recommended (≥ 150 minutes/week) High level of walking (≥ 180 minutes/week)	$\uparrow$ accessibility of public open space assoc. with $\uparrow$ use (p for trend < 0.000) $\uparrow$ access to <u>large and attractive</u> public open space more likely to use (OR= 2.05; 1.52- 2.75) and achieve high levels of walking (OR=1.50; 1.06-2.13) Access of public open space NS assoc. with sufficient PA or walking as recommended.
Heinrich 2007 (101)	N=452 44 $\pm$ 17 yrs 73% F	Audited NBs: # of PA resources Cost for use of facilities	United States 800m radius	# days walked per week # days of VPA per week % meeting MPA guidelines	Greater accessibility (free) of PA resources sig. related to VPA. NS assoc. between # of PA resources and VPA, guidelines or walking.
Hillsdon 2006 (125)	N=4,732 40-70 years 56% F	GIS-mapped urban green space 61 green spaces	United Kingdom	Total hours of recreational PA per week	NB measures of access to green space NS assoc. with recreational PA.
Hino 2011 (102)	N=1,206 46 $\pm$ 17 years 62% F	500m buffer around homes: Density and distance of recreation Infrastructure Density of sports facilities	Brazil	IPAQ: Walking during leisure time and MVPA Meeting recommendations (≥ 150 min/week) vs. not meeting recommendations	Higher walking assoc. with having ≥ 2 gyms vs. none and shorter distance to recreation centers. Higher MVPA assoc. with having ≥ 2 gyms vs. none.
Jones 2009 (128)	N= 6,821	All public green spaces were mapped using GIS	England Census tracts	Report of use of green space Frequency of participation in sport and MPA	Frequency of use declined with distance but only in the most affluent areas. Relationship between PA and perceived accessibility and visit frequency moderated by deprivation.
Kaczynski 2008 (118)	N=380 ≥ 18 years 64% F	Observer recorded park size, features, and distance to participants' homes	Ontario, Canada 33 parks	7-day PA logs: some PA vs. no PA	Parks with more features more likely to be used for PA. Size and distance NS predictors of PA. Park trails had strongest relationship with park use for PA.

Reference	Sample	Environmental variable	Setting	Physical activity or weight status	Associations with outcome
Kaczynski 2009 (107)	N=384 ≥18 years 63% F	Distance to closest park Park area within 1 km Number of parks within 1 km	Ontario, Canada 1km buffer	NB-based PA and park-based PA Weekly minutes of MVPA: none vs. ≥150 minutes/week	2% ↑ odds of ≥150 minutes of total MVPA per additional hectare of park area within 1 km. 17% sig. ↑ odds of ≥150 minutes of total NB-based MVPA per additional park. Living near more parks and parkland showed more positive relationships with activity among women than men.
Kaczynski 2010 (132)	N=384 18-88 years 63% F	Facilities in parks were audited and land use diversity (LUD) around each park was calculated based on the residential, commercial, and institutional hectares within a 500 m polygon buffer Parks categorized into 4 groups (e.g., high LUD/high facilities)	Canada 32 parks from 4 NBs	7-day log Use vs. non-use of park for PA Use vs. non-use of park for recreation Use vs. non-use of park for transportation	Greater LUD within a park's buffer assoc. with a sig. ↓ likelihood of the park being used for PA. Parks with low LUD and a higher number of facilities were most likely to be used for PA. Greater LUD surrounding a park less likely to be used for PA. LUD was not related to park being used for recreation or transportation PA.
Kaczynski 2011 (90)	N=585 ≥18 years 55% F	Total area of park space accessible within a 1-km radius of each home: high vs. low nearby park space	Waterloo, Ontario 4 NBs	7-day PA recall: some vs. no park-based PA	Greater park space availability sig. assoc. with ↑ likelihood of engaging in at least some park-based PA (OR=2.19, 95% CI=1.48–3.16).
Lackey 2009 (27)	N=574 18-88 years 55% F	Measured distance to closest park	Ontario, Canada	NB-based PA vs. none Park-based PA vs. none	Access to a park within 750m of home sig. predictor of NB-based PA. Distance to park NS assoc. with park-based PA.
Lee 2007 (116)	N=2,672 25-74 years F only	<u>NB-level PA resources:</u> # of gyms # of parks Density of gyms Density of parks	United States 82 census defined NBs	Daily energy expenditure (kcal/kg/day) MPA VPA	NS assoc. between PA resources and PA Interaction between NB SES and PA resources: availability of PA resources greater in lower SES NBs vs. higher-SES NBs.

Reference	Sample	Environmental variable	Setting	Physical activity or weight status	Associations with outcome
Li 2005 (111)	N=577 65-94 years 64% F	Area of green & open space for recreation	United States Portland, Oregon	NB walking activity	Area of green & open spaces sig. and positively related to walking at the NB level.
Li 2008 (112)	N=1,221 50-75years 43% F	Green and open spaces	United States Portland, Oregon	NB walking Met guidelines, insufficiently active, inactive	Green and open spaces for recreation assoc. with more NB walking and meeting PA recommendations.
Maas 2008 (113)	N=4,899	Green space within a 1km and 3km radius around postal code	Netherlands	# of minutes of walking, cycling (both during leisure time and commuting purposes), sport activities and gardening per week	NS relationship between amount of green space and meeting PA recommendations, sports and walking for commuting purposes. Higher green space assoc. with walking and cycling less during leisure time.
McCormack 2006 (150)	N=1,006 18-59 years 66% F	NB index (density or count of destinations within respondents' NB) 3 main types: 1) beaches & rivers 2) <i>parks & ovals</i> 3) <i>formal facilities</i>	Australia	1) Walking only 2) VPA only 3) MPA only 4) other recreation PA only 5) multiple recreation PAs	Distance traveled to formal rec. facilities differed between types of PA MPA traveled further vs. VPA and multiple PAs. VPA traveled further vs. non-VPA to same type of destination. Club members traveled further.
McCormack 2008 (122)	N=1,394 18-59 years 69% F	Within 400m & 1500m Park present	Australia	Frequency & duration of walking for recreation, walking for transport, & VPA	<u>Within 400m & 1500m:</u> NS assoc. between parks and PA
Mowen 2007 (73)	N=1,515 50-99 years 66% F	Objective park proximity	United States	Park visitation frequency Park visitation duration 1-question on PA	Park proximity was directly related to park use duration.
Nagel 2008 (120)	N=546 Older adults 70% F	NBs: quarter-mile (0.4 km) and half-mile (0.8 km) radius Distance from each participant's residence to the nearest park/green space	United States	Yale Physical Activity Scale: Total weekly walking time (walking, some walking, no walking)	NS assoc. between distance to park and walking time.

Reference	Sample	Environmental variable	Setting	Physical activity or weight status	Associations with outcome
Panter 2008 (108)	N=401 ≥16 years 66% F	Leisure facilities: sports facilities & gyms Parks Green spaces	England 6NBs of different deprivation	Meeting PA guidelines vs. those that did not (5xweek). Reporting ≥5 sessions of walking and aerobic activities per week vs. those who did not	Living in the closest tertile to a park or greenspace more likely to report ≥5 sessions of PA (p=0.05). NS assoc. between access to leisure facilities and any PA or walking.
Parra 2010 (130)	N=1,966 ≥60 years 63% F	Park density	Bogota	Park use (1 question)	Higher park density assoc. with increased park use (significant trend for density).
Pouliou 2010 (137)	N=115,548 ≥20 years 50% F	Density of recreational facilities 1km buffers	Toronto & Vancouver CMAAs 2003 CCHS	BMI: overweight/obesity	Density of recreation facilities NS correlated with BMI in bivariate models (not included in final models).
Riva 2007 (133)	N=1,006 25-55 years 49%	# facilities per 1000 residents	Alberta, Ontario, Quebec	Use of facilities for VPA	Density of facilities not assoc. with use.
Rutt 2005 (103)	N=452 42±17 years 71% F	Sidewalk presence # and distance to PA facilities NB = 2.5 mile radius	United States El Paso, Texas	BMI (continuous measure) PA (light, moderate & vigorous) Television time	Structural equation modeling was used and identified that increased distance to PA facilities predicted VPA, but not BMI.
Sallis 1990 (106)	N=2,053 48±17 years 42% F	Density of pay and free facilities (Objectively plotted addresses) Proximity to facilities	United States San Diego, CA	VPA frequency per week (sedentary vs. exerciser)	Greater density of pay facilities assoc. with exercisers (p<.05). NS assoc. with proximity or density of free facilities.
Tilt 2007 (74)	N=494 57% F	GIS destinations within a .4-mile distance Normalized vegetation index Objective greenness	United States	Self-Reported Destinations, Walking Trips, and BMI.	Walking NS assoc. with greenness. In areas with high accessibility, BMI was lower in areas that had high NDVI or more greenness (interaction p=.03).

Reference	Sample	Environmental variable	Setting	Physical activity or weight status	Associations with outcome
Troped 2001 (147)	N=413 52±17 years 60% F	3 Objective GIS measures: 1) Distance to bikeway 2) Steep hill to bikeway 3) Cross busy street to bikeway	United States Arlington, Massachusetts	Use or nonuse of bikeway	Greater reported distance assoc. with less use (OR=0.58, 95% CI:0.45, .73) Steep hill barrier assoc. with bikeway nonuse (OR=1.90, 95% CI: 1.09, 3.32).
van Lenthe 2005 (104)	N=8,767 20-69 years 50-52%	Proximity to NB facilities (food shops & recreational facilities)	Netherlands	Participation in sports	Poorest proximity to sports facilities sig. assoc. with greater odds of no sports participation (OR=1.23, 1.05-1.45).
Wendel-Vos 2004 (126)	N=11,541 20-59 years 54% F	Area of sports grounds Park area 2 NBs: 300m & 500m buffers	Netherlands	Walking and cycling	<u>In 300m buffer:</u> ↑ area of sport grounds sig. assoc. with general bicycling, NS assoc. with walking. ↑ area of parks sig. assoc. with bicycling for commuting purposes, NS assoc. with walking. <u>In 500m buffer:</u> NS assoc. between sports grounds and park and walking/cycling.
Witten 2008 (121)	N= 12,529	Access to parks and beaches, measured in minutes taken by a car	New Zealand 1178 NBs	BMI	NB access to parks not assoc. with BMI, sedentary behaviour or PA, after controlling for individual-level socio-economic variables, and NB-level deprivation and urban/rural status.

Assoc. – association, BMI – body mass index, CI – confidence interval, C-S – cross-sectional study design, F – females, IPAQ – International Physical Activity Questionnaire, kcal – kilocalories, km – kilometers, LTPA – leisure-time physical activity, m – meter, MPA – moderate physical activity, MVPA – moderate-to-vigorous physical activity, N – study sample size, NB – neighbourhood, NEWS – Neighborhood Environment Walkability Scale, NS – not significant, PA – physical activity, NQLS – Neighborhood Quality of Life Study, NS – non significant, OM – objective measure, OR – odds ratio, PAQ – physical activity questionnaire, PCS – prospective cohort study design, sig. – significant, U.S. – United States, VPA – vigorous physical activity, yrs – years

Table 2.4 Characteristics and main findings of studies examining relationships between objectively measured built recreation environments and directly measured physical activity and body mass index among adults (alphabetical order based on first author)

Reference	Sample	Environmental variable	Setting	Physical activity or weight status	Associations with outcome
Heinrich 2008 (138)	N=421 18-93 years 72% F	Cost for use of resources Presence and quality of PA resources	United States Housing development 800m radius	BMI, overweight (25-29.9 kg/m ²) and obesity (>30 kg/m ²)	Negative correlations between obesity prevalence and resource cost (p = .09), presence (p=.04), and quality (p = .04). In males , higher quality PA feature ratings predicted lower BMI.
Jilcott 2007 (148)	N=123 53 ±7 years F only	Proximity using GIS road network distance to closest resource and existence within 1- and 2-mile buffers around homes	United States North Carolina counties	Accelerometer-measured MVPA (minutes per day)	NS relationships were found between MVPA and proximity to parks.
King 2003 (151)	N=158 52-62 years F only	Parks, walk/bike trails, golf courses were geocoded.	United States Census tracts	Pedometer assessed PA over 1 week: steps/day	Parks, walk/bike trails NS assoc. with steps/day. Living within walking distance of golf course sig. assoc. with PA.
McAlexander 2009 (140)	N=216 ≥18 years 64% F	PA resource density PA resource accessibility	United States low-income	BMI % body fat	PA resource accessibility NS assoc. with BMI or % of body fat. (Sig. assoc with street connectivity)
Mobley 2006 (141)	N=2,692 30-78 years F only	# of fitness facilities per 1,000 residents	United States County level	BMI (continuous variable)	Sig. assoc. between ↑ # of fitness facilities per 1000 residents with ↓ BMI
Stafford 2007 (139)	N=6,848 ≥16 years 56% F	Leisure centres (# of swimming pools, expenditure on leisure & recreation)	England & Scotland	BMI	NS assoc. between # of swimming pools with BMI, but was in expected direction (negative).
Troped 2010 (152)	N=148 44±13 years	50-m and 1-km home and work buffers Vegetation index (green space)	United States Massachusetts	Accelerometer derived daily minutes of MVPA	Vegetation index inversely assoc. with MVPA within 1km home buffer.

Assoc. – association, BMI – body mass index, C-S – cross-sectional, F – female, km – kilometer, MVPA – moderate to vigorous physical activity, NB – neighbourhood, NS – non-significant, PA – physical activity

2.4 Social environments and physical activity and obesity

While the built environment may have an independent influence on PA and overweight/obesity, the social environment can also have independent effects, but can also mediate the effects of the built environment on health behaviours. The social environment often determines why individuals make various choices and the behavioural patterns they subsequently adopt.

Investigations of relationships between neighbourhood social environments and PA or BMI are most often assessed using measures such as aggregated income levels or indices of area deprivation (29). Fewer studies have investigated the relationships of PA and BMI with other neighbourhood social factors such as crime, civic participation and social cohesion. Studies investigating the association between the social environment and PA and body composition show a clustering of methods, with perceived social environment studies focusing more on social capital and safety while objectively measured studies focus on area SES and crime rates.

2.4.1 *Perceived social environments and self-reported physical activity, body mass index or obesity*

Key studies investigating the relationships between the *perceived* social environment and *self-reported* PA, BMI or obesity in adults are presented in **Table 2.5**. Findings are mixed and are likely attributable to the different questions/survey methods used to quantify perceived recreation environments and in the self-reporting of PA and BMI.

In adults, both significant positive and non-significant associations have been reported between PA and area/neighbourhood SES, social capital and safety/crime. Positive associations indicate that higher area SES and social capital and lower crime

rates are associated with higher levels of PA and lower BMI. Significant positive cross-sectional associations have been reported between PA and perceived higher area SES (104), higher social capital/cohesion/participation (75;99;153-156), higher social support for PA (46;85;100;146), and lower crime levels/higher safety (33;38;50;100;144;156-160). Fewer studies have reported a lack of significant association with PA and self-reported neighbourhood social capital/cohesion (144;158;161-163), social support for PA (57), or crime levels/safety (33;34;40;57;75;86;99;161;164). The cross-sectional findings are very mixed.

Only two longitudinal studies have looked at the effects of neighbourhood safety and social capital on changes in PA. Handy *et al.* looked at changes to MVPA in adults living in Northern California and found that higher perceived safety and neighbourhood socialization were predictive of increases in MVPA over one year (155). Sallis *et al.* also looked at changes in MVPA after a 6-month follow-up of adults from the Activity Counselling Trial (165). They reported that self-reported high level of crime at baseline was associated with lower MVPA at 6-months (165).

Area SES was only investigated in one study using aggregated survey responses, no studies asked participants to perceive their neighbourhood SES. The majority of studies using measures of perception assessed neighbourhood crime rates or perceptions of safety and neighbourhood social cohesiveness or collectiveness. The heterogeneity in findings is likely attributed to the different definitions of neighbourhood/community, questions asked about social environments, and the PA outcomes used (e.g. walking, MVPA, exercise, sports participation, etc.).

Fewer studies have looked at the associations between perceived social environments and self-reported BMI. Three of the studies showed a significant

relationship between lower perceived safety or higher perceived crime and greater BMI (166-168). Two studies reported no significant relationships between self-reported neighbourhood collective efficacy or trust and BMI (166;169). Overall, the cross-sectional evidence is weak and there have been no known longitudinal studies to assess the relationships between perceived social environments and self-reported BMI.

2.4.2 Perceived social environments and directly measured physical activity or body mass index

Only two known cross-sectional studies have investigated the relationships between the *perceived social environment* and *directly measured* PA or BMI, their data are presented in **Table 2.6**. One study assessed the associations between perceived neighbourhood safety and pedometer-derived steps per day (170). The study found that daytime safety was not significantly associated with steps per day, but in females only, lower perceived safety at night was associated with fewer steps per day (170). The second study looked at mothers with young children and also examined perceptions of neighbourhood safety and collective efficacy and their associations with directly measured BMI to assess obesity (166). The study found that lower perceived neighbourhood safety was associated with greater odds of being obese, but that collective efficacy had no significant relationship with obesity (166). Both studies were conducted using U.S. samples. There is not enough evidence to generalize the findings regarding the perceived social environment and directly measured PA or BMI. However, the two studies both show that perceived safety may be important for female outcomes.

2.4.3 *Objectively measured social environments and self-reported physical activity or body mass index*

Key studies investigating the relationships between *objectively* measured social environments and *self-reported* PA and BMI in adults are presented in **Table 2.7**. In adults, both significant positive and non-significant associations have been reported between self-reported PA and objectively measured area/neighbourhood SES, social capital and safety/crime. Positive associations indicate that higher area SES and social capital and lower crime rates are associated with higher levels of PA and lower BMI and the opposite with lower SES, lower social capital and higher crime are associated with lower PA and higher BMI. Significant positive cross-sectional associations have been reported between PA and objectively measured area SES (34;68;100;102;116;133;171-182), higher social capital (183), and lower crime levels/higher safety (33;149;179;184;185). Only a handful of studies have reported a lack of significant associations with self-reported PA and objectively measured area SES (75;176;184;186) or crime rates (153).

The majority of cross-sectional studies have investigated area-level SES as a gauge of the social environment, fewer have looked at crime rates and only one looked at collective social capital. These exposures are likely more common as they are often easier variables to ascertain from Census data and police databases. Findings generally identify a significant association between area-level SES or crime and self-reported PA. Interestingly, the relationship between area-level SES and PA appears to be dependent on the type or intensity of PA being studied. For example, two studies have shown that lower area SES is associated with higher walking for transport, but lower walking for recreation, overall levels of PA, moderate PA, or vigorous PA (100;186). Another study

showed that higher neighbourhood SES was associated with a lower likelihood of walking for transport (187), while a further study showed that lower neighbourhood incomes were associated with an increased likelihood of neighbourhood walking (99). Van Lenthe and colleagues reported a similar finding showing that lower neighbourhood SES was associated with reduced odds of never walking (104). Lee *et al.* reported that higher area SES was associated with greater likelihood of vigorous PA whereas lower area SES was associated with greater likelihood of moderate PA (116). It appears, that at least cross-sectionally, lower area SES may be associated with lower intensities of PA, specifically walking for transport, whereas higher SES may be associated with higher intensity and recreation-based PA.

Two longitudinal studies, both conducted in the United States, investigated the affect of area-level SES on PA changes over time (172;188). Boone-Heinonen *et al.* performed a 15-year follow-up of young adults into mid-adulthood and identified an ethnicity difference in the relationship between census tract level neighbourhood deprivation and PA (172). Among Black individuals there were significant negative associations between neighbourhood-level deprivation quartiles and self-reported PA while this relationship was essentially non-existent in White individuals (172). Similarly, Yen and colleagues also found that the associations between area poverty and changes in PA were dependent on race (188). Blacks and non-Blacks who lived in a poverty area had similar changes in PA, but for those who lived in a non-poverty area, Blacks showed a greater decrease in PA over time (188).

Several studies investigated the associations between objectively measured social environments and self-reported BMI. Similar to the PA literature, findings for BMI generally show positive associations with area SES. Positive associations indicate that

higher area SES and/or social capital are associated with lower BMI and the opposite where lower SES and/or lower social capital are associated with higher BMI. Significant positive cross-sectional associations have been reported between PA and objectively measured area SES (97;134;168;173;175;177;183;189-194) and higher social capital (183). Only a few studies have reported a lack of significant associations with self-reported BMI and objectively measured area SES (136;182;195) or crime rates (134). A single study reported that higher area affluence was associated with an increased likelihood of obesity (196).

Three studies reported on longitudinal findings between neighbourhood social environments and BMI (77;97). Berry and co-authors reported on findings from a 6-year follow-up of adults from low, mid and high SES neighbourhoods in Edmonton, Alberta (77;97). They identified that neighbourhood SES was predictive of changes in BMI, with individuals residing in lower SES neighbourhoods more likely to have significant increases in their BMI over the 6-year follow-up (77;97). The other longitudinal study examined the prevalence of obesity in New York City over a 5-year period as it related to neighbourhood crime and income (135). The study showed that a higher median neighbourhood income was associated with lower prevalence of obesity, while crime was not significantly associated with obesity prevalence (135). The longitudinal findings support the general consensus of the cross-sectional research, indicating that lower area SES is associated with higher BMI and increases in BMI over time.

2.4.4 *Objectively measured social environments and directly measured physical activity, body mass index or waist circumference*

Key studies investigating the relationships between *objectively* measured social environments and *directly measured* PA, BMI and waist circumference in adults are presented in **Table 2.8**. Few studies examined the links between objectively measured social environment and measured PA and BMI/waist circumference likely due to the time and cost intensive nature of their direct assessment. Only one known study has investigated the association between objectively measured neighbourhood SES and accelerometer derived PA. Van Dyck and colleagues recently reported on data from 24 neighbourhoods in Belgium (187). The neighbourhoods were selected based on neighbourhood SES and walkability, with 6 neighbourhoods considered high-walkable/high SES, 6 low walkable/high SES, 6 high walkable/low SES and 6 low walkable/low SES (187). Findings of their cross-sectional study identified that neighbourhood SES was not significantly associated with directly measured PA (187).

There were more studies that examined objectively measured social environments and directly measured BMI or waist circumference. Both significant negative and non-significant associations have been reported between directly measured BMI or waist circumference and objectively measured area/neighbourhood SES, social capital and crime. Negative associations indicate that higher areas SES and social capital and lower crime rates are associated with lower BMIs and waist circumferences or the opposite where lower SES, lower social capital and higher crime are associated with lower PA and higher BMIs. Significant negative associations have been found between measured BMI or waist circumference and objectively assessed area SES (197-201) and crime levels (139;184). Two studies reported no significant association between directly measured

BMI and objectively measured area SES (184;202). Only one known study has examined the longitudinal associations between neighbourhood SES and BMI. A U.S. based study found that neighbourhood SES was independently and inversely associated with BMI at baseline in women and Black men, but not significantly associated with 5-year changes in BMI (201).

Table 2.5 Characteristics and main findings of studies examining relationships between perceived social environments and self-reported physical activity or body mass index among adults activity (alphabetical order based on first author)

Reference	Sample	Environmental variable	Setting	Physical activity or weight status	Associations with main outcome
Ball 2001 (46)	N=3,392 ≥18 years 54% F	Companionship for walking in the NB	Australia	Walking for exercise (walking/not walking)	No company for walking assoc. with lower likelihood of walking (OR=0.69, 95% CI: 0.59-0.80).
Ball 2010 (153)	N=1,405 F only 18-65 years	NB-level social capital: interpersonal trust, norms of reciprocity, social cohesion derived by aggregating survey data.	Australia 45 NBs	Long form of the IPAQ for leisure-time PA, leisure-time walking and leisure-time walking in the NB	Higher NB-level interpersonal trust assoc. with 73% greater odds of any LTPA.
Bergman 2009 (50)	N=2,500 18-74 years 53% F	Perception of other physically active people in the NB NB safety from crime	Sweden	Short IPAQ <u>Moderately active:</u> ≥600 MET minutes·week <u>Time spent walking:</u> low, (< 80 mins), moderate (80–300 mins) and high (>300 mins)	Lowest tertile of fear of crime had greater odds of being in the upper tertile of walking (OR=1.64, 95% CI: 1.14 – 2.36). NS assoc. with odds of being in the moderately PA category.
Brennan 2003 (154)	N=1,818 ≥18 years 67% F	Protective social factors scale: community competence and capacity, collective efficacy, social capital	United States	Meeting PA recommendations	Very low social factor scale assoc. with sig. lower likelihood of meeting PA recommendations vs. very high scale (OR=0.63, 95% CI: 0.46-0.85).
Burdette, 2006	N=2,445 28 ± 6 years F only	Perception of NB safety Collective efficacy (social cohesion)	United States	BMI (measured in 72% & self-reported in 28%) Obesity = BMI ≥30	Prevalence of obesity ↑ across tertiles of NB safety from safest to least safe (37% vs. 41% vs. 46%, p<.01). Prevalence of obesity NS different across tertiles of collective efficacy.
Burdette 2008 (167)	N=1,338 18-94 years 60% F	Perceived NB disorder: NB crime NB noise NB cleanliness	United States Texas	Obese vs. nonobese: BMI ≥30	For every unit increase in NB disorder the odds of obesity increased by 19%.

Reference	Sample	Environmental variable	Setting	Physical activity or weight status	Associations with main outcome
CDC 1999 (203)	N=12767 ≥18 years 58% F	Perception of NB safety from crime	United States	Physical inactivity	Unsafe NB assoc. with being inactive.
Cleland 2010a (204)	N=4,108 18-45 years F only	NB cohesion NB safety	Australia Low SES NBs	Long IPAQ: LTPA classified based on PA recs. as none (0 min/week), insufficient (≤149 min/week), or sufficient (≥150 min/week)	↑ odds of sufficient LTPA vs. no LTPA with ↑ NB safety. NS between LTPA and NB cohesion.
Cleland 2010b (161)	N=244 18-65 years F only	Social participation NB Safety	Australia Low SES NBs	Long IPAQ: insufficient (<150 min/week) vs. meeting recommended levels (≥150 min/week)	NS assoc. between social environment and meeting recommended PA levels.
Fish 2010 (168)	N=2,255 ≥18 years 57% F	Perceived NB safety	United States Los Angeles, California	BMI	NS assoc. between perceived NB safety and BMI in Ordinary Least Squares regression Using instrumental variables model to control for endogeneity: Perceiving NB as unsafe assoc. with higher BMI (OR=2.81 kg/m ² , p=.04) vs. perceived NB safe.
Fisher 2004 (99)	N=582 ≥65 years 69% F	Individual responses aggregated to the NB level: Social cohesion Safety for walking Ratio of perceived problems	United States Portland, Oregon	NB walking activity	Living in higher social cohesive NBs more likely to walk. Safety and problems NS assoc. to walking.
Giles-Corti & Donovan 2002 (100)	N=1,773 18-59 years M+F	NB attractiveness, safety & interest	Australia	High vigorous (>1680 METs-mins/week) Sufficiently active (≥30 mins/day of MPA) Walking as recommended (≥6 x 30 mins per week)	<u>Top vs. other quartiles of perception:</u> NB is attractive and safe sig. assoc. with walking for recreation (OR=1.49, 95% CI: 1.14-1.95) and walking as recommended (OR=1.50, 95% CI: 1.08-2.09), NS assoc. with walking for transport.

Reference	Sample	Environmental variable	Setting	Physical activity or weight status	Associations with main outcome
Granner 2007 (38)	N= 1,806 ≥18 years	Safety of recreational areas in the county that respondent may use for PA Safety of trails from crime	United States	<u>Meeting guidelines:</u> MPA (≥ 5 times/wk, ≥30 min/day) or VPA (≥ 3 times/wk, ≥20min/ day) <u>Walker vs. irregular/non-walker</u>	Trails safe vs. unsafe sig. assoc. with ↓ likelihood of meeting recommendations (OR=0.72, 95% CI: 0.55-0.95) and ↓ odds of regular walking (OR=0.69, 0.52-0.91). NS assoc. with safety of recreational areas.
Handy 2008 (155)	N _{C-S} = 1682 N _{PCS} =1352 47-58% F	NB Safety NB socialization (interaction between neighbours)	United States 8 Northern California NBs	Frequency of MVPA within the NB and changes in PA within the NB	<u>Cross-sectional:</u> ↑ NB socialization assoc. with ↑ exercise frequency. <u>Longitudinal:</u> ↑ NB safety and NB socialization assoc. with ↑ changes in exercise.
Harrison 2007 (144)	N=15,461 50 ±18 years 55% F	Sense of belonging in NB In NB how much of a problem is vandalism, assaults & muggings, speeding traffic Subject of personal crime in past year?	England	PA: participating in at least 5 sessions per week of MVPA with each session lasting at least 15 minutes	NS assoc. between PA and sense of belonging to NB, vandalism a problem, assaults or muggings, or victims of crime Feeling unsafe in NB during day (OR= 0.70) and at night (OR=0.82) sig. less likely to be physically active vs. feel safe.
Hoehner 2005 (57)	N=1,068 18-96 years M+F	Feel safe from crime Neighbours physically active	United States	IPAQ-Long (all domain PA)	NS assoc. between social environment and recreational PA
Huston 2003 (40)	N=1,796 ≥18 yrs	NB safety from crime	United States	LTPA Place of LTPA	NB safety from crime NS assoc. with LTPA or place of LTPA.
Ishii 2010 (205)	N=1,928 20-79 years 50% F	NB safety Frequency of observing others exercising	Japan	IPAQ: # of weekly minutes of walking, MPA and VPA Self-efficacy for PA	Structural Equation Modeling did not any effects of NB safety or frequency of seeing others on PA
Kamphuis 2008 (156)	N=3,839 25-75 years 53% F	NB safety Social cohesion	Netherlands NBs	Sports participation	Smaller social networks and low social cohesion assoc. with ↑ odds of no sports. In full model, low NB safety and social cohesion and high social deprivation remained sig. assoc. with no sports.

Reference	Sample	Environmental variable	Setting	Physical activity or weight status	Associations with main outcome
Lindstrom 2003 (162)	N=3377 20-80 years 51% F	NB Social capital: proportion of the total population within each NB that migrated from the NB in 1993	Sweden	LTPA	NB social capital NS assoc. with LTPA
McGinn 2008 (33)	N=1,659 ≥18 years 54% F	Perceived crime index	United States North Carolina	LTPA, outdoor LTPA & walking: (1) meets recommendations, (2) insufficiently active, (3) inactive Transportation activity	↓ perceiving NB crime more likely to be active vs. inactive for LTPA and outdoor LTPA. NS assoc. between perceived crime and walking or transportation activity.
Moore 2009 (169)	N=291 18-55 years	Community or volunteer participation	Montreal, Quebec census tracts	Waist circumference BMI	NS assoc. with trust or participation and waist circumference and BMI.
Mota 2007 (159)	N=181 Elderly	Perceived NB environments	Portugal	Summed score for work, sport, and leisure items provided an index of global activity	Only NB safety was related to total PA, LTPA, and sport activities. Feeling safe assoc. with sig. lower odds of total PA (OR=0.23) and sig. greater odds of leisure PA (OR=1.13).
Pichon 2007 (164)	N=526 Latinas 21-74years	Perceived NB safety and aesthetics Acculturation	United States	Short IPAQ: meeting vs. not meeting current PA Regular walkers (≥150 min/wk) vs. nonregular walkers	Perceived NB safety/aesthetics NS assoc. with any of the PA outcomes (all p > .05).
Rhodes 2007 (86)	N=358 ≥18 years 49% F	Perceived crime	British Columbia	Leisure-time walking over past 2 months (Godin Leisure Time Exercise Questionnaire)	Perceived crime NS assoc. with walking.
Sallis 2007 (165)	N=861 35-75 years 45% F PCS (6 months)	Frequent sightings of people walking or exercising High crime Perceived NB safety	United States	7-day PAR: minutes of MVPA	In women, high crime was assoc. with approximately 1 hr less MVPA per week In men, frequently seeing people being active in their NBs assoc. with 75 min per week more MVPA.

Reference	Sample	Environmental variable	Setting	Physical activity or weight status	Associations with main outcome
Stahl 2001 (146)	N=3,342 18-96 years 57% F	Supportive physical & policy environment: # of facilities, regulations/incentives, policies	Europe	PA: yes/no to: do you do any gymnastics, PA or sports?	Social environment strongest predictor of PA. Low vs. high support from local environment assoc. with sedentary behavior (OR=1.31, p=.012).
Thompson 2003 (85)	N=350 20-50 years F only	People in NB exercise Belonging to community groups	United States	Meets PA recommendations	Seeing people in NB exercising more likely to meet PA recommendations.
Tucker-Seeley 2009 (160)	N=18,370 ≥50 years 54% F	Perceived NB safety	United States	LTPA	After adjustment, older adults who perceived their NB as safe had higher LTPA vs. perceive NB as unsafe. Assoc. no longer sig. when self-rated health added.
Ueshima 2010 (163)	N=2260 53±17 years 58% F	Perceived trust of others in the community: low, mid, and high Participation in voluntary groups/social capital	Japan	Inactive vs. active	Higher trust was assoc. with a sig. lower odds of physical inactivity (OR = 0.58, 95% CI = 0.42–0.79) vs. low trust. NS assoc. with social capital & PA.
van Lenthe 2005 (104)	N=8,767 20-69 years 50-52% F	NB socioeconomic environment (aggregated at NB level – education, occupation, employment & quartiled) Safety of the NBs	Netherlands	Walking or cycling to shops or work Walking, cycling or gardening in leisure time Participation in sports	Living in most disadvantaged NBs sig. ↑ odds of almost never walking, cycling or gardening in leisure time (OR=1.54, 1.21-1.91) & ↑ odds of never participating in sports (OR=1.55, 95% CI: 1.33-1.81). Almost never participating in sports sig. ↑ in NBs requiring most police attention (OR=1.17, 1.00-1.38).
Wen 2007 (75)	N= 41545 51% F	Social cohesion Safety	United States Census tracts	Walking at recommended levels	NB social cohesion (OR=1.09; 95% CI= 1.04, 1.14) sig. assoc. with walking at recommended levels, after adjusting for demographics and NB SES. NS assoc. with safety and walking.

Reference	Sample	Environmental variable	Setting	Physical activity or weight status	Associations with main outcome
Wilson 2004 (34)	N=1,194 18-96 years 56% F	Perceptions of NB crime High vs. low SES tracts	United States	Walkers vs. non-walkers Meeting PA recommendations	Low SES NBs (vs. high SES) reported higher perceptions of NB crime, unattended dogs, unpleasantness of NB, and untrustworthy neighbours. NS assoc. with perceived safety and PA.

Assoc. – association, BMI – body mass index, CI – confidence interval, C-S – cross-sectional, F – female, IPAQ – International Physical Activity Questionnaire, LTPA – leisure time physical activity, MPA – moderate physical activity, MVPA – moderate to vigorous physical activity, N – sample size, NB – neighbourhood, NS – non-significant, OR – odds ratio, PA – physical activity, PAR – physical activity recall, PCS – prospective cohort study, SES – socioeconomic status, sig. – significant, VPA – vigorous physical activity

Table 2.6 Characteristics and main findings of studies examining relationships between perceived social environments and directly measured physical activity or body mass index among adults (alphabetical order based on first author)

Reference	Sample	Environmental variable	Setting	Physical activity or Weight status	Associations with main outcome
Bennett 2007 (170)	N=1,180 M=49 years 73% F	Perceptions of NB safety	United States 12 urban low-income housing complexes	5-day pedometer: steps per day	NS assoc. between daytime safety reports and PA. NS assoc. between night-time safety reports and PA among men (p = 0.23) but women who reported feeling unsafe vs. safe at night showed sig. fewer steps per day (4,302 vs. 5,178, p = 0.01).
Burdette 2006 (166)	N=2,445 28 ± 6 years F only	Perception of NB safety Collective efficacy (social cohesion)	United States	BMI (measured in 72% & self-reported in 28%) Obesity = BMI ≥30	Prevalence of obesity ↑ across tertiles of NB safety from safest to least safe (37% vs. 41% vs. 46%, p=.007), but did not differ across tertiles of collective efficacy from highest to lowest (41% vs. 40% vs. 42%, p=.67)

Assoc. – association, BMI – body mass index, F – female, M – mean, N – sample size, NB – neighbourhood, NS – non-significant, PA – physical activity, sig. – significant

Table 2.7 Characteristics and main findings of studies examining relationships between objectively measured social environments and self-reported physical activity, body mass index or obesity among adults (alphabetical order based on first author)

Reference	Sample	Environmental variable	Setting	Physical activity or weight status	Associations with main outcome
Annear 2009 (171)	N=63 65-91 years	Two NBs: high vs. low deprivation	New Zealand	Number of times engaged in LTPA in previous two weeks	Higher deprivation had sig. less LTPA NB deprivation sig. correlated with LTPA.
Ball 2010 (153)	N=1,405 F only 18-65 years	Crimes within NBs obtained from Victoria Police.	Australia	Long IPAQ: LTPA, leisure-time walking, leisure-time walking in the NB	Crime NS assoc. with any form of PA.
Berry 2010a (97)	N=572 (PCS) and 1164 (C-S) ≥18 years	NB SES index: low, med, high	Edmonton, Alberta	Short form of the IPAQ: low, moderate or high PA Stable, increased or decreased PA BMI and change in BMI	<u>Longitudinal results:</u> Lowest SES NBs had largest ↑s in BMI vs. medium and high SES NBs. <u>Cross-sectional results:</u> Low SES NBs had higher BMIs vs. medium SES or high SES NBs.
Berry 2010b (77)	N=500 18-90 years 48% F PCS (6 yrs)	NB SES index: low, med, high	Edmonton, Alberta	BMI and change in BMI	Lower SES NBs were more likely to have ↑ BMI.
Black 2010a (134)	N=9,916 ≥18 years	NB vulnerability score Violent crime per 10,000 NB income median	United States New York	Obesity (BMI≥30 kg/m ²)	↑ NB-level income assoc. with ↓ obesity. Obesity NS predicted by violent crime. NB vulnerability NS assoc. with ↑ obesity.
Black 2010b (135)	N=48,506 ≥18 years PCS (5 yrs)	NB vulnerability score (including violent crime) NB income median	United States New York	Obesity (BMI≥30 kg/m ²)	Higher NB income sig. assoc. with ↓ obesity. NB vulnerability score was NS with obesity.
Bolivar 2010 (68)	N=13,193 ≥16 years 51% F	SES environment: economic level of the municipality, size of the municipality and its illiteracy and unemployment rates	Spain	Self-reported PA during free time: some PA vs. sedentary	Higher illiteracy rate positively assoc. with sedentariness (OR _{men} =1.39; 95% CI: 1.21-1.59 (OR _{women} = 1.22; 95% CI: 1.07-1.40). In men , living in municipalities with a high economic level less likely to be sedentary (OR = 0.79; 95% CI: 0.68-0.91).

Reference	Sample	Environmental variable	Setting	Physical activity or weight status	Associations with main outcome
Boone-Heinonen 2011 (172)	N=5,115 18-30 years at baseline PCS (15 years)	Census tract level NB deprivation: % with income <150% of federal poverty level, percent of persons ≥25 years with < high school	United States	Frequency of moderate and vigorous recreational sports, exercise and leisure activities	Among blacks, NB deprivation related to lower PA. Among whites, NB deprivation had weak and less consistent assoc. with PA.
Chen 2010 (196)	N=27,593 50% F	NB SES measured using per-capita personal income NB ethnic composition	Taiwan townships	Obese: BMI of ≥ 27kg/m ²	Living in affluent NBs assoc. with ↑ risk of obesity.
Cochrane 2009 (149)	N=761 ≥15 years 55% F	Safety and crime (from local NB statistics)	England Deprived areas	Long IPAQ: sum of active transport, garden and domestic, and leisure	Count per head of population reporting criminal damage negatively assoc. with PA.
Cubbin 2006 (173)	N=18,081 25-64 years	NB level deprivation using the Care Need Index (CNI)	Sweden	Physical inactivity Obesity (BMI ≥30)	High NB deprivation more likely to be physically inactive (aOR=1.24) and obese (aOR = 1.26).
Dawson 2007 (206)	N=680 ≥50 years 72% F	Deprivation index	United Kingdom	Barriers to NB walking	Lower end of the deprivation index sig. assoc. with reporting a number of barriers to NB walking.
Diez-Roux 2000 (174)	N=70,534 ≥18 years 57% F	Income inequality by the Robin Hood Index (proportion of aggregate income that must be redistributed from households above the mean to those below the mean to achieve equality in the distribution of income)	United States	BMI Sedentarism	In men , ↑state inequality assoc. with ↑ % sedentary, but NS assoc. with BMI. In women , ↑ state inequality sig. assoc. with ↑ % sedentary & BMI. In both men and women , BMI positively assoc. with state inequality among persons with individual-level incomes <\$25,000 & negatively assoc. with state inequality among those with individual-level incomes ≥\$25,00, but only sig. in women . In men and women , sedentarism sig. assoc. with state inequality across categories of individual-level income, but assoc. stronger at lower levels of income.

Reference	Sample	Environmental variable	Setting	Physical activity or weight status	Associations with main outcome
Dragano 2007 (175)	N=11,554 45-69 years 52-55% F	NB SES: unemployment rate & overcrowding	Germany & Czech Republic	Low PA (regular LTPA/sports <1 x week) Obesity: BMI ≥ 30 kg/m ²	Prevalence of obesity and low PA increased in both countries with increasing unemployment rate
Fish 2010 (168)	N=2,255 ≥ 18 years 57% F	NB SES index	United States	BMI	Increased NB deprivation assoc. with higher BMI
Fisher 2004 (99)	N=582 ≥ 65 years 69% F	% NBs with income <\$15,000	United States Oregon	NB walking activity	NBs with higher proportion of low income assoc. with higher levels of NB walking
Giles-Corti & Donovan 2002 (100)	N=1803 18-59 years	High SES vs. low SES NBs	Australia	VPA Walking as recommended ($\geq 6 \times 30$ mins per week)	NS assoc. between NB SES and walking for transport, leisure or as recommended Low NB SES vs. high SES sig. less likely to do any VPA (OR=0.64, 0.50–0.83) or meet recommendations (OR=0.68, 0.48–0.96).
Giles-Corti 2003 (136)	N=1,755 18-59 years M+F	Area of residence SES	Australia	BMI (obese >30 kg/m ² , overweight >25 kg/m ² , normal weight ≤ 25 kg/m ²)	Overweight & obesity NS assoc. with area of residence SES.
Glass 2006 (184)	N=1,140 50-70 years 66% F	Townsend score/deprivation NB Affluence Index NB Psychosocial Hazards	United States Baltimore	PVPA LTPA	Living in NBs with $\uparrow$ psychosocial hazards less likely to be physically active. Townsend score had weaker assoc. with PA. NB Affluence index unrelated to PA.
Hino 2011 (102)	N=1206 46 $\pm$ 17 years 62% F	Area income level	Brazil	IPAQ: Walking during leisure time and MVPA	Higher area income level sig. assoc. with more walking and higher MVPA.
Kavanagh 2005 (176)	N=2,349 18-74 years 62% F	Local area SES strata based on income (i.e. High SES vs. Middle SES vs. Low SES)	Australia Census collector districts	Overall levels of PA (Active Australia Survey) Walking, swimming, cycling, & jogging frequency	Living in low SES strata less likely to have sufficient overall PA (OR=0.70; 0.55-0.90) and less likely to jog (OR=0.69; 0.51-0.94). Area level SES stratum NS assoc. with walking, cycling or swimming.

Reference	Sample	Environmental variable	Setting	Physical activity or weight status	Associations with main outcome
Kim 2006 (183)	N=181, 200 ≥18 years 55% F	State-level social capital index State-level 1995 estimated Gini coefficient: mean household income, and % of Black residents	United States	Leisure time MVPA (MPA ≥30mins x5/week or VPA ≥20 mins x 3/week) Obesity: BMI ≥30kg/m2	<u>Individuals nested within states:</u> ↑ social capital assoc. with ↓ odds of obesity. Females with high social capital had sig. lower odds of physical inactivity. <u>Individuals nested within counties within states:</u> ↑ Gini coefficient associated with lower odds of obesity. ↑ social capital sig. assoc. with ↑ odds of PA.
King 2005 (195)	N=4913 18-74 years 73% F	Area socioeconomic disadvantage categorised as high, medium or low (low <\$400/week)	Australia	BMI	NS assoc. between areas socioeconomic advantage and BMI.
Kuhle 2008 (177)	N=12,428 ≥18 years 58% F	Area-level household income at census level: Lowest Middle-low Middle-high Highest	Canada 2004 CCHS Census Dissemination Areas as proxy for NB	Overweight (BMI≥25) Low fruit and vegetable intake Total daily energy intake Eating out Low PA (<1.5 kcal/kg/day) Former smoker	Women: Compared to lowest NB SES, lower-middle sig. more likely to be overweight, and higher-middle sig. less likely to be overweight. NS difference in highest vs. lowest. Men: Compared to lowest NB SES, lower-middle and highest NB SES sig. less likely to be overweight. NS assoc. in middle-highest.
Lee 2007 (116)	N=2,672 25-74 years F only	<u>Tertiles of SES NB index:</u> <high school education, median annual family income, % blue collar workers, % unemployed, median housing value	United States census defined NBs	Daily energy expenditure (kcal/kg/day) MPA VPA	<u>Daily energy expenditure (DEE):</u> Low SES vs. moderate SES had sig. lower DEE (OR=0.02, 95% CI: 0.01-0.03). NS difference between moderate and high NB SES. <u>MPA:</u> NS. differences between NB SES. <u>VPA:</u> NS differences between NB SES.

Reference	Sample	Environmental variable	Setting	Physical activity or weight status	Associations with main outcome
Lindstrom 2003 (162)	N=3377 20-80 years 51% F	NB Social capital: proportion of the total population within each NB that migrated from the NB in 1993	Sweden	LTPA	NB social capital did not explain any variation in LTPA
Matheson 2008 (189)	N= 64,277 20-64 years 50% F	Material Deprivation Index: % < high school, lone parent families, families receiving government transfer payments, % unemployed, living below low income cut off, and homes needing major repair Census-tract NB data from 2001 Census	Canada CCHS Cycles 1.1/2.1	BMI	Women living in a deprived area have a higher BMI vs. women living in less disadvantaged areas Sig. interaction between sex and area-level deprivation on BMI
McCormack 2006 (150)	N=1,006 18-59 years 66% F	Social disadvantage index	Australia	Road network distances to recreational PA facilities	Socio-economically disadvantaged areas travel further to use recreation PA places
McDonald 2008 (185)	N=359 52% F	Crime data from police department for property and violent	United States California	Minutes walked	Sig. negative assoc. between violent crime and minutes walked per day. Neither property nor quality of life crimes were correlated with amount of walking.
McGinn 2008 (33)	N=1,659 ≥18 years 54% F	OM crime for 303 participants within 1-mile radius: number of calls for service for 1) criminal offences, incivilities, traffic-related offences	United States North Carolina	Meet recommendation: LTPA, outdoor LTPA & walking:	Sig. assoc. between all crime data and meeting recommendations vs. being inactive, low crime = higher odds of meeting recommendations.
Pascual 2007 (178)	N=19,324 16-74 years M+F	<u>Current and over time</u> Average provincial income (GDP) Provincial income inequality (Gini coefficient)	Spanish provinces	Some activity vs. none	Lowest provincial GDPs assoc. with inactivity. Gini coefficient NS assoc. with inactivity.

Reference	Sample	Environmental variable	Setting	Physical activity or weight status	Associations with main outcome
Piro 2006 (179)	N=3,499 74/75 years	NB violence: cases of violence per 1000 inhabitants NB average income	Norway	Past year PA recall: less than one hour a week vs. more than one hour a week	Women: High NB average income assoc. with higher odds of high PA (OR= 1.58, 95% CI: 1.19, 2.10). High perceived safety assoc. with higher odds of being physically active (OR= 0.64, 95% CI: 0.47, 0.87). Men: High NB violence assoc. with lower odds of high PA OR=0.58, 95% CI: 0.41, 0.82)
Regidor 2008 (190)	N=17,917 16-74 years	# of times % pop with low education was high # of times GDP was low # times Gini coefficient high	Spain	Overweight BMI ≥ 27	Odds of overweight higher in those in province where a high % of the population had low education and low GDP, but NS for Gini coefficient.
Riva 2007 (133)	N=3,192 χ =38 years M=51%	Local area SES (i.e. <\$40,000, \$40,000 \$60,000, >\$60,000)	Canada Local area	Use of facilities for VPA	Women in more affluent areas more likely to use facilities vs. other areas
Robert 2004 (191)	N=3,617 ≥ 25 years 63% F	Community socioeconomic disadvantage index from census (% households receiving public assistance, % families with incomes >\$30,000, % adult unemployment) Community income inequality Community Black proportion	United States Enumeration districts	BMI	In women , living in communities with higher socioeconomic disadvantage and greater income inequality assoc. with higher BMI net of age, race, individual SES, PA, smoking, stress and social support Results not seen in men Community disadvantage further reduces, but does not eliminate, the black disadvantage in BMI among women
Roman 2008 (207)	N=803 59% F	Number of violent crimes Concentrated disadvantage Residential stability Racial heterogeneity NB-level collective efficacy	United States Washington	Avoidance of walking outside due to crime (i.e. fear)	In full model, NS assoc. between any SE variable and avoidance of walking because of fear.

Reference	Sample	Environmental variable	Setting	Physical activity or weight status	Associations with main outcome
Ross 2000 (180)	18-92 years 59% F	NB education NB ethnicity NB poverty NB racial composition	United States Census tract	Walking (# days/week) Strenuous exercise (e.g. running, basketball, aerobics, tennis, swimming, biking etc.)	Walking assoc. with NBs with higher # of people with college degree and below the poverty line
Ross 2007 (192)	N=32,964 20-64 years 52% F	<u>NB level:</u> % of recent immigrants ≤5 yrs, proportion with low education, NB median household income, dwelling density <u>Metropolitan level:</u> % of CMA dwellings that are single or detached units, dwelling density, % of CMA pop living in urban core affluence by median CMA household income	Canada CMAs 2001/02 CCHS	BMI (continuous measure)	Women: NBs with high proportion of low education had sig higher BMI. Dwelling density and median household income of NB NS assoc. with BMI. Men: NBs with a high proportion of recent immigrants had sig. lower BMI NBs with a high proportion of low education had sig. higher BMI Dwelling density and median household income of NB not assoc. with BMI
Sundquist 1999 (181)	N=9,240 25-74 years M+F	Aggregated SES: Care Need Index (CNI) – absolute size & age of local population, material deprivation, socio-demographic factors related to family structures, social instability, & cultural needs Townsend score	Sweden	<u>BMI</u> : normal weight (BMI<23.8 for females & <25 for males); overweight (23.8≤BMI<28.6 for females & 25.0≤BMI<30.0 for males); obese (≥28.6 for females & ≥30 for males) <u>Physical activity</u> : almost no PA vs. regular PA at least 1x week	Individuals living in most deprived NBs had a greater risk for engaging in no PA and being obese when adjusted for individual SES
Turrell 2010 (186)	N=11,037 40-65 years 56% F	NB Disadvantage	Australia 200 NBs	General walking MPA VPA Total activity Walking for transport Cycling for transport	Residents of advantaged NBs reported sig. higher levels of total activity, walking, MPA and VPA, but were sig. less likely to walk for transport. NS assoc. between NB disadvantage and cycling for transport.

Reference	Sample	Environmental variable	Setting	Physical activity or weight status	Associations with main outcome
Van Dyck 2010 (187)	N=1166 20-65 yrs 52% F	6 high-walkable/high-SES 6 low-walkable/high-SES 6 high-walkable/low-SES 6 low-walkable/low-SES NBs	Belgium	long Dutch IPAQ: work, transportation, recreation, and household PA	Living in a high-SES NB sig. assoc. with less walking for transport and more motorized transport.
van Lenthe 2002 (193)	N=8,897 20-70 years 51% F	NB Deprivation (aggregated education, occupation, employment) into quartiles	Netherlands	Overweight ≥ 25 kg/m ²	Mean BMI and prevalence of overweight $\uparrow$ with $\uparrow$ NB deprivation. Increasing odds of overweight by $\uparrow$ NB deprivation in women , but not men .
van Lenthe 2005 (104)	N=8,767 20-69 years 50-52% F	NB socioeconomic environment (aggregated at NB level – education, occupation, employment & quartiled)	Netherlands	Walking or cycling to shops or work Walking, cycling or gardening in leisure time Participation in sports	Living in most disadvantaged NBs sig. lower odds of almost never walking or cycling to shops or work (OR=0.68, 0.56-0.82), $\uparrow$ odds of almost never walking, cycling or gardening in leisure time (OR=1.54, 1.21-1.91), & $\uparrow$ odds of never participating in sports (OR=1.55, 1.33-1.81).
Wang 2007 (194)	N=7,595 25-74 years 54-58% F	Census data for socioeconomic environment NB index	United States census tracts	BMI – risk of overweight	NB SES sig. assoc. with BMI; participants living in low SES NBs had mean ~ 0.6 kg/m ² higher than participants in high SES NBs.
Wen 2007 (75)	N= 41,545 51% F	NB SES using Census	United States census tracts	Walking at recommended levels: ≥ 150 minutes/week	NB SES was NS correlate of walking at recommended levels.
Wilson 2004 (34)	N=1,194 18-96 years 56% F	High vs. low SES tracts	United States	Walkers vs. non-walkers Meeting PA recommendations	Respondents from low SES NBs reported less PA.
Wilson 2010 (182)	N=1,203 ≥ 18 years	High vs. low SES NBs	Scotland vs. Hamilton, Ontario, Canada	Under/normal weight (< 25 kg/m ²), overweight (25.0-29.9 kg/m ²), obese (≥ 30 kg/m ²) Any PA vs. no PA	Sig. differences in BMI between low and high SES NBs in Hamilton, but not Glasgow. Physical inactivity higher in lower SES NBs in both Hamilton and Glasgow. NS assoc. within the NBs for obesity.

Reference	Sample	Environmental variable	Setting	Physical activity or weight status	Associations with main outcome
Yen 1998 (188)	N=1,451 ≥20 years 42% F PCS	Poverty areas (census tracts with low income, low education, substandard housing, unemployment)	United States census tracts	Change in PA level (frequency in active sports, swimming, long walk, gardening, and physical exercises)	PA lower in poverty areas in both years Adjusting for age, sex and baseline score, poverty area showed greater ↓ in PA vs. no poverty Assoc. between poverty area and change in PA dependent on race and income level.

Assoc. – association, BMI – body mass index, C-S – cross-sectional, CI – confidence interval, F – female, GIS – geographical information systems, IPAQ – International Physical Activity Questionnaire, LTPA – leisure time physical activity, MVPA – moderate to vigorous physical activity, N – sample size, NB – neighbourhood, NS – non-significant, OR – odds ratio, PA – physical activity, PAR – physical activity recall, PCS – prospective cohort study, SES – socioeconomic status, sig. – significant, VPA – vigorous physical activity, WC – waist circumference

Table 2.8 Characteristics and main findings of studies examining relationships between objectively measured social environments and directly measured physical activity, body mass index or waist circumference among adults (alphabetical order based on first author)

Reference	Sample	Environmental variable	Setting	Physical activity or Weight status	Associations with main outcome
Do 2007 (197)	N=5,493 54% F	NB disadvantage	United States Census tracts	BMI	Relationship between NB disadvantage and BMI dependent on race. Higher NB disadvantage assoc. with higher BMI in White and Mexican-American females and Mexican-American males.
Ellaway 1997 (198)	N=691 40-60 years 55% F	NB Deprivation	Scotland	BMI WC Waist-to-hip ratio	Socially deprived NBs had higher BMI, WC and waist-to-hip ratio.
Glass 2006 (184)	N=1,140 50-70 years 66% F	# & location of violent crimes, 911 emergency calls (aggregated) Townsend score (deprivation) NB Affluence Index NB Psychosocial Hazards scale (give rise to higher fear or alarm)	United States Baltimore	BMI: obese >29.9 kg/m ²	Living in NBs with ↑ psychosocial hazards more likely to be obese. Townsend score had a weaker assoc., with sig. trend with increase scores assoc. with increasing odds of obesity. NB Affluence index NS related to BMI.
Leal 2011 (199)	N=7,230 30-79 years 41% F	3 NB socioeconomic indicators: education, income, real estate prices	France	BMI WC	BMI/WC ↑ with ↓NB SES, especially with NB education measured within 500-m radius buffers around residences; assoc. stronger for women.
Mujahid 2005 (201)	N=13,167 45-64 years PCS (9 years)	<u>NB SES</u> : median household income, median value of housing, net rental income, % adults with high school, % adults with college, % persons in executive, managerial or professional specialty occupations	United States (census defined block groups)	BMI (measured at baseline & follow-up)	<u>Cross-sectional</u> : NB SES characteristics independently and inversely assoc. with BMI at baseline in women and Black men. <u>Longitudinal</u> : NB SES NS assoc. with changes in BMI.
Rundle 2008 (202)	N=13,102 ≥30 years	ZIP-code level SES	United States New York	BMI	Zip-code poverty rate NS assoc. with BMI.

Reference	Sample	Environmental variable	Setting	Physical activity or Weight status	Associations with main outcome
Stafford 2007 (139)	N=6,848 ≥16 years 56% F	NB social disorder (neighbours threatening, not trusting neighbours, fear, vandalism, & litter)	England & Scotland	Obesity: BMI & waist-to-hip ratio	NB disorder positively assoc. with overall obesity and central obesity Assoc. between NB disorder & BMI was linked through average sports participation rate. Greater NB disorder directly assoc. with higher waist-to-hip ratio.
Van Dyck 2010 (187)	N=1,166 20-65 years 52% F	NB SES	Belgium	Accelerometer MVPA	NB SES NS assoc. with accelerometer MVPA.

Assoc. – association, BMI – body mass index, C-S – cross-sectional, GIS – geographical information systems, F – female, MVPA – moderate to vigorous physical activity, N – sample size, NB – neighbourhood, NHANES – National Health and Nutrition Examination Survey, NS – non-significant, PA – physical activity, PCS – prospective cohort study, SES – socioeconomic status, sig. – significant, WC – waist circumference

2.4.5 *Summary*

The majority of perceived social environment research has involved social capital, social support for PA and safety whereas the majority of objectively measured research has focused on area-level SES and crime rates. Findings from the perceived social environment literature are mixed with several studies reporting significant and non-significant relationships with self-reported PA. Very few studies have examined the associations with directly measured PA or self-reported or measured BMI. Longitudinal studies are limited, but have shown more consistent relationships between higher safety/lower crime and greater amounts of self-reported PA.

A large body of research has examined the objectively measured social environment and self-reported PA and BMI. Most studies report significant relationships between greater area SES and lower crime with higher PA and lower BMI. Interestingly, the relationship between neighbourhood SES and PA may be dependent on the type and intensity of PA under investigation. Evidence suggests that higher neighbourhood SES may be more associated with total PA and higher intensities of PA while lower neighbourhood SES may influence walking for transportation purposes. These relationships are intuitively appealing as lower SES individuals may rely more heavily on active transportation and higher SES individuals may have the income to support the use of private/fee-based recreation facilities and vigorous sport activities. Longitudinal studies suggest that race/ethnicity may interact with the relationship between neighbourhood SES and PA over time. Furthermore, longitudinal studies while limited, suggest that area SES can predict changes in BMI. Canadian data remain limited and there have been fewer studies that have looked at the influence of social capital (civic participation, sense of belonging) on self-reported PA or BMI.

Very few studies have examined the relationships between the objectively measured social environment and directly measured PA, BMI or waist circumference. Only one study to date has looked at objectively measured PA using accelerometer and found no significant association between neighbourhood SES and MVPA. A limited number of studies have investigated crime rates with BMI or waist circumference, and have found that greater crime was associated with larger BMIs or waist circumferences. The findings for areas SES and BMI are mixed. Only one study has examined longitudinal associations and has found that neighbourhood SES was not associated with changes in BMI over time. There is no known Canadian study to have examined these relationships in adults.

2.5 Synergistic effects of built and social environments

The social and built environments do not necessarily exist independently of each other (28), but rather can have synergistic or opposing effects on PA and BMI. In Canada, recreation deserts have been reported in areas of social disadvantage/distress (208). In Ottawa, analysis of data from the ONS shows that availability of recreation facilities is greatest in the most advantaged/higher SES neighbourhoods (209). Several other independent studies have reported positive relationships between lower area SES and reduced access to PA facilities, meaning that as area SES decreases the number of facilities and proximity decreases (210-214).

This ‘double jeopardy’ or synergistic effect may put individuals living in low SES and low built recreation environments at a greater risk for lower PA and higher BMI. While this double jeopardy has been noted several times in the literature, it has been suggested that poorer neighbourhoods may not always lack health promoting resources such as recreation facilities and it is possible that the segregation between neighbourhood SES and recreation

access is more marked in the U.S. where the social gradient and racial differences are greater (215). In addition, it has been suggested that more disadvantaged populations may have poorer access to quality resources rather than any resource, and that individuals are likely influenced by locations other than the immediate residential environment such as workplaces and schools (215). Furthermore, it is also possible that individuals living in more deprived areas perceive poorer accessibility even when they have greater objectively measured accessibility (128).

While it is possible that a ‘double jeopardy’ can exist, it is also feasible that the built and social environments can be antagonistic for each other in relation to PA and BMI. For instance, lower SES can be conducive to increased PA due to a reliance on active transportation and lower BMI due to decreased access to food (188). Further, a recreation environment may offer plenty of opportunities, but this may come at a price with a neighbourhood design that does not promote walkability.

2.6 Gender differences

An individual’s sex plays a unique role in their health behaviour practices and in the development of health outcomes. It is important to understand how gender impacts health and influences behaviours in order to inform interventions and programs that will work for both males and females. Gender differences in PA levels are repeatedly reported in the literature. Males have been shown to have significantly higher levels of PA than females (3;216;217). Differences may be age dependent as shown by data from the 2009 CHMS. Results from the CHMS identified that only between 20 to 39 years did men accumulate more accelerometer measured MVPA than women (3). Additionally, overall men were significantly more likely to meet steps per day recommendations than women (39% vs.

30%), however, when analyzed by age categories, the differences were only significant for the 40-59 year age category with (47% vs. 33%) (3).

Gender-based analyses are often lacking in studies examining the relationships between environments and health outcomes (e.g., PA and obesity) (218;219). A recent review of environmental determinants of PA in adults remarked that statements regarding possible differences between males and females in access to recreation facilities was not yet possible (219). Some primary studies have suggested that determinants of access and use of facilities may differ between men and women (49;66;133;220). Women have been shown to be more likely than men to feel their neighbourhoods are unsafe for exercise (49) or show a significant association between safety and PA (170). It has also been shown that the relationship between neighbourhood/area SES and PA (133;179) and obesity (174;191;193;221) may also be stronger in females. Gender-specific findings are noted in **bold in Tables 2.1 to 2.8.**

2.7 Study rationale

More Canadians than ever are urban dwellers. According to the 2006 census, more than 80% of Canadians lived in urban environments (222). With the majority of Canadians living in these urban areas the built environment within these centres has become increasingly important as a determinant of health behaviours and outcomes such as PA and BMI. In order to assess the impact of environments on PA, measurements must be appropriate. Study results have been conflicting concerning the validity of methods for measuring PA. To date there has been no known attempt made to consolidate this information to provide an evidence-based approach to describing their abilities to assess PA in adult populations. Therefore, this thesis systematically reviews the literature to determine the extent of

agreement between self-reported and directly measured PA in adults. Knowledge generated from the systematic review of PA measurement is used to inform the interpretation of results with built and social environmental exposures. Furthermore, as PA measured by self-report and direct methods are likely not assessing the same parameter (i.e. perceived vs. actual; total vs. partial), and being that self-reports of height and weight are not always valid and reliable (21), this thesis reports on investigations using both self-report and direct measures of PA and BMI.

With an increase in sedentary jobs and an increased reliance on motorized transport due to growing suburbs, recreational PA or LTPA (non-transport) represents an important opportunity to achieve recommended PA levels (223). Literature suggests a relationship exists between environmental factors and individual health behaviours. Few studies have examined the combined and relative influences of the built and social environments on rates of PA specifically for recreation, and even fewer have done so collectively in a Canadian population (219;224-226). Furthermore, sex-based analyses are also lacking (218;219).

Interventions focused on the individual are unlikely to succeed if the environmental conditions in which they are delivered are not supportive. Therefore, there is a need to address the environment factors associated with behaviour prior to the development and delivery of individual-level interventions (227). “Creating supportive environments has the potential to encourage more PA at a population level, because the physical environment has the capacity to influence large numbers of people. It also provides ‘behaviour settings’ that can influence the behaviours undertaken in those settings and provides opportunities, barriers, and cues that can facilitate or discourage behaviour including PA” (228). A Canadian think tank of selected policy and research priorities related to obesity identified the need to further prove links among built environment factors such as proximity and density of

amenities, the quality of the built environment and health including obesity (229). Social environmental factors have the capacity to mediate the effects of the built environment and influence the adoption of healthy behaviours such as PA. These factors are also likely to differ between sexes as PA preferences are different and biological and socio-cultural programming is different. This thesis employs the use of geographically coded environmental features of Ottawa neighbourhoods as they relate to PA and overweight/obesity and examines the associations separately in males and females. This research is timely and original and adds to the sparse Canadian literature in the area. It employs a multi-disciplinary and multi-sectoral approach to study the associations between objective measures of the social and built environments and both objective and subjective measures of PA and overweight/obesity in adults across City of Ottawa neighbourhoods while applying a multi-level model and sex-based analysis.

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CHAPTER 3: MANUSCRIPT 1

This manuscript was written and published according to specifications for the peer-reviewed journal *Transdisciplinary Studies in Population Health Series*. It appears in its published format.

Title:

A population health approach to Obesity in Canada – putting the problem back into context.

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Citation:

Prince, SA. (2009). A population health approach to Obesity in Canada – putting the problem back into context. *Transdisciplinary Studies in Population Health Series*. Vol 1(1), p23-33.

A POPULATION HEALTH APPROACH TO OBESITY IN CANADA - PUTTING THE PROBLEM BACK INTO CONTEXT¹

L'OBÉSITÉ AU CANADA SELON L'APPROCHE DE SANTÉ DES POPULATIONS - METTRE LE PROBLÈME DANS SON CONTEXTE

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Abstract

Overweight and obesity have become increasingly prevalent in Canada and across the world. It is now recognized as a global pandemic, even affecting developing nations. It has become increasingly important to understand how populations are affected differently and identify key determinants; therefore, the objective of this paper is to apply a population health approach to examine the problem of obesity specifically within a Canadian context. This paper applies a population health approach to examine the problem of obesity specifically within Canada. Current prevention and treatment strategies are discussed with regard to their appropriateness for decreasing the prevalence and risk factors of obesity not only at the individual level, but at the population level. In order to emphasize the interactive roles of various determinants of health, levels of influence and sectors for intervention, population health frameworks are discussed to emphasize gaps in the literature and propose directions for future research and development.

Résumé

L'obésité devient de plus en plus répandue au Canada et à travers le monde. Cette condition est maintenant reconnue comme une pandémie mondiale, affectant même les pays en développement. Il est devenu de plus en plus important de comprendre comment les populations sont différemment affectées et d'identifier les déterminants clés; donc, l'objectif de cet article est d'appliquer une approche de santé des populations pour examiner le problème de l'obésité en particulier dans un contexte canadien. Cet article utilise une approche de santé des populations pour examiner le problème de l'obésité en particulier au Canada. Les stratégies actuelles de prévention et de traitement sont discutées en ce qui concerne leur pertinence pour diminuer les facteurs de prévalence et de risque d'obésité, non seulement sur le plan individuel, mais aussi sur le plan des populations. Pour faire ressortir les rôles interactifs des divers déterminants de la santé, des niveaux d'influence et des secteurs d'intervention, divers modèles conceptuels de santé des populations sont discutés pour souligner les écarts dans la littérature et proposer des directions pour la recherche et le développement futur.

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¹ CITATION: Prince, S.A (2009). A population health approach to obesity in Canada – Putting the problem back into context. *Transdisciplinary Studies in Population Health Series*, Vol. 1 (1), p. 22- 33.

Introduction

Overweight and obesity are chronic conditions that have become increasingly prevalent in the past 15-20 years. Obesity has come to be recognized as both a Canadian "epidemic" and a global "pandemic" (1-3). Globally, it has affected even the poorest nations with developing countries now experiencing upward shifts in their average body mass indexes (BMIs) (4). The World Health Organization (WHO) recognizes obesity as a global health issue with one billion adults worldwide identified as overweight and an additional 300 million obese (1). It has become increasingly important to understand how populations are affected differently and identify key determinants; therefore, the objective of this paper is to apply a population health approach to examine the problem of obesity specifically within Canada.

Canada has also seen an increase in the proportion of its citizens who are classified as overweight/obese over the past several decades. The 2004 Canadian Community Health Survey (CCHS) is the most recent survey to have collected measured height and weight data in a representative sample of Canadians. The 2004 CCHS identified that 23% of Canadians aged 18 or older were considered obese and an additional 36% were classified as overweight (5). This obesity rate is higher than the 14% reported in the 1978/79 Canada Health Survey, which was the previous Canadian survey to have obtained measured height and weight data (6).

Obesity is associated with an increased risk for several non-communicable diseases including Type 2 diabetes, elevated blood pressure, heart disease, stroke, gallbladder disease, osteoarthritis, sleep apnea, and some cancers and mental health illnesses (7;8). Non-communicable diseases are threatening to overwhelm worldwide health care services and are projected to continue to rise while disease burden from communicable diseases (e.g. cholera, small pox, etc.) declines (9). For example, in 1990 disease burden from ischaemic heart disease, which is directly

linked to obesity, was ranked fifth in the world using disability-adjusted life years (DALYs) and is estimated to become the leading cause of disease burden by 2020 (9).

Overweight and obesity are considered modifiable health factors for several diseases and are associated with high health care costs. In 2001, these costs were estimated at \$4.3 billion or 2.2% of the total Canadian health care expenditure (10). The distribution of obesity-related health care expenditures in Canada varies between provinces likely as a result of varying prevalence rates and provincial funding for intervention and treatment. Interestingly, in 2004, Newfoundland and Labrador (33.9%), New Brunswick (29.2%), Saskatchewan (30.8%), and Manitoba (28.2%) were reported to have the highest prevalence rates of obesity and consequently the highest percentage of direct annual costs (11). British Columbia has in the past reported the lowest percentage of direct annual costs attributed to obesity (4.5%), likely reflecting the lowest provincial rates of obesity (19.2%) (11-13).

In order to effect change and design appropriate interventions that will target these inequalities, it is important to understand the risk factors that explain why rates differ between population groups and within them. This paper will apply a population health approach to examine the problem of obesity specifically within Canada. Current prevention and treatment strategies are discussed with regard to their appropriateness for decreasing the prevalence and risk factors of obesity not only at the individual level, but at the population level. Geographical differences in obesity rates and the prevalence of risk factors (e.g. physical activity rates, health care expenditures) exist and as such, the social and physical environments are discussed as key determinants of obesity. These environmental determinants along with individual biological and behavioural determinants play important roles in the development and prevention of physical inactivity, unhealthy eating, and obesity. In order to emphasize the interactive roles of various determinants of health, levels

of influence and sectors for intervention, population health frameworks are discussed to emphasize gaps in the literature and current prevention strategies and propose directions for future research and development.

Current Prevention and Treatment Strategies

The high costs and poor health outcomes associated with obesity have caused a recent shift of public focus and attention to the identification of possible risk factors and prevention and treatment strategies. Current population level prevention strategies are mainly composed of health promotion and education activities. Canadian initiatives include such endeavors as Canada's Food Guide (14), Canada's Physical Activity Guide (15), Canada's Nutrition Labeling program (16), restaurant programs (e.g. Heart and Stroke Foundation of Canada's Health Check) (17), surveillance programs (e.g. Canadian Health Measures Survey) (18), and recently the Pan-Canadian Healthy Living Strategy (19).

Treatment strategies are generally delivered at the individual level and largely involve dietary therapy (consumption of a low calorie diet) and exercise therapy (increased physical activity); however, other methods exist such as drug therapy (i.e. appetite suppressants), surgery in the case of morbid obesity (e.g. gastric bypass, gastric banding), behavioural therapy (e.g. cognitive behavioural modification, skills training), and dietary counseling (i.e. lifestyle and dietary modifications) (20).

The Pan-Canadian Healthy Living Strategy was recently developed with a goal to achieve a 20% increase in the proportion of Canadians who are physically active, have healthy eating habits, and are at healthy body weights by the year 2020 (19). This initiative still appears to reflect the main message emitted from current prevention and treatment activities with promotion strategies that place much of the onus on individuals to 'eat less and be more

active' in order to reduce their risk of obesity. To date, however, these efforts have yet to appear effective in decreasing rates of obesity in Canada.

Data from the 2004/05 CCHS identified that 52% of Canadian women and 48% of Canadian men were inactive (expending <1.5 kcal/kg/day) in their leisure time, equated to walking less than half an hour every day and unable to reap the associated health benefits of regular physical activity (21). The prevalence rates of physical inactivity have also been reported as higher among obese Canadian men and women (22). It is important to recognize that these data are based on self-reported measures and may not accurately represent current physical activity levels (23). Regardless, many Canadians are not meeting the Canadian Physical Activity Recommendations. In 2001, the economic costs of physical inactivity in Canada were estimated at \$5.3 billion or 2.6% of the total direct health care expenditures and \$3.7 billion in indirect costs (10). Physical inactivity is a risk factor for obesity and is likely responsible for a portion of obesity-related health care expenditures. It has been estimated that an annual increase of 10% in the prevalence of physical activity could result in savings of \$150 million/year (24). These estimates illustrate that even a modest increase in physical activity could have a significant impact on the health of Canadians and the economy.

Not only is physical activity at suboptimal levels in Canada, but consumption of unhealthy foods is also at an all-time high. The increased availability of energy dense foods that promote the storage of fat (e.g. chocolate, chips, soda, etc.), the high cost of healthy food (e.g. fruits, vegetables, whole grains, etc.), and a rise in the number of fast food venues have all affected Canadians' eating practices (25). Individuals living in lower income households, are more likely to report purchasing fewer milk, fruit and vegetable products (26), and men and women who consume fruit and vegetables less than three times a day are more likely to be obese than those eating these foods five or more

times a day (5). In developed societies, individuals at the lower end of the economic gradient have been shown to have a higher risk for obesity (4).

The Role of the Physical and Social Environments in Creating and Sustaining Inequalities

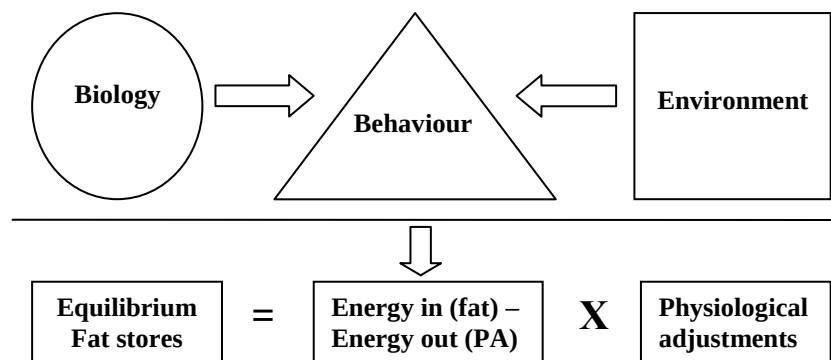
Current strategies place much of the onus on the individual and describe obesity as a result of consuming too many calories and a lack of exercise (27). However, the rise in the prevalence of overweight and obesity indicates that current individual-level strategies are likely not effective in reducing the rates within the Canadian population. It therefore becomes important to conceptualize the problem of obesity within multiple levels of influence and consider the possible gene-environment and behaviour-environment interactions. Individual body weight and body composition are determined by the interactions between their genetics and the

environment in which they live (28). Both human biology and the environment in which populations inhabit can affect behavioural patterns and body composition (see Figure I).

The environment can influence body weight through the facilitation of behaviours such as increased calorie consumption and decreased physical activity that generally lead to a positive energy balance. The physical environment can promote overeating through such variables as food availability and portion sizes, and physical inactivity through facility access, modes of transportation, safety, etc. Interventions focused on the individual are unlikely to succeed if the environmental conditions in which they are delivered are not supportive. Therefore, there is a need to address the environmental factors associated with behaviour prior to the development and delivery of individual-level interventions (29).

Environments that act as promoters of obesity or “obesogenic” environments result from the additive influences of surroundings, opportunities, or conditions in which an individual lives (30). The social environment, which can be examined using such markers as income and education levels, relative deprivation, social support, crime rates, current policies and standards, cultural beliefs, and behavioural norms, has a great impact on what food people consume and how much physical activity they obtain.

Figure I: An ecological model for understanding obesity (PA = physical activity)



Source: Swinburn B, Egger G, Raza F. Dissecting obesogenic environments: the development and application of a framework for identifying and prioritizing environmental interventions for obesity. *Preventive Medicine*. 1999; 29: 563-70. Used by permission.

It often determines why individuals make various choices and the behavioural patterns they subsequently adopt. The physical environment generally refers to what is available to an individual and includes such things as the physical surroundings (e.g. bike paths, green spaces, facilities, etc.) and other less tangible things such as the weather and climate that can affect the capacity of an individual to access and use their surroundings. Both the physical and social environments present barriers and enablers to obtaining adequate levels of physical activity and eating healthily.

For instance, between 1994/95 and 2002/03, members of the highest quintile of household income were less likely to become obese than were those in the lowest income category (31). A similar relationship has been observed for physical activity levels, with lower income individuals less likely to be physically active than individuals with higher incomes (32). Lower income individuals are less able to afford healthier food options (i.e. fruit and vegetables, whole grains, etc.) which in Canada have higher associated costs than more energy dense foods. With the existence of a social gradient, the disparities between populations and the proportion of citizens who are obese or at risk for obesity will likely persist.

Inequalities in the social environment as defined using area level deprivation have also been shown to be associated with and influence access to recreation facilities including green spaces, parks, gyms, recreation centres, and bicycle and walking trails, such that proximity and access differ across areas with different socioeconomic circumstances (33-38). Furthermore, access to recreational facilities have been associated with physical activity levels and obesity (39-48), identifying the capacity of the physical environment to influence an individual's diet and physical activity levels, as well as promote obesity.

Urban design, including land mix use, car time, and distance walked have all been shown to be significantly associated with

obesity (49). Individuals who are located in areas that have more commercial and other non-residential land use walk more such as those in urban centres, get more physical activity, and are less likely to be obese (49). In 2004, Canadian adults living in cities (census metropolitan areas or CMAs), were less likely than those outside of CMAs to be obese (20% vs. 29%) (50). Individuals living in municipalities outside of CMAs and census areas (CAs) who are farthest from urban centres (i.e. less able to commute by foot) were more likely to be obese than those who lived in municipalities which were more strongly influenced by metropolitan design (50). It is hypothesized urban sprawl is associated with negative consequences such as the decreased motivation to walk to locations, an increased reliance on automobiles for travel, and reduced opportunities to exercise in facilities because of time required for travel (50).

Generally, higher obesity rates have been reported in non-CMAs, except for in Newfoundland and Labrador and New Brunswick, which are the provinces with the lowest number of residents living in CMAs and CAs. Also interesting is the comparison between the proportion of residents who are obese and the proportion of individuals living in CMAs and CAs by province. The highest proportions of obesity are seen in the provinces with the lowest number of individuals living in CMAs and CAs (51).

Our current environment is increasingly conducive to automobile use, television viewing, decreased occupational activity, greater consumption of food outside of the home, and increased portion sizes (25). Current prevention and treatment strategies concerning lifestyle and health generally ignore systematic influences and instead focus much of their efforts on individual responsibility. Strategies are often deliverable at a population level, but are largely focused on the individual. If we are to develop prevention and treatment strategies that are to be effective, there is a need to avoid methods that are aimed at individuals in isolation of a societal level of intervention (52). Rather, it has become increasingly important to adopt

individual interventions in conjunction with supportive social change. Anti-smoking campaigns in Canada are prime examples of effective intervention types that were implemented at the society level. The campaigns represented an effective public health effort that included both physical and social environmental changes. Public health messages, increased cigarette taxes, and by-laws preventing individuals from smoking in public places have shown to be effective in decreasing the prevalence of smoking to the lowest rates ever (53).

Adding a Population Health Approach

To elicit change it becomes increasingly important to address the multiple determinants of health across multiple levels and sectors, all factors that are inherent to the application of a population health approach. Kindig and Stoddart have proposed that population health be defined as: “the health outcomes of a group of individuals, including the distribution of such outcomes within the group” (54). Applying this definition of population health to the study of obesity would look to identify the interrelated factors and conditions that increase the risk to the population over the life course, and identify possible systematic variations, such as the social gradient, in order to develop policies and strategies that are effective in reducing risk. Population health frameworks provide the skeleton from which obesity and other health problems can be researched and for which appropriate interventions can be developed. In order to reduce the prevalence of obesity and decrease inequities, strategies should consider both behavioural risk factors (i.e. individual variability, genetics, lifestyles, etc.) and environmental influences (i.e. income, education, urban sprawl, etc.). A population health framework should incorporate determinants at all levels including the macro (international, national), the proximate (community, home/work/school), and the micro or individual level.

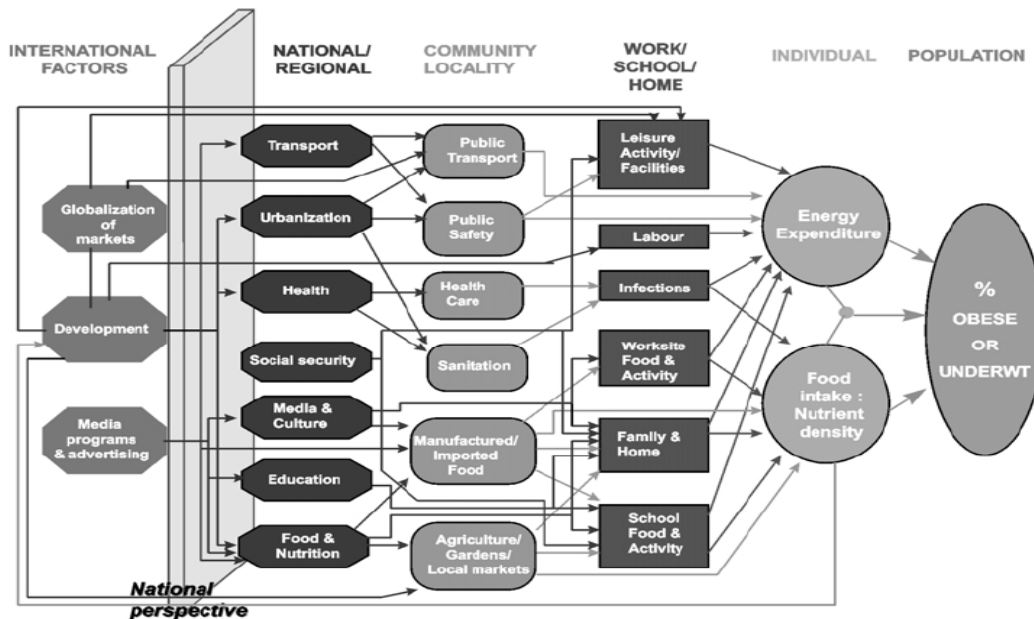
The International Obesity Task Force (IOTF) developed a population health framework (or

causal web) that organizes the determinants of obesity (see Figure II). The IOTF framework maps out the societal policies and processes with direct and indirect influences on the prevalence of obesity, and acknowledges that the lines between determinants will differ between populations (4). It presents many contextual factors such as urbanization, globalization, and social security that have historically been ignored by research and prevention and treatment strategies. Although not explicitly, it acknowledges the transdisciplinary approach required to study the problem. Stakeholders and disciplines from all levels such as geography, sociology, epidemiology, kinesiology, nutrition, medicine, business/industry, health care, the public, and politics must be incorporated to understand the mechanisms by which obesity develops and persists. Obesity research and strategies have unfortunately, generally lacked the cooperative involvement of several stakeholders from all contextual levels. The framework identifies that obesity is not solely an individual or governmental manifestation, but one that is impacted on several levels.

The framework, although developed exclusively for obesity, presents some challenges in its application. While being useful for identifying the transdisciplinary nature and contextual factors that lead to obesity in the population, it does so in a very static fashion. The framework does not propose feedback from one level to the next nor the opportunity for the relationship to change directions. It directs the determinants down from the macro to the micro level and does not acknowledge the existence of inequalities at each level that often persist due to existing socio-economic gradients. As a result, in order to elicit changes at the individual level, interventions should be considered in the context of the various levels.

Huynen and colleagues (2005) developed a multi-nature and multi-level framework (Figure III) for population health (55). While this framework was not developed exclusively for obesity it does provide a more dynamic alternative to the linear IOTF framework.

Figure II. International Obesity Task Force Obesity Framework



Source: Kumanyika SK, Jeffrey RW, Morabia A, Ritenbaugh C, Antipatis VJ. Obesity prevention: the case for action. *International Journal of Obesity* 2002;26:425-36. Used by permission.

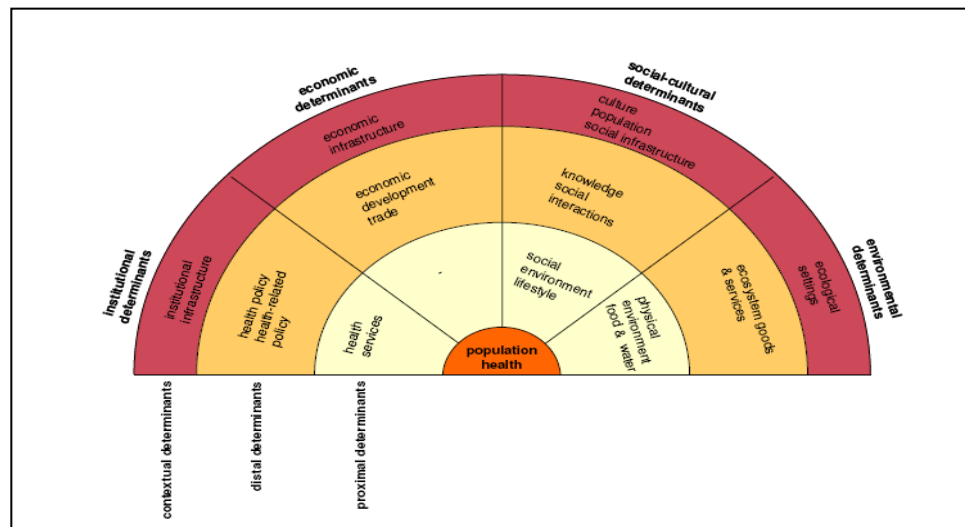
It explicitly identifies the contextual level of the various determinants of obesity and within each determinant the broad system levels (proximal and distal) and factors. Their framework addresses the capacity of inequalities at various levels to exhibit non-linear impacts on others. Its dynamic nature identifies that each level and factor can impact another irrespective of direction. However, the model does not address the individual determinants of health such as individual susceptibility, genetic predisposition, and lifestyle/behaviour. It is important that health prevention and treatment strategies acknowledge the individual variability that is present within a population.

A combination of the more obesity-specific IOTF framework and the one presented by Huynen and colleagues may provide a more comprehensive population health approach to the study of obesity. Figure IV proposes such a framework and considers key determinants of obesity in a dynamic fashion that allows feedback from all levels. This framework

presumes a less rigid cause-effect which is characteristic of the IOTF framework, and recognizes the contextual factors and complexity of obesity. It borrows from complexity theory and maintains a dynamic and open system between the various determinants of obesity.

It incorporates many of the key variables of a complex system including: a large number of components, non-linear interactions with feedback loops, historical influence, and the openness of each system (represented by dashed lines) (56). By allowing the broader macro-level or distal factors to interact with the other proximal factors, it acknowledges the role of broader environmental factors in the development of individual behaviours. It also recognizes the historical influences of an individual or an individual's life course, a variable that is often missing from conceptual frameworks. Habits developed in childhood and childhood environments such as physical activity behaviours, have been shown to be important contributors to the development of adult obesity (57).

Figure III. Huynen *et al.* (2006) multi-nature and multi-level population health framework



Source: Huynen MMTE, Martens P, Hilderink HBM. The health impacts of globalisation: a conceptual framework. *Globalization and Health* 2005;1(14):1-12. Used by permission

Because it is a conceptual framework, it is not meant to provide a causal flow, but rather a paradigm for thinking about obesity as a population health problem. It lays the foundation for theory development and represents the broadest level of conceptualization (58).

Applying this population health framework to the problem of obesity in Canada identifies that obesity is a complex problem with multiple determinants. For example, individuals may be at a greater risk for obesity because they have a genetic predisposition, are from a lower income family, live in a neighbourhood that does not promote physical activity (e.g. is unsafe and amenities are not walkable), has friends and family who are obese and/or does not have access to supportive medical services such as a dietician or a general practitioner. These factors can affect an individual directly or their effects can be cumulative and the determinants can also affect each other. For instance, an individual who is genetically predisposed to being overweight may come from a lower income family increasing their inability to afford to live in a neighbourhood that is conducive to walking which in turn makes them more

sedentary and more likely to become obese. The framework shows how an individual's risk factor can be impacted by the environment in which they live.

Gaps in the Literature

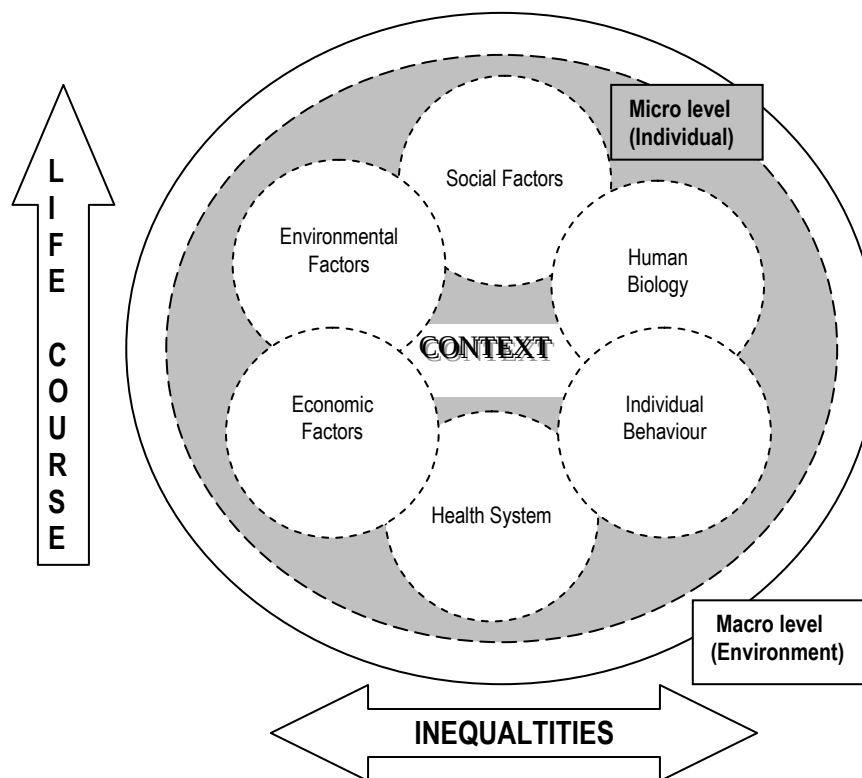
Rapid increases in the prevalence of obesity cannot be explained by genetic changes within populations. While genetics may have the capacity to determine individual susceptibility toward weight gain, it is likely social and environmental changes that are driving this global pandemic (4). Economic growth, modernization, urbanization, and globalization of food markets have all been identified as contributors to the sudden rise (4). Our modern society sees less individuals being physically active and an increased consumption of unhealthy, energy dense foods.

Although a large component of the answer lies in the physical and social environments, most research and strategies to date have focused on the individual level. In Canada, little information has been collected regarding the roles of the social and physical environments on the risk of obesity. Societal and structural changes are important

contextual factors to be considered in the design and delivery of effective individual focused prevention and treatment strategies. Environmental design in Canada has yet to be fully explored for its effects on health and health behaviours. The majority of research that has focused on environmental determinants of physical activity, nutrition, and obesity has been in the American context. Markers of the social environment (e.g. income and educational levels) in Canada are regularly collected; however, surveillance at

the national level remains limited. Few smaller scale studies have examined the impact of the environment on physical activity and obesity, but these are not generalizable to the Canadian population. Furthermore, few prevention strategies have been implemented that involve environmental change. Most current prevention strategies have used a form of public health campaigns and education without changes to community infrastructure and program evaluations remain sparse.

Figure IV. Proposed population health conceptual framework for the study of obesity



Source: Author's figure

Conclusions and Recommendations

Surveillance of populations provides a means by which we can evaluate the association of various factors with obesity and an opportunity to compare changes over time. Natural experiments provide the best means by which social and structural changes could be evaluated. Further research is required to determine the more specific roles of the physical and social environments including the social gradient, on the prevalence of obesity. Canadian data is sparse and multilevel designs assessing the impact of various factors while recognizing their context may provide some suggestion as to where structural and societal changes could be implemented. Research to date has had little involvement of stakeholders at all levels or feedback from various disciplines. Transdisciplinary research and involvement of the public could provide new insight to this

population health problem and feedback regarding the effectiveness of various strategies.

If obesity is to cease as a population-level health problem, it requires a population health approach. The current prevention and treatment strategies are not effective and ignore both the individual variability and the context of the problem. The modern characteristics of the physical and social context in which Canadians live are likely to blame for the rapid increases in the rates of obesity. Social inequalities and environmental barriers are often ignored in obesity strategies and result in the growth of disparities and inequities in health. It is important that further research be conducted to assess the multilevel risk factors of obesity and that intervention work focus not only on individual strategies, but also on the use of contextual changes across multiple sectors.

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CHAPTER 4: MANUSCRIPT 2

This manuscript was written and published in accordance to the specifications for submission to the peer-reviewed *International Journal of Behavioral Nutrition and Physical Activity (IJBNPA)*. It appears in its published format.

Title:

A comparison of direct versus self-report measures for assessing physical activity in adults: a systematic review.

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Suggested citation:

Prince SA, Adamo KB, Hamel ME, Hardt J, Gorber SC, Tremblay M: **A comparison of direct versus self-report measures for assessing physical activity in adults: a systematic review.** *The international journal of behavioral nutrition and physical activity* 2008, **5**:56

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Review

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A comparison of direct versus self-report measures for assessing physical activity in adults: a systematic review

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Published: 6 November 2008

Received: 22 April 2008

Accepted: 6 November 2008

International Journal of Behavioral Nutrition and Physical Activity 2008, 5:56 doi:10.1186/1479-5868-5-56

This article is available from: <http://www.ijbnpa.org/content/5/1/56>

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Abstract

Background: Accurate assessment is required to assess current and changing physical activity levels, and to evaluate the effectiveness of interventions designed to increase activity levels. This study systematically reviewed the literature to determine the extent of agreement between subjectively (self-report e.g. questionnaire, diary) and objectively (directly measured; e.g. accelerometry, doubly labeled water) assessed physical activity in adults.

Methods: Eight electronic databases were searched to identify observational and experimental studies of adult populations. Searching identified 4,463 potential articles. Initial screening found that 293 examined the relationship between self-reported and directly measured physical activity and met the eligibility criteria. Data abstraction was completed for 187 articles, which described comparable data and/or comparisons, while 76 articles lacked comparable data or comparisons, and a further 30 did not meet the review's eligibility requirements. A risk of bias assessment was conducted for all articles from which data was abstracted.

Results: Correlations between self-report and direct measures were generally low-to-moderate and ranged from -0.71 to 0.96. No clear pattern emerged for the mean differences between self-report and direct measures of physical activity. Trends differed by measure of physical activity employed, level of physical activity measured, and the gender of participants. Results of the risk of bias assessment indicated that 38% of the studies had lower quality scores.

Conclusion: The findings suggest that the measurement method may have a significant impact on the observed levels of physical activity. Self-report measures of physical activity were both higher and lower than directly measured levels of physical activity, which poses a problem for both reliance on self-report measures and for attempts to correct for self-report – direct measure differences. This review reveals the need for valid, accurate and reliable measures of physical activity in evaluating current and changing physical activity levels, physical activity interventions, and the relationships between physical activity and health outcomes.

Background

Physical activity is defined as "any bodily movement produced by the skeletal muscle that results in energy expenditure (EE)" [1]. Inactivity is known to be associated with an increased risk for many chronic diseases including: coronary artery disease, stroke, hypertension, colon cancer, breast cancer, Type 2 diabetes, and osteoporosis [2], as well as premature death. The economic burden of physical inactivity in Canada has been estimated to be \$2.1 billion [2]. Physical activity levels are often monitored to assess the health behaviours of the population and their association with health status including mortality and morbidity rates. Accurate assessment of physical activity is required to identify current levels and changes within the population, and to assess the effectiveness of interventions designed to increase activity levels.

Data collection at the population level often involves self-report (subjective) measures of physical activity through the use of questionnaires, diaries/logs, surveys, and interviews. These measures are frequently used due to their practicality, low cost, low participant burden, and general acceptance [3]. Although self-reports are useful for gaining insight into the physical activity levels of populations, they have the capacity to over- or underestimate true physical activity energy expenditure and rates of inactivity. The self-report methods are often wrought with issues of recall and response bias (e.g. social desirability, inaccurate memory) and the inability to capture the absolute level of physical activity.

As self-report methods possess several limitations in terms of their reliability and validity [4], objective or direct measures of physical activity are commonly used to increase precision and accuracy and to validate the self-report measures. Direct measures are believed to offer more precise estimates of energy expenditure and remove many of the issues of recall and response bias. Direct measures consist of calorimetry (i.e., doubly labeled water, indirect, direct), physiologic markers (i.e., cardiorespiratory fitness, biomarkers), motion sensors and monitors (i.e., accelerometers, pedometers, heart rate monitors), and direct observation. Despite the advantages of using direct methods, these types of measures are often time and cost intensive and intrusive rendering them difficult to apply to large epidemiologic settings. These measures also require specialized training and the physical proximity of the participant for data collection. In addition, direct measures each possess their own limitations and no single "gold standard" exists for measuring physical activity or assessing validity [3].

The appropriate method for measuring physical activity at various levels depends on factors such as the number of individuals to be monitored, the time period of measure-

ments and available finances [5]. Many previous studies have examined the reliability and validity of various self-report and direct methods for assessing physical activity. Results from these studies have been conflicting. To our knowledge no attempt has been made to synthesize the literature to determine the validity of physical activity measures in adult populations.

The primary objective of this study was to perform a systematic review to compare self-report versus direct measures for assessing physical activity in observational and experimental studies of adult populations. The results from this systematic review provide a comprehensive summary of past research and a comparison between physical activity levels based on direct versus self-report measures in adult populations.

Methods

Study criteria

The review sought to identify all studies (observational or experimental) that presented a comparison of self-report and direct measurement results to reveal differences in physical activity levels based on measurement in adult populations (18 years and over). Studies which examined only a self-report or direct measure, but not both were not included in the review. All study designs were eligible (e.g. retrospective, prospective, case control, randomized controlled trial, etc.) and both published (peer-reviewed) and unpublished literature were examined.

Only studies involving adult populations with a mean age of 18 years and older were considered. Abstracts and titles were examined for their mention of adult populations (using adult\$.tw.), but the search relied mostly on the subject headings for adult age groups (exp adult/). This systematic review was conducted simultaneously with a systematic review of the same focus in child populations (mean age < 19 years). A separate pediatric review was carried out as a result of differences in measurement methodologies and hypothesized cognitive and recall abilities between adults and children [6].

The eligible self-report measures of physical activity included: diaries or logs; questionnaires; surveys; and recall interviews. Proxy-reports were excluded because they present issues of reliability due to the potential heterogeneity of reporters (e.g., spouse, trainer, coach, parent, caregiver). The eligible direct measures of physical activity included: doubly-labeled water (DLW), indirect or direct calorimetry, accelerometry, pedometry, heart rate monitoring (HRM), global positioning systems, and direct observation. Although no language restrictions were imposed in the search, only English language articles were included in the review. Abstracts were included if they provided sufficient details to meet inclusion criteria.

Search strategy

The following electronic bibliographic databases were searched using a comprehensive search strategy to identify relevant studies reporting the use of both self-report and direct measures for assessing individual physical activity levels: Ovid MEDLINE(R) (1950 to April Week 4 2007); Ovid EMBASE (1980 to 2007 Week 18); Ovid CINAHL (1982 to April Week 4 2007); Ovid PsycINFO (1806 to April Week 1 2007); SPORTDiscus (1830 to April 2007); Physical Education Index (1970 to April 2007); Dissertations and Theses (1861 to April 2007); and Ovid MEDLINE (R) Daily Update (May 4, 2007). The search strategy is illustrated using the MEDLINE search as an example (Table 1) and was modified according to the indexing systems of the other databases. The OVID interface was used to search MEDLINE, EMBASE, CINAHL, and PsycINFO; Ebscohost was used to search SPORTDiscus; Scholar's Portal was used to search Physical Education Index; and ProQuest for Dissertations and Theses. Grey literature (non-peer reviewed works) included published abstracts and conference proceedings, published lists of theses and dissertations, and government reports. Knowledgeable researchers in the field were solicited for key studies of interest. The bibliographies of key studies selected for the review were examined to identify further studies.

Two independent reviewers screened the titles and abstracts of all studies to identify potentially-relevant articles. Duplicates were manually removed. The full texts of all studies that met the inclusion criteria were then obtained and reviewed. When disagreements between reviewers occurred, consensus was achieved through discussion and/or with a third reviewer.

Standardized data abstraction forms were completed by one reviewer and verified by two others. Information was extracted on the type of study design, participant characteristics, sample size, and methods of physical activity measurement (self-report and direct measures employed, units of measurement, duration of direct measure, length of recall, and length of time between the self-report and directly measured estimates). Reviewers were not blinded to the authors or journals when extracting data.

Risk of bias assessment

The Downs and Black [7] checklist was used to assess the risk of bias. The Downs and Black instrument was recommended for assessing risk of bias in observational studies in a recent systematic review [8] and other assessments [9] and was employed in this review to assess study quality including reporting, external validity, and internal validity (bias). The Downs and Black checklist consists of 27 items with a maximum count of 32 points. A modified version of the checklist was employed with items that were not

relevant to the objectives of this review removed. The adapted checklist consisted of 15 items, including items 1-4, 6, 7, 9-13, 16-18, and 20 from the original list, with a maximum possible count of 15 points (higher scores indicate superior quality). The risk of bias assessment was carried out by two independent assessors and when disagreements between assessors occurred, consensus was achieved through discussion.

Data synthesis

Percent mean difference was used as the main outcome of this analysis; it was calculated using the formula: [(self-report mean - direct mean)/direct mean]. Only studies with units of measurement that were the same for both the self-report and direct measures were used to calculate percent mean differences. Units were converted where possible. These studies were included in the direct comparison analyses. Forest plots (graphical displays of the percent mean differences across the individual studies) were constructed to present overall trends in agreement of physical activity by direct measure and gender. As most studies did not employ the same units of measurement (e.g. kcal/week, MET/day, MET-min/day) and did not report a measure of variance (e.g. standard deviations or standard errors), pooled estimates and confidence intervals were not calculated.

Results

Description of studies

The preliminary search of electronic bibliographic databases, reference lists and grey literature identified 4,463 citations (see Figure 1). Of these, 1,638 were identified in MEDLINE, 1,306 in EMBASE, 732 in CINAHL, 218 in PsycINFO, 133 in SportDISCUS, 34 in Physical Education Index, 3 in MEDLINE Daily Update, and 399 from Dissertations and Theses. After a preliminary title and abstract review, 296 full text articles were retrieved for a detailed assessment. Of these, 173 met the criteria for study inclusion. One hundred and forty-eight of these studies reported correlation statistics [10-157]. Seventy-four studies contained comparable data meaning the self-report and direct measurements were reported using the same units [11,15,17,19,20,23,32,33,44,48,53,56-59,65,73-77,80,88,90,92,94,100,102,105,111,114,116,119-121,128,131,134,135,138-140,143,148,151,153,154,158-183]. These studies were included in the direct comparison analyses and their characteristics are described in Table 2. Common reasons for excluding studies included: populations with mean ages less than 18 years, the absence of directly measured and self-report data on the same population, non-English language, duplicate reporting of data, and the absence of comparable units between measures or the absence of a direct comparison.

Table 1: Medline search strategy

1	self report\$.tw.
2	questionnaire\$.tw.
3	diary.tw.
4	log\$.tw.
5	survey.tw.
6	interview\$.tw.
7	recall.tw.
8	physical activity assessment.tw.
9	Minnesota Leisure Time Physical Activity Questionnaire.tw.
10	Framingham Leisure Time Physical Activity Questionnaire\$.tw.
11	Global Physical Activity Questionnaire\$.tw.
12	(International Physical Activity Questionnaire or IPAQ\$.tw.
13	(Godin Leisure Time Exercise Questionnaire or Godin-Shephard Leisure Time Exercise Questionnaire\$.tw.
14	seven day physical activity recall\$.tw.
15	(Bouchard three day physical activity record or bouchard 3 day physical activity record\$.tw.
16	Baecke Questionnaire of Habitual Physical Activity.tw.
17	Modified Baecke Questionnaire for Older Adults\$.tw.
18	Modifiable Activity Questionnaire\$.tw.
19	Aerobics Center Longitudinal Study Physical Activity Questionnaire.tw.
20	CARDIA Physical Activity Questionnaire\$.tw.
21	(Health Insurance Plan of New York Activity Questionnaire or HIP activity questionnaire).tw.
22	(physical activity questionnaire of the kuopio ischemic heart disease study or physical activity questionnaire of the KIHD study).tw.
23	Paffenbarger Physical Activity Questionnaire\$.tw.
24	Lipid Research Clinics Questionnaire.tw.
25	Stanford Physical Activity Questionnaire\$.tw.
26	Tecumseh Occupational Physical Activity Questionnaire\$.tw.
27	Physical Activity Scale for the Elderly.tw.
28	Canada Fitness Survey\$.tw.
29	(The MONICA Optional Study of Physical Activity or MOSPA\$.tw.
30	Framingham Physical Activity Index.tw.
31	YALE Physical Activity Survey\$.tw.
32	Zutphen Physical Activity Questionnaire\$.tw.
33	or/1-32
34	(doubly labeled water or doubly labelled water).tw.
35	calorimet\$.tw.
36	heart rate monitor\$.tw.
37	acceleromet\$.tw.
38	pedomet\$.tw.
39	activity monitor\$.tw.
40	CSA monitor.tw.
41	or/34-40
42	direct\$ observ\$.tw.
43	((direct\$ or physical or objective) adj2 measur\$.tw.
44	((reference or gold or criter\$) adj standard\$.tw.
45	(reliability or validity).tw.
46	or/42-45
47	physical activity.tw.
48	exercise.tw.
49	walk\$.tw.
50	physical fitness.tw.
51	or/47-50
52	46 and 51
53	41 or 52
54	33 and 53
55	adult\$.tw.
56	exp adult/
57	or/55-56
58	54 and 57

Table 2: Study and participant characteristics for studies with directly comparable data

First Author – Year	Age Range or Mean (SD)	N _{analyzed}			Population	Direct Measure	Indirect Measure	Units	Testing Conditions*
		Total	Men	Women					
Adams 2003 A	40–65	80	0	80	Disease free	Accel	7-day PAR – Light	kcal/kg/day	A
Adams 2003 B						Accel	7-day PAR – MPA		
Adams 2003 C						Accel	7-day PAR – VPA		
Adams 2005 A	40–65	80	0	80	Disease free	DLW	7-day PAR 1	kcal/kg/day	C
Adams 2005 B						DLW	7-day PAR 2		
Adams 2005 C						DLW	24-hr PAR		
Ainsworth 1993 A	23–59	75	27	48	White collar workers	Accel	7-day PAR	average MET	NS
Ainsworth 1993 B						Accel	Tecumseh		
Ainsworth 1993 C						Accel	PAR		
Ainsworth 2000	20–60	50	0	50	Females	Accel	KPAS	MET-min/day	A
Atienza 2005	60.3 (9.1)	15	0	15	Filipino American	Accel	3-day PAD	min/3-day	A
Barnard 2002	22–59	15	8	7	Healthy volunteers	DLW	MAQ	MJ	NS
Bassett 2000	25–70	96	48	48	General population	Ped	CAQ	kcal/week	D
Bernstein 1998	35–69	41	18	23	General population	HRM	PAFQ	kcal/day	C
Bonnefoy 2001	66–82	19	19	0	Elderly	DLW	QAPSE	kcal/day	A
Boulay 1994 A	21 (5)	15	15	0	X-Country skiers	HRM	3-day PAD	MJ/day	C
Boulay 1994 B	22 (1)				Controls	HRM			
Buchowski 1999 A	20–50	115	45	70	Volunteers – Normal	Indirect cal.	PAD ≤ 2.4 METS	min/day	A
Buchowski 1999 B						Indirect cal.	PAD 2.5–4.4 METS		
Buchowski 1999 C						Indirect cal.	PAD ≥ 4.5 METS		
Buchowski 1999 D					Volunteers – Exercise	Indirect cal.	PAD ≤ 2.4 METS		
Buchowski 1999 E						Indirect cal.	PAD 2.5–4.4 METS		
Buchowski 1999 F						Indirect cal.	PAD ≥ 4.5 METS		
Clark 1994 A	37.3 (3.6)	14	0	14	Large eaters	DLW	PAD	MJ/day	C
Clark 1994 B	39.7 (2.0)				Small eaters	DLW			
Conway 2002 A	42 (2.3)	24	24	0	Feeding study	DLW	Minnesota	MJ/day	C
Conway 2002 B						DLW	Tecumseh		
Conway 2002 AA	41.2 (2.0)	24	24	0	Feeding study	DLW	PAR	MJ/day	C
Conway 2002 BB						DLW	Stanford		
Davis 2004 A	19–69	62	24	38	Obese	Accel	YPAS	kcal/day	NS
Davis 2004 B						Accel		kcal/kg/day	
Davis 2004 C					Normal weight	Accel		kcal/day	
Davis 2004 D						Accel		kcal/kg/day	
Ekelund 2006 A	20–69	185	87	98	Swedish adults	Accel	IPAQ – MPA	min/day	A
Ekelund 2006 B						Accel	IPAQ – VPA		
Fogelholm 1998	29–46	20	0	20	Overwgt premenopause	HRM	PAD	min/day	A
Friedenreich 2006 A	35–65	154	75	79	Healthy Canadians	Accel	PAQ	MET-hr/week	B
Friedenreich 2006 B						Accel	7-day PAR	MET-hr/week	
Friedenreich 2006 C						Accel	PAQ	hr/week	
Friedenreich 2006 D						Accel	7-day PAR	hr/week	
Hagfors 2005	diet 58.8 (9.9), control 59.5 (8.1)	9	3	6	Rheumatoid Arthritis	DLW	3-day PAR	MJ/day	C

Table 2: Study and participant characteristics for studies with directly comparable data (Continued)

Hayden-Wade 2003 A	18-67	69	25	44	Active and sedentary	Accel	7-day PAR – MPA	min/week	A
Hayden-Wade 2003 B						Accel	7-day PAR – Hard		
Hayden-Wade 2003 C						Accel	7-day PAR – Vhard		
Iqbal 2006 A	26 (3.8)	50	0	50	Pakistani	Accel	MOSPA – LT	kcal/day	A
Iqbal 2006 B						Accel	MOSPA – ST		
Irwin 2001 A	27-65	24	24	0	Adult men	DLW	7-day PAR	kcal/day	C
Irwin 2001 B						DLW	PAL		
Jacobs Jr 1993 A	20-59	78	28	50		Accel	Minnesota	MET/min/day	NS
Jacobs Jr 1993 B						Accel	7-day PAR		
Jacobs Jr 1993 C						Accel	CAQ		
Jakicic 1998 A	25-50	50	0	50	Overwgt under reporters	Accel	PAR	min/week	A
Jakicic 1998 B					Overwgt over reporters	Accel	PAR		
Johnson Kozlow 2006 A	35-77	96	0	96	Breast cancer	Accel	IPAQ	min/week	A
Johnson Kozlow 2006 B		63	0	63			7-day PAR		
Johnson-Kozlow 2007	38-72	63	0	63	Breast cancer	Accel	WHIQ	min/week	A
Koulouri 2006 A	28.3 (6.0)	10			Healthy – baseline	Ped	PAD	KJ	A
Koulouri 2006 B					Healthy – intervention	Ped			
Lasuzzo 2004	71.7 (8.2)	39	19	20	Seniors	Accel	Fullerton	MET-min/day	A
Leenders 1998 A	18-40	10	0	10	Healthy females	Accel, HRM, DLW	7-day PAR	kcal/day	A
Leenders 1998 B						Accel, DLW	PAEE	kcal/day	
Leenders 2000	26 (6.6)	12	0	12	Healthy college	Accel, Ped	7-day PAR	kcal/kg/day	A
Leenders 2001	21-37	13	0	13	Healthy females	Accel, Ped, DLW	7-day PAR	kcal/day	A
Lemmer 2001 A	20-30	40	21	19	Younger males	Accel	PAQ	kj/day	C
Lemmer 2001 B	65-75				Older males	Accel			
Levin 1999 A	21-59	77	28	49	Healthy volunteers	Accel	4-week PAR	MET-min/day	C
Levin 1999 B							SAFE		
Liu 2001	22-86	31			Elderly Chinese	Indirect cal.	PAQ	kcal	NS
Lof 2003 A	21-41	34	0	34	Healthy Swedish	Accel, HRM, DLW	PAQ – TEE	kj/24-hour	A
Lof 2003 B						HRM	PAQ – PAEE		
Lovejoy 2001 A	47.4 (0.2)	149	0	149	Premenopausal African	Accel	PAQ	kj/day	D
Lovejoy 2001 B					Premenopausal White	Accel		kj/day	
Masse 1999	35-61	31	0	31	Volunteers	Accel	3-day PAD	kcal/day	A
Matthews 1995 A	26.7	25	14	11	University volunteers	Accel	3-day PAL	kcal/day	A
Matthews 1995 B							7-day PAR		
Matthews 2005 A	46	69			Volunteers	Accel	24-hr PAR	min/day	C
Matthews 2005 B						Accel		min/wk	
Matthews 2005 C						Accel	STAR Closed	min/day	
Matthews 2005 D						Accel		min/wk	
Matthews 2005 E						Accel	STAR Open	min/day	
Matthews 2005 F						Accel		min/wk	
McDermott 2000 A	67.2 (7.0)	41	19	22	Peripheral Arterial Disease	Accel	LTPAQ	kcal/week	A
McDermott 2000 B	66.1 (5.4)				Non-PAD	Accel			
Meriwether 2006 A	20-61	63	10	58	Volunteers	Accel	PAAT	min/week	A
Meriwether 2006 B						Accel	IPAQ		
Miller 2005 A	61.6 (7.2)	13			Diabetic/CABG intervention	Accel	7-day PAD	kcal/kg/day	D
Miller 2005 B					Diabetic/CABG control	Accel			
Paton 1996	26-45	10	10	0	HIV positive	DLW	PAD	PA Level	A

Table 2: Study and participant characteristics for studies with directly comparable data (Continued)

Paul 2005	39 (9)	12	12	0	Non-smoking	DLW	7-day PAQ	MJ/day	A
Pitta 2005 A	61 (8)	13	10	3	COPD – Walking	Accel	1-day PAD	mins.	A
Pitta 2005 B					COPD – Cycling	Accel			
Pitta 2005 C					COPD – Standing	Accel			
Pitta 2005 D					COPD – Sitting	Accel			
Pitta 2005 E					COPD – Lying	Accel			
Racette 1995 A	21–47	14	0	14	Obese	HRM, DLW	7-day PAR	MJ/day	C
Racette 1995 B						HRM		kcal/day	
Richardson 1994 A	20–59	78	28	50	Healthy	Accel	Minnesota	MET/min/day	C
Richardson 1994 B						Accel	4-week PAQ		
Richardson 1994 C						Accel	48-hr PAL		
Richardson 1995	20–59	78	28	50	Healthy	Accel	Baecke	MET/min/day	A
Richardson 2001	20–59	77	27	50	Healthy	Accel	Stanford 7-day PAR	MET/min/day	A
Rothenberg 1998	73	20	8	12	Healthy, free-living	HRM, DLW	PAD	MJ/day	C
Rutgers 1997 A	68–78	13	0	13	Elderly – individual calibration	HRM	PAQ	MJ/day	A
Rutgers 1997 B					Elderly – group calibration	HRM			
Schmidt 2003 A	39–65	58	0	58	College – Freedson	Accel	PAL	min/day	A
Schmidt 2003 B					College – Hendelman	Accel			
Schmidt 2003 C					College – Swartz	Accel			
Schmidt 2006 A	18–47	54	0	54	Pregnant – Freedson	Accel	PPAQ	MET-min/day	C
Schmidt 2006 B					Pregnant – Hendelman	Accel			
Schmidt 2006 C					Pregnant – Swartz	Accel			
Schulz 1989 A	20–30	6	4	2	Healthy university	HRM – Proc 1	PAD – Procedure 5	MJ/day	A
Schulz 1989 B						HRM – Proc 2	PAD – Procedure 5		
Schulz 1989 C						HRM – Proc 3	PAD – Procedure 5		
Schulz 1989 D						HRM – Proc 4	PAD – Procedure 5		
Schulz 1989 E						HRM – Proc 1	PAD – Procedure 6		
Schulz 1989 F						HRM – Proc 2	PAD – Procedure 6		
Schulz 1989 G						HRM – Proc 3	PAD – Procedure 6		
Schulz 1989 H						HRM – Proc 4	PAD – Procedure 6		
Schulz 1989 I						DLW	PAD – Procedure 5		
Schulz 1989 J						DLW	PAD – Procedure 6		
Seale 2002 A	67–82	27	14	13	Rural elderly	DLW	7-day PAR – PAWT	MJ/day	C
Seale 2002 B						DLW	7-day PAR – PABMR		
Seale 2002 C						DLW	7-day PAR – PAREE		
Sjostrom 2002 A	41 (10)	445	202	243	Swedish	Accel	IPAQ – MPA	min/day	A
Sjostrom 2002 B						Accel	IPAQ – VPA		
Sobngwi 2001	19–68	89	44	45	Cameroonian	Accel	SSAAQ	MET-hr/day	C
Soundy 2005 A	52.9 (9.0)	9			Severe mental illness	Accel	PAQ – week 2	kcal/day	C
Soundy 2005 B						Accel	PAQ – week 6		
Starling 1998	52–79	65	28	37	Older free-living	DLW	Minnesota	kcal/day	NS
Starling 1999 A	45–84	67	32	35	Older free-living	Accel, DLW	YPAS	kcal/day	NS
Starling 1999 B						Accel	Minnesota		
Staten 2001 A	31–60	35	0	35	Sedentary	DLW	AAFQ (28-day)	kJ/day	NS
Staten 2001 B						DLW	AAFQ (7-day)		
Stein 2003 A	30.6 (4.7)	56	0	56	Pregnant – active	Accel, HRM	PAL	kcal/day	A
Stein 2003 B	27.9 (5.4)				Pregnant – sedentary	Accel, HRM			

Table 2: Study and participant characteristics for studies with directly comparable data (Continued)

Strath 2003 A	20-56	25	12	13	General population	Accel	CAQ - MPA	min/day	A
Strath 2003 B						Accel	CAQ - VPA		
Strath 2003 C						Accel	CAQ - MPA+ VPA		
Strath 2004	20-65	15	12	14	General population	Accel	CAQ (with HR)	MET-min/wk	NS
Taylor 1984 A	34-69	12	12	0	White males	Accel	Stanford	kcal/day	NS
Taylor 1984 B						Accel		kcal/kg/day	
Taylor 1984 C						Accel	PAD	kcal/day	
Taylor 1984 D						Accel		kcal/kg/day	
Timperio 2003 A	M 37.8 (12.7), F 39.6 (17.0)	122	55	63	Overweight	Accel	PAQ > 3 MET	min/day	A
Timperio 2003 B						Accel	PAQ 3-5.9 MET		
Timperio 2003 C						Accel	PAQ > 6 MET		
Timperio 2004 A	18-75	551	241	310	Free-living	Accel	AAS - Log	min/day	A
Timperio 2004 B						Accel	AAS - No log		
Timperio 2004 C						Accel	IPAQ-S - Log		
Timperio 2004 D						Accel	IPAQ-S - No log		
Timperio 2004 E						Accel	IPAQ-L - Log		
Timperio 2004 F						Accel	IPAQ-L - No log		
Timperio 2004 G						Accel	BRFSS - Log		
Timperio 2004 H						Accel	BRFSS - No log		
Tzetzis 2001	19-21	75	33	42	Novice skiers	HRM	PAQ	time/task	B
Wadsworth 2006 A	18-24	71	0	71	College - controls	Accel	IPAQ - MPA	min/day	A
Wadsworth 2006 B					College - controls	Accel	IPAQ - VPA		
Wadsworth 2006 C					College - Intervention	Accel	IPAQ - MPA		
Wadsworth 2006 D					College - Intervention	Accel	IPAQ - VPA		
Walsh 2004 A	20-46	75	0	75	Overweight White	DLW	Tecumseh	kcal/day	NS
Walsh 2004 B					Overweight Black	DLW			
Walsh 2004 C					Control White	DLW			
Walsh 2004 D					Control Black	DLW			
Washburn 2003	18-33	46	17	29	Sedentary mod obese	DLW	PAR	kJ/day	C
Wendel-Vos 2003 A	44 (6)	50	36	14	Healthy bank workers	Accel	PAQ 2-4 MET	MET	D
Wendel-Vos 2003 B						Accel	PAQ 4-6.5 MET		
Wendel-Vos 2003 C						Accel	PAQ 6.5+ MET		
Wickel 2006	18-23	70	13	57	University	Accel	PAD	kcal/day	A
Wilbur 2001 A	45-65	156	0	156	Healthy employees	HRM	PAQ	min/walk	A
Wilbur 2001 B						HRM	PAL		

* A - measuring same length of time (e.g. 7-days, 1 week) and no time lag, B - same length with time lag, C - different length with no time lag, D - different length with a time lag, NS - not stated
 Abbreviations: AAFQ - Arizona Activity Frequency Questionnaire, AAS - Active Australia Survey, Accel. - accelerometer, BRFSS - Behavioral Risk Factor Surveillance System, Cal. - calorimetry, CABG - Coronary Artery Bypass Graft, CAQ - College Alumnus Questionnaire, COPD - chronic obstructive pulmonary disease, DLW - doubly labeled water, F - female, Fullerton - Fullerton Physical Activity Questionnaire, HRM - heart rate monitor, IPAQ - International Physical Activity Questionnaire, kcal - kilocalorie, kJ - kilojoules, KPAS - Kaiser Physical Activity Survey, LTPAQ - Leisure Time Physical Activity Questionnaire, M - male, MAQ - Modifiable Activity Questionnaire, MET - metabolic equivalent, MJ - mega joules, min - minute, Minnesota - Minnesota Leisure Time Physical Activity Questionnaire, MOSPA - Monica Optional Study of Physical Activity questionnaire, MPS - moderate physical activity, PAAT - Physical Activity Assessment Tool, PAD - physical activity diary, PAEE - physical activity energy expenditure, PAFQ - Physical Activity Frequency Questionnaire, PAL - physical activity log, PAQ - physical activity questionnaire, PAR - physical activity recall, Ped. - pedometer, SAFE - Survey of Activity, Fitness, and Exercise, SSAAQ - Sub-Saharan Africa Activity Questionnaire, Stanford - Stanford Physical Activity Questionnaire, STAR - Short Telephone-administered Activity Recall, Tecumseh - Tecumseh Community Health Survey, TEE - total energy expenditure, Vhard - very hard, VPA - vigorous physical activity, WHIQ - Women's Health Initiative Questionnaire, wk - week, YPAS - Yale Physical Activity Survey

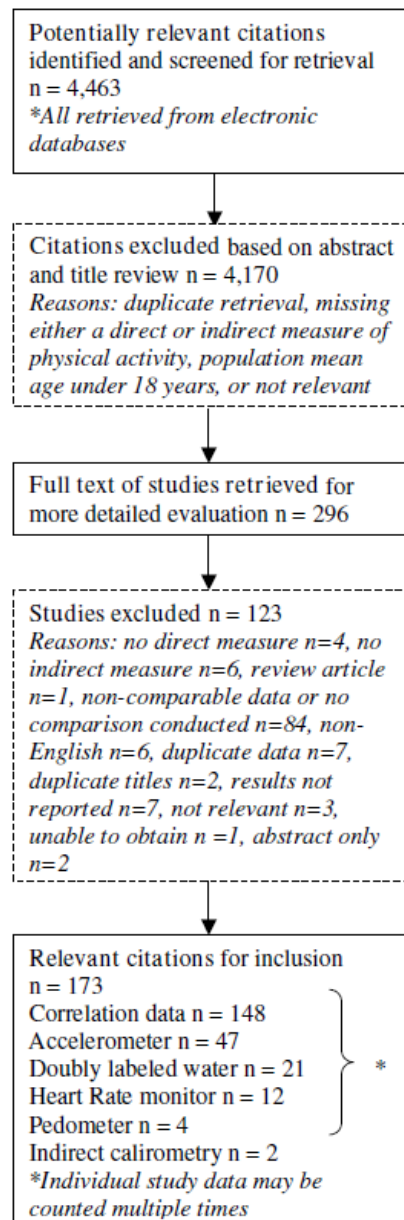


Figure 1
Results of the literature search.

Data abstraction identified three articles and two dissertations that analyzed and reported duplicate data in multiple papers [184-188]. Authors of suspected duplications were contacted and in cases where several publications reported the same analyses from the same data source, only one study per data source/analysis was retained in order to avoid double counting. Studies were retained based on the most pertinent and most recent data, as well as the largest sample size. Studies included were published over a 24-year period from 1983 to 2007. All studies were written in English. Nineteen of the studies used randomized controlled trial designs [22,24,26,28,30,50,53,61,84,91,124,148,149,163,165,171,181] and all others used observational designs (e.g. case control, cross-sectional, longitudinal). All included studies were published as journal articles except for 19 dissertations [16,24,30,34,38,45,49,61,64,69,71,73,74,78,99,107,117,163,171].

Participants in the studies ranged from 10 to 101 years of age. Although the focus of the review was on those aged 18 and over, studies that had a range of ages less than 18 years were not excluded as long as the mean age of the sample was over 18 years. Sample sizes ranged from a low of six [21] to a high of 2,721 in Craig *et al.*'s work that assessed the validity of the International Physical Activity Questionnaire (IPAQ) [35]. There were a greater number of studies reporting on female-only data than studies reporting on male-only data.

A total of five direct measures were used in the assessment of physical activity and included: accelerometers, DLW, indirect calorimetry, HRM, and pedometers. Of the studies included in the synthesis of directly comparable data (Table 2), accelerometers were the most frequently used direct measure and indirect calorimetry was the least used. A variety of self-report measures were employed, but the seven-day physical activity recall (7-day PAR) [189] was the most cited. Over half of the studies reported that the self-report and directly assessed physical activity levels were measured over the same length of time (e.g. seven days) and over the same period of time (i.e. no time lag between measurements). There were also a considerable number who reported measurements over the same period of time, but that did not measure the same length of time (e.g. self-report over seven days, directly measured over three days). Eleven of the studies in Table 2 lacked any mention of time [59,131,135,138,143,159,160,164,177,178,183].

Risk of bias assessment

Risk of bias was assessed for all included studies (n = 173) including those reporting only correlation data. The range of items met on the modified Downs and Black tool was 8 to 15 (maximum possible count was 15) with a mean of

11.7 ± 1.2. Results of the risk of bias assessment indicated that 38% (65/173) of the studies had lower quality (based on a median split count of < 12/15). All studies were given maximum points for describing study objectives. All but one study scored maximum points for describing the main outcomes to be measured and the interventions used (including comparison methods between measures). Although most studies carried out some sort of significance testing on results, most did not report the actual probability values associated with the estimates or their associated measures of random variability (e.g. standard error or confidence intervals). Most studies obtained a high number of items on the reporting section (maximum count of 8) with a mean of 6.9 ± 0.9.

The external validity section of the risk of bias assessment had a maximum count of three and consisted of reporting on the representativeness of the subjects and the testing conditions. Almost all of the studies (166/173) reported that the staff, places and facilities where the participants were tested were representative of the testing conditions that would be expected by most individuals (e.g. real-life and free-living situations). However, 87% (151/173) of the studies did not report on the representativeness of the subjects asked to participate in the study and 95% (165/173) of the studies failed to report on the representativeness of those who were prepared to participate (enrolled) compared to the entire population from which they were recruited (received a score of 0). As a result, the external validity ratings of most studies were poor with a mean of 1.1 ± 0.5.

In order to obtain the maximum number of items (four) in the internal validity section, studies must have reported whether any of the results of the study were based on "data dredging", whether the analyses adjusted for any time lag between the two measurements or different lengths of follow-up, whether the statistical tests used to assess the main outcomes were appropriate, and whether the main outcome measures were accurate (valid and reliable). Internal validity item counts were generally high with the majority of studies having obtained a four.

A qualitative analysis was conducted on the top seven (scores of 14 and 15 out of 15) and lowest seven studies (8 and 9 out of 15) based on scores from the risk of bias assessment. No conclusive patterns were identified from this analysis. The results from the accelerometer studies were further examined, as this was the only group of studies with a good distribution of low and high quality studies based on the accelerometer median split of bias scores. Findings from this analysis did not identify any clear patterns in the differences in agreement between physical activity measured by self-report compared to accelerometer when grouped by low and high quality.

Data synthesis

One hundred and forty-eight studies [10,11,13-157,190] reported correlation statistics between self-report and direct measurements of physical activity. Figure 2 is a plot of all extracted correlations and shows that overall, there is no clear trend in the degree of correlation between self-reported and directly measured physical activity, regardless of the direct method employed. Overall, correlations were low-to-moderate with a mean of 0.37 (SD = 0.25) and a range of -0.71 to 0.98. Mean correlations were higher in studies reporting results for males-only ($r = 0.47$) versus studies reporting results for females-only ($r = 0.36$), but with very similar ranges (males: -0.17 to 0.93 vs. females: -0.17 to 0.95).

Seventy-four studies contained comparable data on the measurement of physical activity based on self-report and directly measured values. Table 2 describes these studies and their subcomponents. Percent mean differences were calculated for all of these studies and are presented as forest plots in Figures 3 to 8. Negative values indicate that self-report estimates were lower than the amount of physical activity assessed by direct methods while positive values indicate values that are higher. Sixty percent of the percent mean differences indicated that self-reported physical activity estimates were higher than those measured by direct methods.

Studies with extreme percent mean differences ($\geq 400\%$) were removed from the forest plots for clarity purposes [11,139,151,181]. All outlying data were from studies where physical activity was categorized by level of exertion (e.g. easy, moderate, vigorous) and outliers represent physical activity data categorized as vigorous or of high energy expenditure. While not all data categorized as vigorous had percent mean differences $\geq 400\%$, a pattern emerged whereby greater percent mean differences between the self-report and direct measures was larger for vigorous levels of physical activity than for light or moderate activities [11,44,56,134,139,151,175,181,182].

Percent mean differences were examined separately for the five different direct measures. Accelerometers were the most used direct measure. Self-report measures of physical activity were generally higher than those directly measured by accelerometers (Figures 3 to 5). Studies reporting data for males and females combined ($n = 58$) had a mean percent difference of 44% (range: -78% to 500%), with similar findings for the male-only data ($n = 32$) (mean: 44%, range: -100% to 425%). However, female-only data ($n = 60$) identified that, on average, females self-reported higher levels of physical activity compared to accelerometers with a mean percent difference of 138% (range: -100% to 4024%).

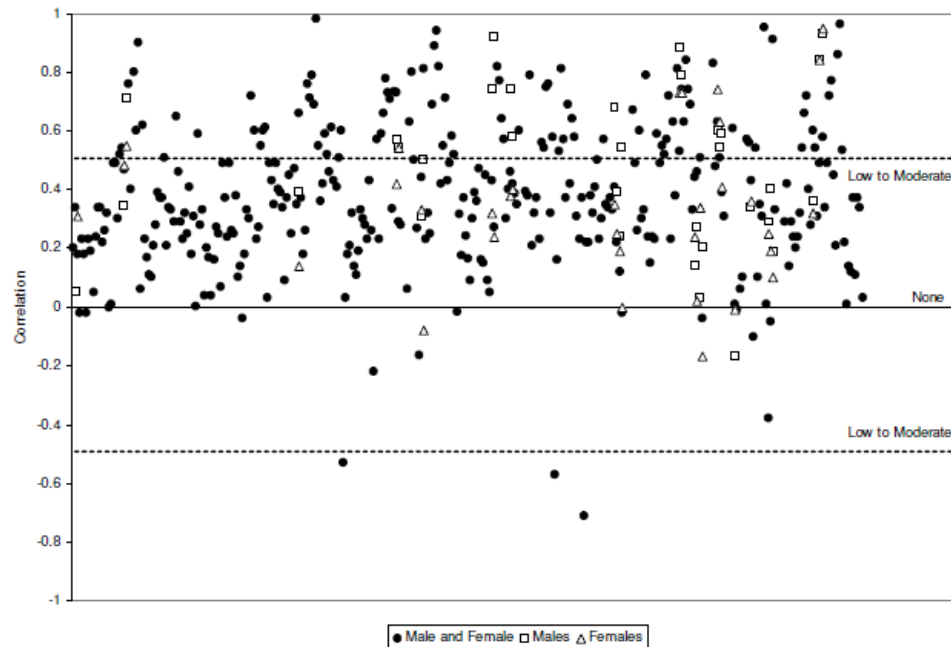


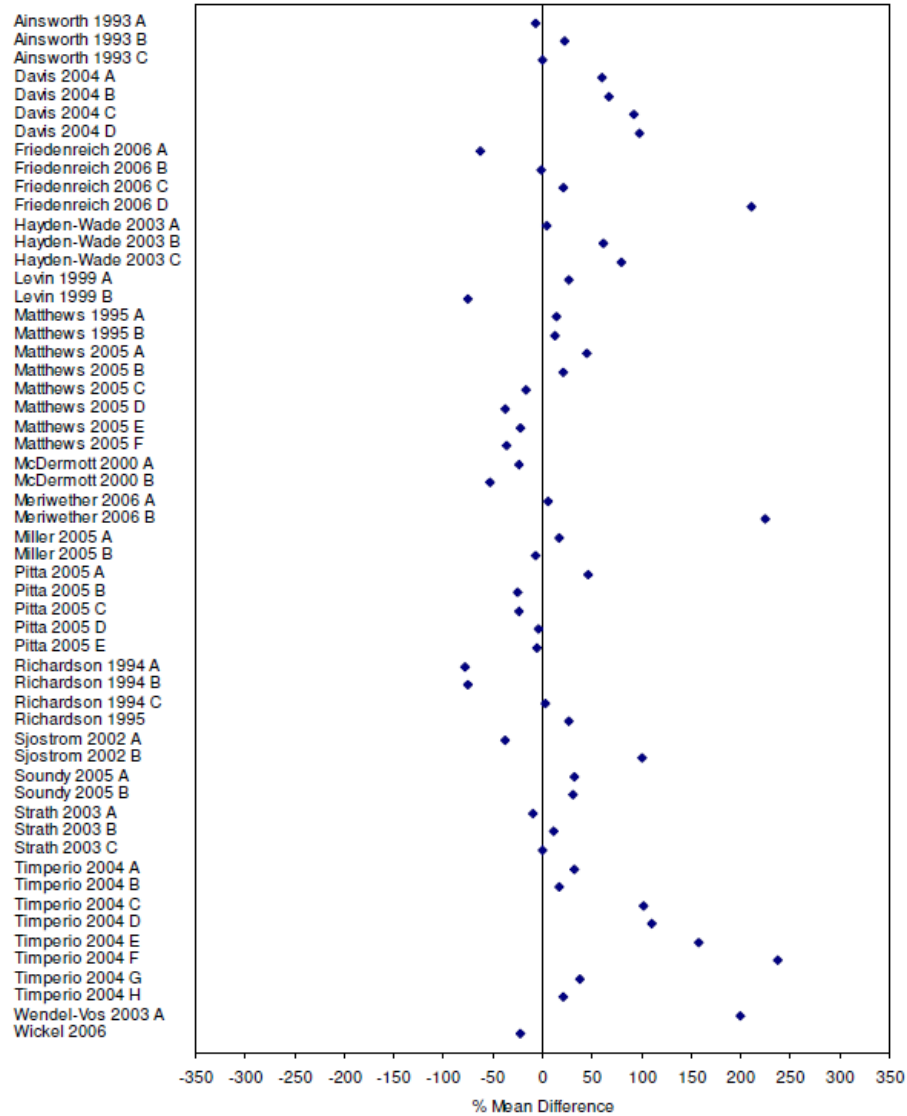
Figure 2
Scatter plot of all correlation coefficients between direct measures and self-report measures.

The second-most common direct measure employed was DLW and comparable data with self-report measures are presented in Figures 6 to 8. Studies reporting on combined male and female data ($n = 6$) indicated that self-report measures of physical activity were lower when compared to DLW measures with a mean percent difference of -9% and a range of -1% to -26%. Results for male-only ($n = 16$) and female-only ($n = 23$) data were less distinct with percent mean differences and ranges of -4.5% (-78% to 37%) and 7% (-58% to 113%), respectively.

A greater number of HRM and self-report comparisons were observed for studies with both male and female participants ($n = 11$) or female-only populations ($n = 13$) versus male-only populations ($n = 3$). Female-only results showed a general trend toward higher levels of self-reported physical activity (mean 11%, range: -5% to 45%), while the male-only (mean -9%, range: -24% to 5%) and combined (mean -2%, range: -21% to 67%) data had a greater number of studies with lower self-reported physical activity levels when compared to results of HRM.

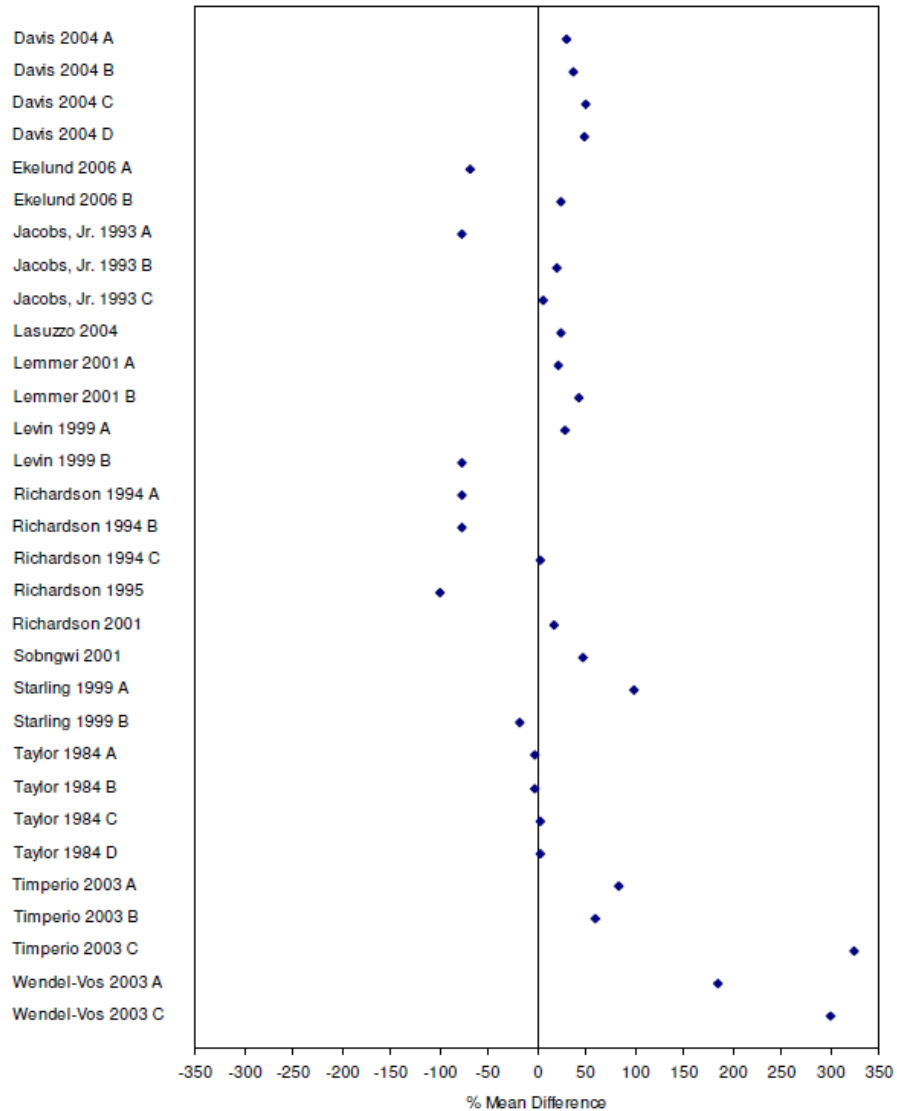
Pedometers and indirect calorimetry were the least commonly used direct measures for studies with comparable data. There were a total of eight comparisons from four studies for pedometers and 15 from two studies for indirect calorimetry (Figures 6 to 8) making it difficult to draw conclusions with regard to patterns of agreement between the self-report and direct measures. However, seven [19,75,76,167] of the eight pedometer comparisons reported higher levels of physical activity by self-report when compared to the pedometer results. The eighth comparison [19] which involved female-only data saw no difference between the two measures. The indirect calorimetry results were less straightforward and presented no obvious patterns in agreement.

Subgroups were qualitatively examined to assess whether any differences existed in the degree of agreement between self-reported and directly measured physical activity. No clear patterns emerged within studies reporting on elderly (range or mean ≥ 65 years) populations [23,73,77,92,105,116,174] or within studies reporting on



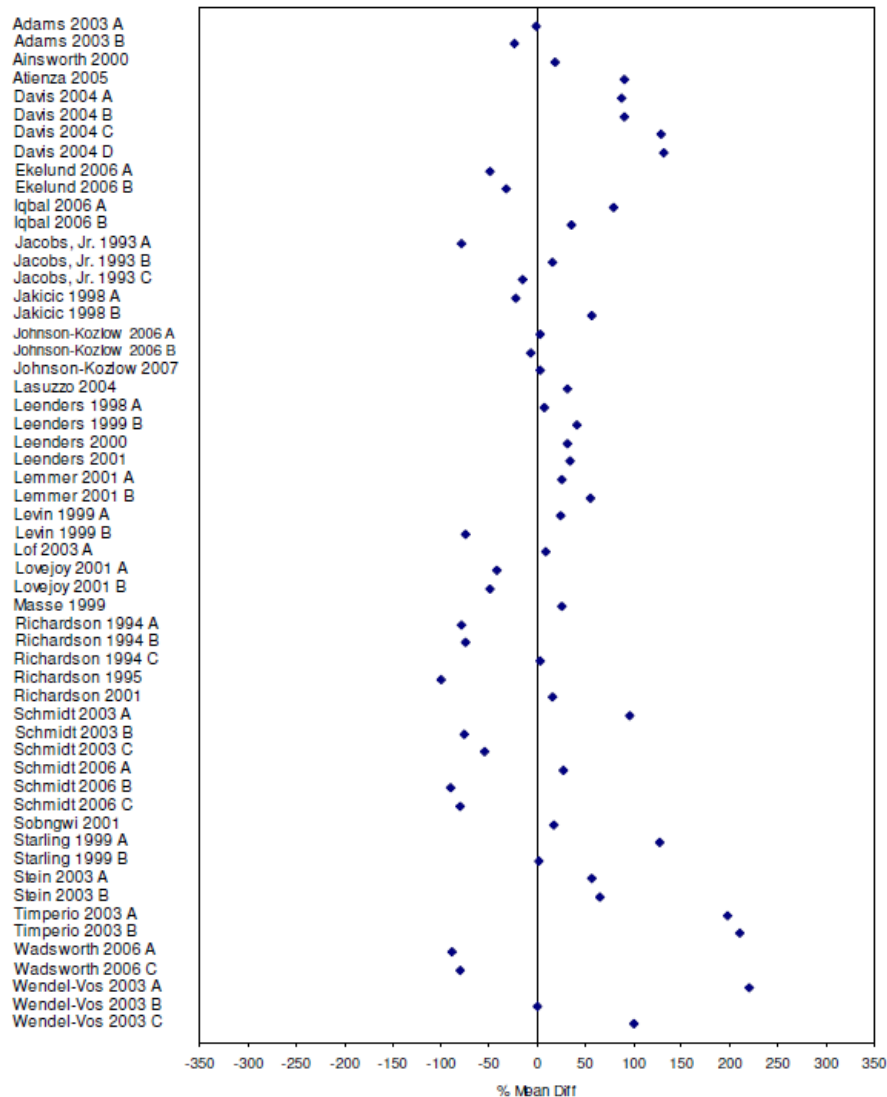
*Values $\geq 400\%$ are not displayed

Figure 3
Forest plot of percent mean differences between accelerometers and self-report measures from studies reporting combined results for males and females (excluding outliers $\geq 400\%$).



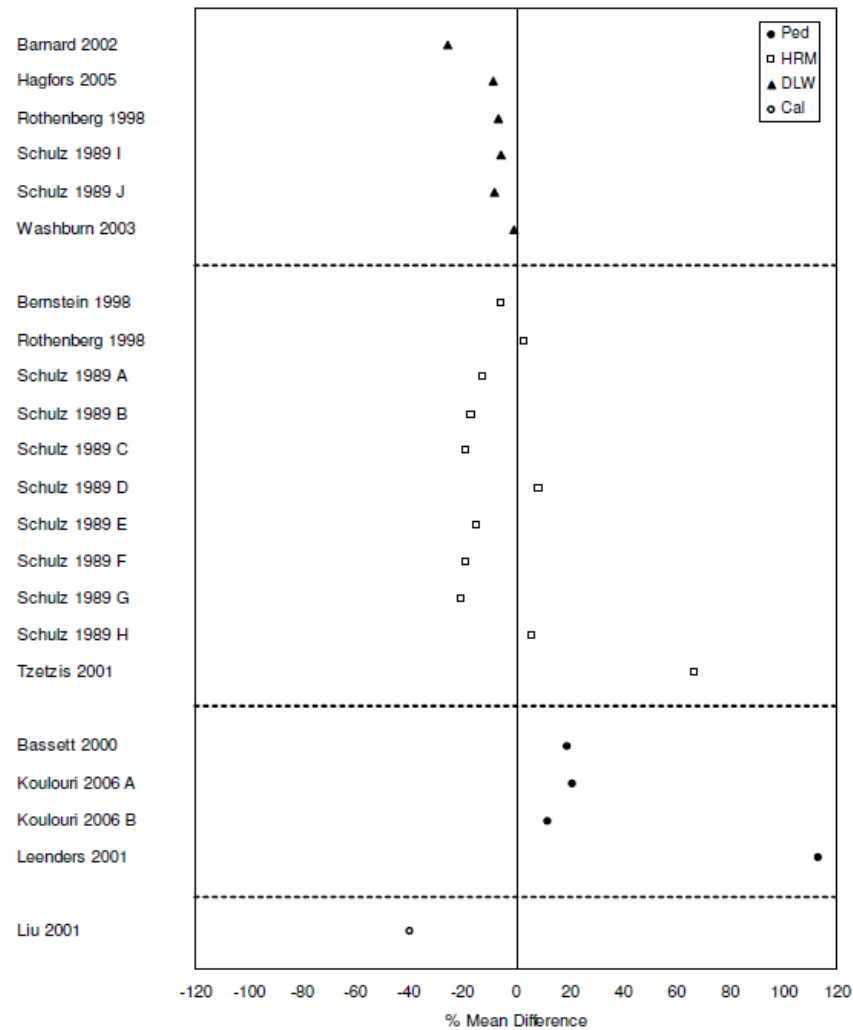
*Values $\geq 400\%$ are not displayed

Figure 4
Forest plot of percent mean differences between accelerometers and self-report measures from studies reporting results for males only (excluding outliers $\geq 400\%$).



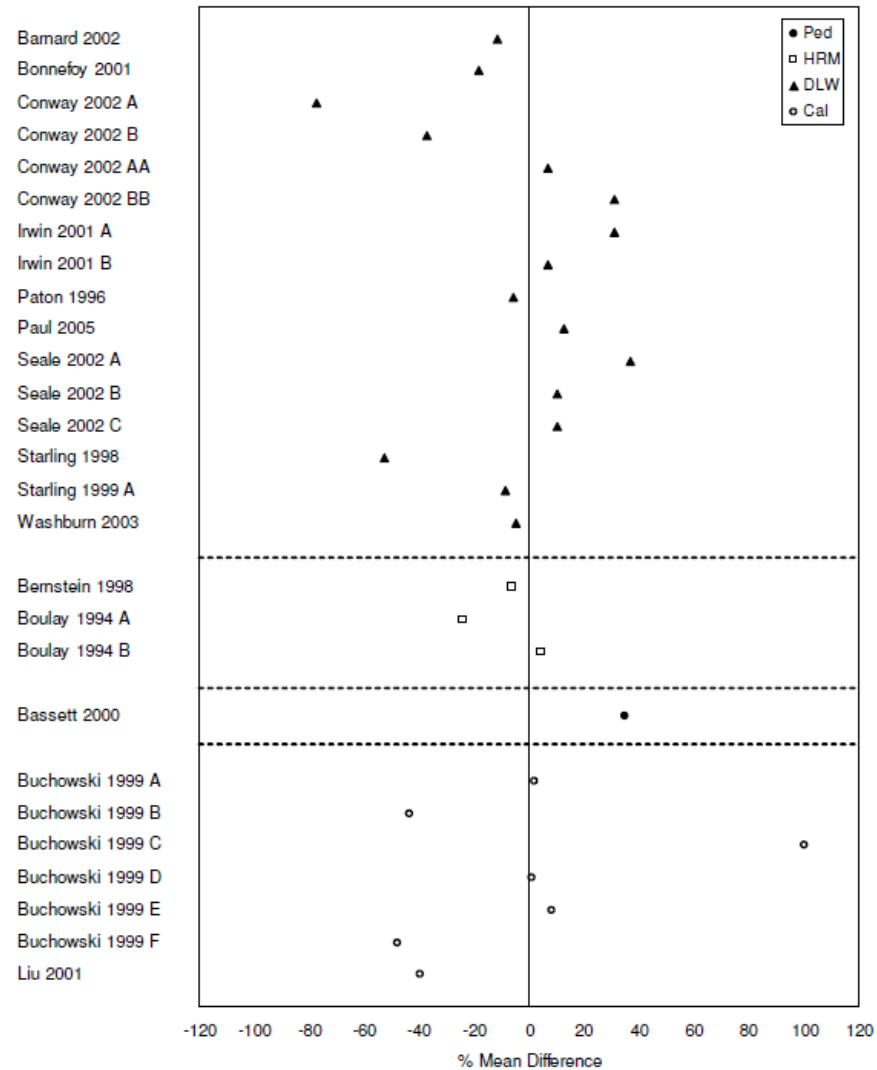
*Values $\geq 400\%$ are not displayed

Figure 5
Forest plot of percent mean differences between accelerometers and self-report measures from studies reporting results for females only (excluding outliers $\geq 400\%$).



*Values $\geq 400\%$ are not displayed

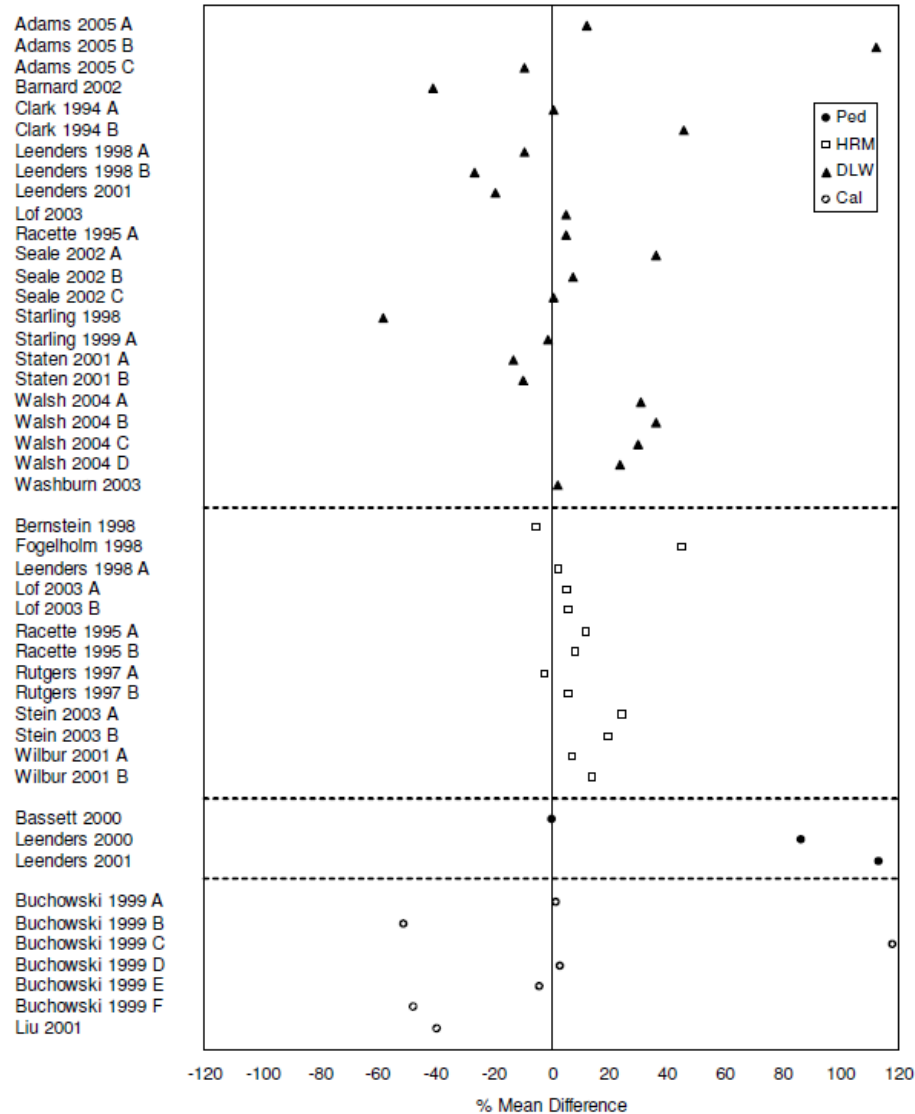
Figure 6
Forest plot of percent mean differences between doubly-labeled water, heart rate monitoring, pedometers, and indirect calorimetry and self-report measures from studies reporting combined results for males and females (excluding outliers $\geq 400\%$). Cal – calorimetry, DLW – doubly labeled water, HRM – heart rate monitor, Ped – pedometer.



*Values $\geq 400\%$ are not displayed

Figure 7

Forest plot of percent mean differences between doubly-labeled water, heart rate monitoring, pedometers, and indirect calorimetry and self-report measures from studies reporting results for males only (excluding outliers $\geq 400\%$). Cal – calorimetry, DLW – doubly labeled water, HRM – heart rate monitor, Ped – pedometer.



*Values $\geq 400\%$ are not displayed

Figure 8
Forest plot of percent mean differences between doubly-labeled water, heart rate monitoring, pedometers, and indirect calorimetry and self-report measures from studies reporting results for females only (excluding outliers $\geq 400\%$). Cal – calorimetry, DLW – doubly labeled water, HRM – heart rate monitor, Ped – pedometer.

different time lags and periods of measurement. Few studies with comparable data reported exclusively on overweight/obese populations, but amongst those captured, the majority of studies reported higher levels of physical activity by self-report compared to the direct measures [139,143,148,163-165,172]. However, it was not possible to compare the overweight/obese percent mean differences to those reported in general populations.

Meta-analyses were not possible due to the substantial heterogeneity in units of reporting for physical activity measured by the various self-report and direct methods across the studies, and the significant lack of data with comparable units across measures. As a result, we were unable to determine the sensitivity of the values and the associated measures of error for the studies. Overall effect sizes to summarize the magnitude of discrepancy across the various measures of physical activity could therefore not be calculated.

Discussion

To the authors' knowledge this review represents the most comprehensive attempt to examine the relationship between self-report and directly measured estimates of adult physical activity in the international literature. Risk of bias was assessed and identified that just over one third of the studies had lower quality based on their description of the methods and external and internal validity. Overall, no clear trends emerged in the over- or underreporting of physical activity by self-report compared to direct methods. However, some results suggest that patterns in the agreement between self-report and direct measures of physical activity may exist, but they are likely to differ depending on the direct methods used for comparison and the sex of the population sampled. Interestingly, findings also identified that studies which categorized physical activity by level of exertion (e.g. light, moderate, vigorous) exhibited a trend wherein these categorized studies saw the mean percent differences between the self-report and direct measures increasing with the higher category levels of intensity (i.e. vigorous physical activity). These larger differences may reflect a problem with self-report measures attempting to capture higher levels of physical activity, or problems with participant interpretation and recall.

Many of the studies tested the relationship between self-report and direct measures by using a correlation coefficient, but this is limited as correlation is only able to measure the strength of the relationship between two variables and cannot assess the level of agreement between them, as well as ignoring any bias in the data [191]. A more useful approach, the Bland-Altman method, provides a means for assessing the level of agreement between self-report and direct measures by deriving the mean dif-

ference between the two measures and the limits of agreement. If the two measures possess good agreement and measure the same parameter of physical activity, then the cheaper and less invasive self-report methods may be valid substitutes for direct methods.

A meta-analysis would have allowed us to estimate the overall effect sizes for each of the direct measures and undertake a sensitivity analysis to further understand the degree of bias in the studies. Unfortunately, inconsistent methods and reporting among the studies included made such an analysis methodologically inappropriate. Further research in this area would benefit from greater consistency in the units of reporting and the methods used to facilitate comparisons. For instance, many studies did not report results using the same units, so estimates of agreement between the self-report and direct measures could not be computed. There was also an inconsistency in the number of days measured and the time lag between the self-report and direct measures. It is recommended that authors present their results using the same units for both measures (e.g. minutes/day, kcal/day), that the two measurements assess physical activity for and over the same time period, and that all relevant data including a mean and measurement of variance (i.e. standard deviation, standard error) be included in all reports.

Adhering to consistent reporting criteria would increase the comparability of results across studies and enable the calculation of overall effect sizes. At the population level, over- or underestimation of physical activity prevalence has important implications as these data are used to monitor physical activity trends, determine spending for research and physical activity interventions and programming, and to estimate physical inactivity-related risks of disease. Future studies may wish to refer to the updated Compendium of Physical Activities [192] which provides a coding scheme to classify physical activity by rate of energy expenditure. The Compendium offers a means to increase the comparability of results between self-report and direct measures, as well as across studies.

A lack of a clear trend amongst the differences between the self-report methods for assessing physical activity and the more robust direct methods is of concern, especially when trying to establish whether the measures could be used interchangeably. There are several possible explanations for the lack of a clear trend in the data. Many self-report instruments (such as the 7-day PAR) may not have the ability to account for activities of less than 10 minutes in duration or those with a level of exertion lower than brisk walking [193], whereas some of the direct methods (such as DLW) may capture all forms of physical movement. However, it is important to recognize that other direct measures such as accelerometers are unable to capture cer-

tain types of activities such as swimming and activities involving the use of upper extremities. Our findings demonstrate the inherent difficulty self-report measures possess when trying to accurately capture data at various levels of exertion. Compared to direct measures, self-report methods appear to estimate greater amounts of higher intensity (i.e. vigorous) physical activities than in the low-to-moderate levels.

Just as with some self-report measures not being able to capture all forms of activity, some direct measures may capture non-physical activity. For instance, the DLW technique is an accurate assessment of total energy expenditure, but it does not only capture physical activity, but rather all forms of energy expenditure including resting energy expenditure and the thermogenic effect of food. DLW is therefore expected to overestimate physical activity unless corrections are made. These and other measurement errors may inflate the between-individual variability in the energy expended in physical activity [194]. Finally, direct methods may be too sensitive to small errors derived from the various calibration methods employed and the equations used to define and categorize physical activity.

It is important to take into account all of these factors when comparing self-report and direct measures of physical activity. In specific circumstances (e.g. at different levels of activity) these two methods may not be comparable as they are not able to capture the same parameters of physical activity. Self-report measures may not be able to accurately capture all levels of activity, but they may be able to capture how difficult an individual perceives an activity to be and the type of activity that is undertaken (e.g. leisure, work, transportation). Direct measures, on the other hand, may be more able to capture some of the information not captured in self-report methods (e.g. incidental daily movement and lower intensity activities), but also possess their own limitations such as the inability to capture arm movements and various types of physical activity (e.g. swimming).

Concern regarding the discrepancy between self-reported and directly measured physical activity were recently reported by Troiano and colleagues who examined data from the 2003–2004 National Health and Nutrition Examination Survey (NHANES) which contained the first direct measurements of physical activity in a nationally representative U.S. sample [195]. They compared self-reported adherence estimates of physical activity recommendations with those directly measured by accelerometer. Their findings identified that self-reported adherence estimates were much higher than those measured by accelerometer. The authors hypothesize that the overestimation may be a result of respondents misclassifying sed-

entary or light activity as moderate or from underestimations of activity duration by the accelerometers.

Other factors, such as those related to the population under study, may influence the ability of self-report and direct methods to capture the same measurement. For example, our findings show that in studies with a focus on overweight/obese individuals, self-reported physical activity was overestimated in all cases except for DLW studies involving combined male/female and male-only data. Our results differed from those reported by Irwin, Ainsworth and Conway (2001) [58]. Their study consisted of 24 males and used DLW to compare energy expenditure estimates with those obtained by physical activity record and the 7-day PAR. The investigators observed an overestimation of energy expenditure in participants with higher body fat using the physical activity record, but not the 7-day PAR. A comparison of the same sample by body mass index (BMI) identified that those with a BMI ≥ 25 kg/m² overestimated energy expenditure from physical activity records and the 7-day PAR. In confirmation of the trends within our accelerometer data, a recent study (published after our search) of 154 subjects compared a physical activity questionnaire to accelerometry data and identified that the accuracy of the physical activity questionnaire was higher for males than females and for those with a lower BMI [196]. It is likely that a response bias exists due to social desirability, and influences the degree of over-reporting of physical activity by overweight/obese individuals. Future research and synthesis is needed to identify whether a bias does in fact exist and if so, whether it differs by gender, and to what extent.

This review had limitations that should be considered when examining the results. First, the sample was limited to studies that included directly comparable data between self-report and direct measures (same units for both measures) or a comparison by way of correlation. Access to primary data from each study was not feasible; therefore, we relied upon reported comparisons and the means of measured physical activity. This reduced the number of studies with reported measures of physical activity by self-report and direct methods and limited our ability to accurately assess the degree of agreement between the two measures. However, when possible we converted non-comparable units to increase the number of studies used. The review did not assess the agreement between proxy-reported physical activity and direct measures. Proxy-report data are less prevalent but is an important means for assessing physical activity in sub-populations such as those who are chronically ill, disabled, or elderly, and who are unable to self-report on their own physical activity levels. Further research is required to assess the validity of proxy-report measures of physical activity when com-

pared to direct methods. Finally, this review did not discern between differences in study protocols related to calibration, cut-points, or collection of the measurements and other population specific characteristics.

Conclusion

In conclusion, this review provides an objective summary of the difference in physical activity levels assessed via self-report methods compared to directly measured physical activity. The results may assist researchers considering the use of self-report or direct measurement methods and serves as a note of caution that self-report and directly measured physical activity can differ greatly. Overall there were no clear trends in the degree to which physical activity measured by self-report and direct measures differ. The strength of trends differed by the direct method employed and by the gender of the population sampled. One-third of the studies were of poor quality with most studies having failed to report actual probabilities or measures of variability for estimates and the representativeness of their samples. The costs and benefits of direct measurement need to be considered in any study in order to determine if the added resources required for personnel training and laboratory analyses justify the possible increase in the precision of results. At this time, it is not possible to draw any definitive conclusions concerning the validity of self-report measurements compared to various direct methods, but caution should be exerted when comparing studies across methods.

Competing interests

The authors declare that they have no competing interests.

Authors' contributions

SAP carried out the design, bibliographic search, article screening, data abstraction and synthesis and drafted and edited the manuscript. KBA participated in its design and coordination and helped edit the manuscript. MH participated in article screening, data abstraction and editing of the manuscript. JH participated in data abstraction, data synthesis and helped edit the manuscript. SCG participated in the design of the study, provided methodological input, and assisted in the editing of the manuscript. MT conceived the study, and participated in its design and coordination and helped to draft the manuscript. All authors read and approved the final manuscript.

Acknowledgements

The authors would like to thank David Moher for insightful guidance in the development of the research methods and Margaret Sampson for her technical assistance with the search strategy. The first author acknowledges financial support from Statistics Canada for the preparation of the paper.

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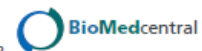
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CHAPTER 5: MANUSCRIPT 3

This manuscript was written and published in accordance to the specifications for submission to the peer-reviewed *International Journal of Environmental Research and Public Health*. It appears here in its published format.

Title:

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Suggested citation:

Prince S.A., Kristjansson E.A., Russell K., Billette J.-M., Sawada M., Ali A., Tremblay M.S., Prud'homme D. A Multilevel Analysis of Neighbourhood Built and Social Environments and Adult Self-Reported Physical Activity and Body Mass Index in Ottawa, Canada. *International Journal of Environmental Research and Public Health*. 2011; 8(10):3953-3978.

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Article

A Multilevel Analysis of Neighbourhood Built and Social Environments and Adult Self-Reported Physical Activity and Body Mass Index in Ottawa, Canada

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Received: 6 July 2011; in revised form: 27 September 2011 / Accepted: 4 October 2011 /
Published: 14 October 2011

Abstract: Canadian research examining the combined effects of social and built environments on physical activity (PA) and obesity is limited. The purpose of this study was to determine the relationships among built and social environments and PA and

overweight/obesity in 85 Ottawa neighbourhoods. Self-reported PA, height and weight were collected from 3,883 adults using the International PA Questionnaire from the 2003-2007 samples of the Rapid Risk Factor Surveillance System. Data on neighbourhood characteristics were obtained from the Ottawa Neighbourhood Study; a large study of neighbourhoods and health in Ottawa. Two-level binomial logistic regression models stratified by sex were used to examine the relationships of environmental and individual variables with PA and overweight/obesity while using survey weights. Results identified that approximately half of the adults were insufficiently active or overweight/obese. Multilevel models identified that for every additional convenience store, men were two times more likely to be physically active (OR = 2.08, 95% CI: 1.72, 2.43) and with every additional specialty food store women were almost two times more likely to be overweight or obese (OR = 1.77, 95% CI: 1.33, 2.20). Higher green space was associated with a reduced likelihood of PA (OR = 0.93, 95% CI: 0.86, 0.99) and increased odds of overweight and obesity in men (OR = 1.10, 95% CI: 1.01, 1.19), and decreased odds of overweight/obesity in women (OR = 0.66, 95% CI: 0.44, 0.89). In men, neighbourhood socioeconomic scores, voting rates and sense of community belonging were all significantly associated with overweight/obesity. Intraclass coefficients were low, but identified that the majority of neighbourhood variation in outcomes was explained by the models. Findings identified that green space, food landscapes and social cohesiveness may play different roles on PA and overweight/obesity in men and women and future prospective studies are needed.

Keywords: physical activity; obesity; neighbourhood; environment; population health

1. Introduction

Physical inactivity is a known risk factor for several chronic illnesses as well as premature mortality [1]. Even with physical activity's (PA) known protective effects, average Canadian levels continue to fall short of recommendations. Data from the 2009 Canadian Community Health Survey (CCHS) showed that 51% of Canadian women and 44% of men reported that they were inactive ($<1.5 \text{ kcal} \cdot \text{kg}^{-1} \cdot \text{day}^{-1}$) in their leisure time [2]. In addition, 59% of Canadian men and 44% of women reported that they were overweight or obese [3].

Historically, studies of PA have focused on individual demographic factors such as age, sex, education, and income [4]. However, these factors cannot fully explain the rise in the rates of physical inactivity and obesity seen in the last few decades [5] and the social and built environments have been posited as possible contributors to current trends [6].

Much of the previous work on the association between the built environment and PA has focused on self-report methods of perceived access to the environment [7]. Generally, results show that higher perceived access to recreation resources is associated with an increased likelihood of PA, but with mixed evidence [8]. Objectively measured studies were also mixed, but generally reported positive associations between PA and number of, and distance to, walking/bike paths; recreation/fitness

facilities; and parks and green spaces [4,7,9]. While results are also heterogenous, studies suggest that overweight and obesity are generally related to lower access to environmental supports [10].

While the built environment may have an independent effect on PA and overweight/obesity, the social environment has the capacity to mediate the effects of the built environment and exerts its own influence through such factors as recreation and urban planning policies and funding, safety of facilities and resources, and social support for healthy behaviours such as regular PA. Neighbourhood social factors are often assessed using area-level measures such as average income levels or area deprivation [11]. Several studies have reported inverse relationships between area deprivation and access to PA facilities [12-14]. Evidence also suggests that area deprivation is associated with higher rates of inactivity [14-16] and obesity [17,18]. In addition, research has shown that other social factors such as neighbourhood social capital, social cohesion and safety also have the capacity to influence levels of PA [19-22].

Research examining the influences of the built and social environments on rates of PA has largely occurred in non-Canadian populations [23]. Furthermore, sex-based analyses are often lacking in these studies [24] and conclusions regarding possible sex differences in environmental determinants are not yet possible [25]. To address gaps in previous research this study assessed objectively measured built and social environmental factors and their relationships with self-reported PA and overweight/obesity using a sex-specific multilevel model while controlling for individual-level variables in a large random sample of adults within the City of Ottawa. Our hypothesis was that inactivity and overweight/obesity rates would be highest in neighbourhood environments that were not conducive for recreational PA, such as areas with a low number of facilities, parks, and walking paths, limited green space, or where crime rates were higher, and where socioeconomic status and social capital were lower.

2. Methods

A multilevel framework was used to examine the associations between individual- and neighbourhood-level characteristics with PA and overweight/obesity levels in 85 City of Ottawa neighbourhoods. The study received ethical approval from the University of Ottawa's Health Science Research Ethics Board (#H10-08-11) and the City of Ottawa Public Health Research Ethics Board (#128-09).

2.1. Rapid Risk Factor Surveillance System (RRFSS)

The RRFSS (www.rfss.on.ca) is an annual cross-sectional survey used to gather surveillance data of importance to public health in Ontario municipalities. The RRFSS survey employed modified random digit dialling to produce a sample of households. Approximately 85% of the completed interviews formed a sample representative of the Ottawa population. The other 15% of the sample comprised an over-sample of parts of the city that according to Statistics Canada, have a higher concentration of people with a French mother tongue. Within households, interviews were completed with an adult (≥ 18 years with the next birthday). Respondents who were unable to speak English or French, who were physically or mentally incapacitated or living in institutions, were excluded from participation.

Five years of data from RRFSS (2003–2007 samples) were combined to create a dataset of 5,025 respondents. Survey year aggregation allowed for more accurate model estimates. Pregnant women, respondents missing any of the variables (not including sense of community belonging) used in the models, those living outside of the defined study neighbourhoods, and neighbourhoods with a cell count of less than five were excluded from the analyses. After excluding these cases, the final unweighted sample used for analyses was 3,383 respondents. The distribution of the sample across the five survey years is as follows: 714 (21%) in 2003; 745 (22%) in 2004; 689 (20%) in 2005; 613 (18%) in 2006; and 622 (18%) in 2007. The response rates for the survey years are as follows: 60% (2003); 59% (2004); 64% (2005); 66% (2006); and 59% (2007).

2.2. Ottawa Neighbourhood Study (ONS)

Built and social environment characteristics were collected by the ONS; a large study of neighbourhoods and health outcomes in Ottawa, Canada. Briefly, neighbourhoods were defined based on natural barriers, similarity in socioeconomics and demographics, Ottawa Multiple Listing Services (real estate) maps, and participatory mapping feedback from community members and experts [26]. Most neighbourhoods contained >4000 people. Objectively measured built environment data were collected from 2006 to 2008 using the following methods: 1) 2006 Canadian census household data; 2) GIS data from DMTI Spatial Inc., the City of Ottawa, and the National Capital Commission (NCC); 3) telephone contact with businesses; 4) web-based research (e.g., Canada 411, websites, Google Maps); 5) team knowledge of local resources; and 6) field research and validation (e.g., car, walking, bicycle). A further in-depth description of methods related to the ONS and its derived variables is available elsewhere [26].

2.3. Neighbourhood Environments

The neighbourhood built environment related to recreation and food availability was assessed using objective variables geocoded to the 85 Ottawa neighbourhoods from the ONS.

2.3.1. Recreation Environment

Recreational facilities were defined using the North American Industry Classification System–Canada (NAICS) Code 71 [27]. For the purposes of the ONS, recreation facilities were only considered if they provided activities for free or at minimal cost (non-commercial) and included community centers providing free access to facilities. The set of recreation measures by neighbourhood included total bike and walk path length (km), counts per 1,000 people of indoor recreation facilities, winter outdoor facilities, summer outdoor facilities, park area (km²), and area of green space (km²). The neighbourhood recreation variables were derived using a combination of GIS capabilities, including address geocoding, spatial query, union and intersection overlay to integrate recreation data found in the numerous layers from the NCC, DMTI Spatial Inc., Statistics Canada 2006 Road Network File, and the City of Ottawa [28]. Of note, green space managed by the City of Ottawa or the NCC was further defined as a ‘park’ and included in park area, while non-managed areas were captured by green space. All of the environment data except for path length were presented per 1,000

people in the neighbourhood to better capture the demand on the facilities rather than raw counts. The recreation environment data were added to the models as continuous variables.

2.3.2. Food Environment

Within the ONS, objective measures of the food environment were identified and classified into five types of food retail outlets according to the NAICS [27]. The ONS compiled data from DMTI Canada Inc., the Ottawa Retail Survey, Canada 411 Business, and web pages of major grocery store, convenience store and fast food chains in Ottawa in addition to field research and local knowledge. The food retail outlets were examined using density (*i.e.*, counts per 1,000 people) and included grocery, convenience and specialty food stores, as well as fast food and full service restaurants. Grocery stores (NAICS code 445110) included both supermarkets and grocery stores with a general line of foods and a full line of fruits, vegetables and fresh meats. Specialty stores (NAICS code 4451) concentrated on specialised food types such as meat stores, seafood stores, fruit and vegetable stores, bakeries, candy and nut stores, dairy stores, bulk food stores, organic food stores, health food stores, and ethnic food stores. Convenience stores (NAICS codes 44512, 445120 and 44711) had a limited line of convenience products (*e.g.*, milk, snack food, dried/canned food) and included gas bars with a convenience store. Fast food outlets (NAICS code 722210) provided limited service including ordering at a counter and paying for food before its delivery and included mall ‘food courts’, pizzerias, and donut and coffee shops. Outlets found in cinemas and temporary in nature (*i.e.*, chip wagons and hot dog stands) were excluded. Restaurants (NAICS code 722110) provided full service, including table ordering from a waiter/waitress and paying for the meal at its completion. Included were hotel restaurants, buffets and bars that served food, ‘mama and papa’ establishments (provided they were licensed registered business) while cafeterias, catering companies, and country/private clubs were excluded. The food environment data were added to the models as continuous variables.

2.3.3. Social Environment

The neighbourhood social environment was examined using a neighbourhood socio-economic status (SES) index, voting rates, crime rates, and sense of community belonging. The neighbourhood SES index, was developed using principal components analysis and includes percent of households below the low-income cut-off (LICO) [29], average household income, percent of unemployed residents, percent of residents with less than a high school education, and percent of single-parent families. The variables were selected based on their established relationships with health and their availability at the neighbourhood level in the 2006 Canadian Census. The SES index was *t*-scored to represent a mean of 50 with a standard deviation of 10; higher scores indicate lower SES. Social capital has been described as elements of community organization such as civic participation and sense of trust between citizens that contributes to the mutual benefit of the community that can be related to health status [30]. Voting rates may represent a community’s sense of engagement in the common good [31]. Furthermore, higher voter participation has been shown to correspond to greater trust and socialization between citizens [31]. Social capital was evaluated by proxy using councillor voting rates from the 2006 Ottawa municipal election and by aggregated neighbourhood values for self-reported strong sense of community belonging from four cycles (years 2000/01, 2003, 2005, 2007) of the

CCHS. Sense of community belonging was ascertained using one question on the CCHS whereby respondents were asked how they would describe their sense of belonging to their local community. Respondents were categorized into two groups: very strong and somewhat strong; and somewhat weak or very weak [32]. Neighbourhood safety was evaluated using City of Ottawa Police 2006 crime incidence rates for each neighbourhood aggregated to crimes against property and crimes against person following the Uniform Crime Reporting (UCR) Survey version 2.2 [33]. Due to population mobility between day, evening and weekends, population normalized crime rates would over-represent downtown core areas with low populations in the central business district of Ottawa and were therefore not calculated. The social environment data were analysed as continuous variables.

2.4. Individual-Level Data

2.4.1. Physical Activity

Previous week PA was self-reported using the short version of the International PA Questionnaire (IPAQ) collected within the RRFSS. The IPAQ has been evaluated in 14 studies and found to have good test-retest reliability and a modest Spearman correlation ($r = 0.30$) with PA measured by accelerometer [34]. The IPAQ captures activity intensity information across the domains of household and yard work activity, occupational activity, self-powered transport, and leisure-time PA. Computation of the total scores requires summation of the duration (in minutes) and frequency (days) for all levels of activities (e.g., low, medium, high). PA was analysed as a binomial outcome with low and moderate reporting of PA (insufficiently active) compared to high levels of PA (active). These cut-offs were recommended by the IPAQ User Guide as higher thresholds of use for distinguishing differences at the population level [35]. Outliers (>960 minutes/day) were not included in the sample.

2.4.2. Overweight and Obesity

Height and weight were self-reported and used to calculate body mass index (BMI) as weight (in kg) divided by height (in m^2). Health Canada BMI guidelines for adults [36] were used to group individuals into the following categories: underweight (<18.5 kg/ m^2), normal weight (18.5 – 24.9 kg/ m^2), overweight (25.0 – 29.9 kg/ m^2), and obese (≥ 30 kg/ m^2). BMI was analysed as a binomial outcome with under- and normal weight compared to those who reported as overweight or obese.

2.5. Covariates

The models controlled for the following covariates at the individual level: age category (18–24, 25–44, 45–64, 65+ years—categorized from continuous response); education ($<$ high school, high school graduate, some post-secondary school, post-secondary degree); household income ($\leq \$29,999$, $\geq \$30,000$), smoking status (daily, occasional, former, never); and season of collection (summer, fall, winter, spring). All covariates were added to the models as categorical variables and all were self-reported in the RRFSS except for season which was derived from the survey completion date. The covariates were all added to the model for their potential to influence PA or overweight/obesity and for their bivariate association with several of the built and social environmental variables.

2.6. Statistical Analysis

All descriptive and comparative analyses were conducted using SAS, version 9.1 (SAS Institute, Inc., Cary, NC) incorporating appropriate survey weights. Means and standard deviations of all exposure and outcome variables were calculated. *T*-tests and chi-square tests were used to identify significant differences between males and females for all individual variables.

Sex-specific binary logistic regression models were used to assess the relationships of environmental and individual variables with the outcomes of PA and overweight/obesity. Variables were conceptually chosen for inclusion in the models based on their relationships with PA and overweight/obesity as reported in the literature and on their availability in the RRFSS and the ONS. The models were built to distinguish between two levels: neighbourhood and individual. Analyses were stratified by sex to control for differences in PA levels and overweight/obesity in males and females. This study had 100% power to detect associations at the individual level and 63%-75% power to detect associations at the neighbourhood level.

A six-step modeling strategy was employed to investigate the built and social environments separately, then together, and finally to look at the relationships once individual variables and season were controlled for. The first step comprised of identifying the null model or a description of the variance in the outcomes explained at the two levels as captured by the intraclass correlation coefficient (ICC). The second step involved the inclusion of all the built environment variables (recreation and food). The social environment variables were added by themselves in the third, the built and social environment variables were added in the fourth, all of the individual-level variables were added in the fifth step, and finally season was added to produce the final full model. All regressions were estimated by residual iterated generalized least squares (RIGLS) and started with 1st order Marginal Quasi-likelihood then proceeded to 2nd order Penalized Quasi-likelihood methods using MLwiN (Release 2.21) [37]. Survey weights (standardized in MLwiN) generated from the RRFSS were used at the individual level, whereas design weights were not available for the neighbourhood level; therefore, level 2 weights were set equal to one. Odds ratios (OR) and their 95% confidence intervals (CI) were estimated from regression coefficients and their standard errors. The ICC was calculated using a latent variable method proposed by Merlo and colleagues [38].

3. Results

3.1. Sample Characteristics

Upon combining the four years of RRFSS data, a total of 5,025 respondents were identified from 85 neighbourhoods in the City of Ottawa. After excluding respondents who were pregnant at the time of response ($n = 51$), had missing information on PA ($n = 308$), BMI ($n = 194$), education ($n = 16$), household income ($n = 632$) or smoking status ($n = 6$), living outside the 89 predefined ONS neighbourhoods ($n = 362$), residing in neighbourhoods without councilor voting rates ($n = 70$), or from neighbourhoods with a cell count of less than five ($n = 3$), the final unweighted sample used for analyses was 3,383 respondents, with 3,514 in the weighted sample (survey weights). Sample distribution among the neighbourhoods ranged from 5 to 210 respondents per neighbourhood, however, standardized survey weights were applied in the multi-level models.

A sensitivity analysis for missing income was performed on outcomes and individual-level variables. Results identified that those missing household income information were more likely to have a lower education and be younger. No other individual variables were shown to differ between income responders and non-responders.

Table 1 provides descriptive characteristics for the weighted sample. Just over half (54%) of the sample was female. Compared with women, men were significantly more likely to be classified as overweight or obese, highly physically active, and report higher income levels. Significant differences in the proportion of male and female respondents to RRFSS were observed across all seasons of data collection.

Table 1. Weighted sample characteristics.

	Total (n = 3,514)	Men (n = 1,632)	Women (n = 1,882)
Age category, n (%)			
18–24 years	401 (11%)	177 (11%)	224 (12%)
25–44 years	1,490 (42%)	700 (43%)	790 (42%)
45–64 years	1,456 (41%)	664 (41%)	791 (42%)
65+ years	167 (5%)	91 (5%)	77 (4%)
Body mass index category, n (%)			
Underweight/Normal weight	1,688 (48%)	556 (34%) *	1,132 (60%) *
Overweight/Obese	1,826 (52%)	1,076 (66%) *	750 (40%) *
Level of physical activity, n (%)			
Insufficiently active	1,706 (49%)	755 (46%) **	951 (51%) **
Active	1,808 (51%)	877 (54%) **	931 (49%) **
Education, n (%)			
Did not graduate from high school	191 (5%)	106 (6%) **	85 (5%) **
Graduated from high school	528 (15%)	243 (15%)	285 (15%)
Some post-high school education	409 (12%)	195 (12%)	214 (11%)
College/university diploma/degree	2,386 (68%)	1,088 (67%)	1,298 (69%)
Household income, n (%)			
≤ \$29,999	393 (11%)	140 (9%) *	252 (13%) *
≥ \$30,000	3,121 (89%)	1,492 (91%) *	1,630 (87%) *
Smoking status, n (%)			
Daily	474 (14%)	237 (15%)	237 (13%)
Occasional	156 (4%)	84 (5%)	72 (4%)
Former	1,022 (29%)	494 (30%)	529 (28%)
Never	1,862 (53%)	817 (50%)	1,044 (55%)
Season of data collection, n (%)			
Summer	907 (26%)	438 (27%) **	469 (25%) **
Fall	886 (25%)	388 (24%) **	498 (26%) **
Winter	794 (23%)	399 (24%) **	395 (21%) **
Spring	927 (26%)	407 (25%) **	520 (28%) **

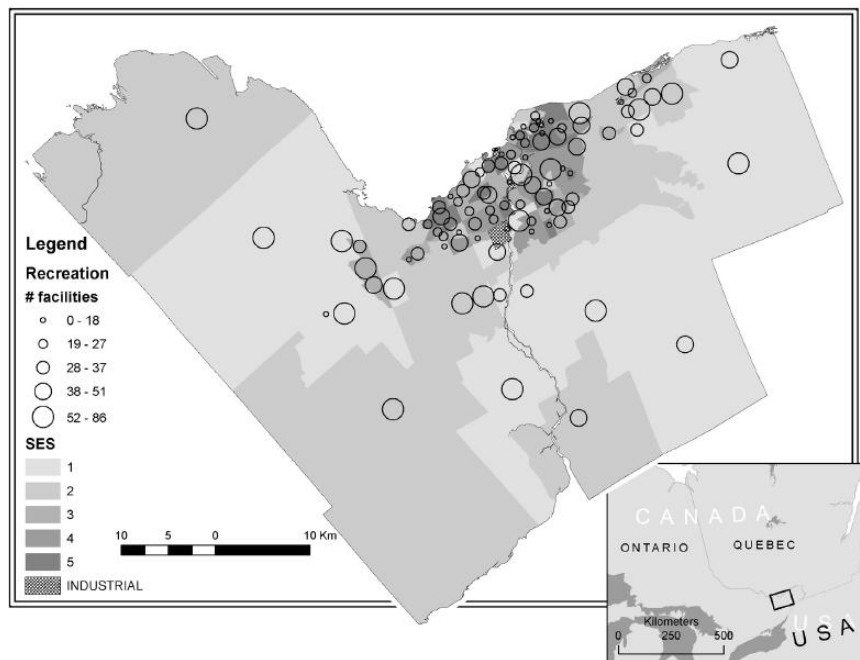
Data are presented as frequencies and proportions unless otherwise stated.

Proportions are significantly different between males and females at * $p < 0.001$, ** $p < 0.05$.

3.2. Neighbourhood Environments

Table 2 provides descriptive characteristics of the 85 neighbourhood environments. Overall the neighbourhoods in the study had more summer outdoor recreation facilities than winter and indoor facilities, and had much higher ratios of park area than open green space. Fast food outlets and restaurants were the most abundant food resources while grocery stores were the least abundant. While there is a wide range between the minimum and maximum neighbourhood values, the median of the SES index score is lower than the index's average, meaning that there were more neighbourhoods with incomes higher than the average. Figure 1 provides a visual representation of the ONS neighbourhood boundaries for the City of Ottawa and the relationship between neighbourhood SES and the density of recreation resources.

Figure 1. Ottawa Neighbourhood Study map including neighbourhood boundaries, SES index and recreation facility density.



* Note: the SES index is reverse coded with higher index scores meaning lower income levels.

Table 2. Neighbourhood characteristics (N = 85).

	Mean $\pm$ SD	Range (min–max)
Recreation environment		
Indoor recreation facilities per 1,000 people	0.17 $\pm$ 0.16	0–0.64
Outdoor–Winter per 1,000 people	0.29 $\pm$ 0.17	0–1.10
Outdoor–Summer per 1,000 people	3.93 $\pm$ 2.01	0–13.98
Park area (km ²) per 1,000 people	39.75 $\pm$ 44.95	2.09–329.42
Bike/walking path length (km)	11.54 $\pm$ 16.24	0–140.83
Green space (km ²) per 1,000 people	0.63 $\pm$ 3.48	0.01–32.09
Food environment		
Grocery stores per 1,000 people	0.12 $\pm$ 0.15	0–0.87
Fast food outlets per 1,000 people	1.24 $\pm$ 2.20	0–17.93
Convenience stores per 1,000 people	0.53 $\pm$ 0.40	0–1.99
Restaurants per 1,000 people	0.97 $\pm$ 1.79	0–14.76
Specialty food stores per 1,000 people	0.38 $\pm$ 0.60	0–4.03
Social environment		
Socioeconomic index (t-score)*	41.75, 48.69, 57.73	36.00–77.69
Strong sense of belonging (%)*	56.00, 60.90, 63.70	36.70–77.90
Councillor voting rates (%)	46.70 $\pm$ 8.25	32.06–100.00
Founded offences of property and violent crime (counts in 2006)	455.01 $\pm$ 440.48	72.00–3019.00

* Quartile 1, Median, Quartile 3.

3.3. Multilevel Analysis

Table 3 provides final multilevel multivariate model results for the relationships between individual and neighbourhood level exposures and individual level PA and overweight/obesity.

3.3.1. Physical Activity Models

Null models (not shown) revealed no significant variability across neighbourhoods for level of PA. The ICCs of the null PA models were low for both females (ICC = 0.01) and males (ICC = 0.01) indicating that a low proportion of the individual variation in level of PA could be explained by neighbourhood-level characteristics. Initial PA models including only the built environment variables showed significantly increased odds for PA with higher numbers of restaurants in females (OR = 1.25, 95% CI: 1.06, 1.45) and convenience stores in males (OR = 1.51, 95% CI: 1.23, 1.79). Contrary to our hypothesis, the likelihood of being physically active was lower for men in neighbourhoods with a higher green space area (OR = 0.90, 95% CI: 0.84, 0.96). These associations remained significant and in the same direction following the addition of the social environment variables, individual-level variables, and season. For men, higher neighbourhood sense of belonging was significantly associated with increased odds of PA only after the inclusion of the built environment variables (OR = 1.02, 95% CI: 1.001, 1.03) and remained significant in the final models. No significant associations were found between social environment variables and female PA. Season was a significant predictor of men's PA, but not women's PA.

Table 3. Multivariate multilevel models for male and female physical activity.

	Null/empty model		Built environment		Social environment		Built and social environment		Built, social and individual model		Full model with season	
	Males	Females	Males	Females	Males	Females	Males	Females	Males	Females	Males	Females
			OR 95%	OR 95%	OR 95%	OR 95%	OR 95%	OR 95%	OR 95%	OR 95%	OR 95%	OR 95%
			CI	CI	CI	CI	CI	CI	CI	CI	CI	CI
Built Environment												
Number of indoor recreation facilities per 1000 people			0.65 (0.31, 1.38)	0.89 (0.91, 1.04)			0.57 (0.28, 1.14)	0.91 (0.53, 1.56)	0.62 (0.28, 1.34)	0.93 (0.55, 1.58)	0.60 (0.27, 1.30)	0.92 (0.54, 1.57)
Number of summer outdoor facilities per 1000 people			1.05 (0.97, 1.14)	1.04 (0.96, 1.13)			1.04 (0.95, 1.13)	1.04 (0.95, 1.14)	1.05 (0.95, 1.15)	1.04 (0.95, 1.14)	1.05 (0.96, 1.15)	1.04 (0.96, 1.14)
Number of winter outdoor facilities per 1000 people			1.04 (0.40, 2.71)	1.06 (0.49, 2.31)			1.00 (0.38, 2.61)	1.10 (0.50, 2.42)	1.05 (0.41, 2.69)	1.11 (0.51, 2.41)	0.85 (0.35, 2.07)	1.10 (0.50, 2.44)
Park area (km ²) per 1000			1.00 (0.99, 1.00)	1.00 (1.00, 1.00)			1.00 (0.99, 1.00)	1.00 (1.00, 1.00)	1.00 (0.99, 1.00)	1.00 (1.00, 1.00)	1.00 (0.99, 1.00)	1.00 (1.00, 1.00)
Green space area (km ²) per 1000 people			0.90 (0.84, 0.96)	0.98 (0.91, 1.04)			0.92 (0.86, 0.98)	0.98 (0.95, 1.14)	0.93 (0.87, 0.99)	0.97 (0.91, 1.03)	0.93 (0.87, 0.99)	0.97 (0.91, 1.03)
Bike and walking path length (km) (total)			1.01 (0.99, 1.02)	1.00 (0.99, 1.02)			1.00 (0.99, 1.02)	1.00 (0.99, 1.02)	1.00 (0.99, 1.02)	1.01 (0.99, 1.02)	1.00 (0.99, 1.02)	1.01 (0.99, 1.02)
Number of grocery stores per 1000 people			0.46 (0.19, 1.15)	1.29 (0.49, 3.37)			0.44 (0.18, 1.03)	1.21 (0.41, 3.55)	0.49 (0.19, 1.27)	1.20 (0.41, 3.53)	0.54 (0.21, 1.39)	1.21 (0.41, 3.57)
Number of convenience stores per 1000 people			1.51 (1.14, 2.00)	1.18 (0.87, 1.61)			1.95 (1.39, 2.74)	1.19 (0.79, 1.78)	2.08 (1.46, 2.96)	1.19 (0.79, 1.81)	2.09 (1.46, 2.99)	1.19 (0.79, 1.81)
Number of fast food outlets per 1000 people			0.96 (0.86, 1.08)	0.93 (0.83, 1.05)			0.97 (0.86, 1.09)	0.93 (0.83, 1.05)	0.98 (0.86, 1.11)	0.92 (0.81, 1.04)	0.97 (0.85, 1.10)	0.91 (0.81, 1.04)
Number of restaurants per 1000 people			1.03 (0.85, 1.27)	1.25 (1.03, 1.52)			0.98 (0.80, 1.19)	1.25 (1.03, 1.51)	0.95 (0.77, 1.18)	1.28 (1.04, 1.56)	0.97 (0.79, 1.20)	1.28 (1.04, 1.56)
Number of specialty stores per 1000 people			0.91 (0.59, 1.41)	0.66 (0.43, 1.01)			0.95 (0.63, 1.44)	0.66 (0.44, 1.00)	1.03 (0.67, 1.58)	0.68 (0.45, 1.04)	0.98 (0.64, 1.48)	0.69 (0.45, 1.04)

Table 3. Cont.

	Null/empty model		Built environment		Social environment		Built and social environment		Built, social and individual model		Full model with season	
	Males	Females	Males	Females	Males	Females	Males	Females	Males	Females	Males	Females
	OR 95% CI	OR 95% CI	OR 95% CI	OR 95% CI	OR 95% CI	OR 95% CI	OR 95% CI	OR 95% CI	OR 95% CI	OR 95% CI	OR 95% CI	OR 95% CI
Social Environment												
t-score SES					0.99 (0.98, 1.00)	1.00 (0.98, 1.01)	0.99 (0.98, 1.00)	1.00 (0.98, 1.02)	0.99 (0.97, 1.00)	1.00 (0.98, 1.02)	0.99 (0.97, 1.00)	1.00 (0.99, 1.02)
Sense of Belonging					1.01 (0.99, 1.03)	1.00 (0.99, 1.02)	1.02 (1.00, 1.03)	1.01 (0.99, 1.02)	1.02 (1.00, 1.03)	1.01 (0.99, 1.02)	1.02 (1.00, 1.03)	1.01 (0.99, 1.02)
Councilor voting					0.99 (0.97, 1.01)	0.99 (0.98, 1.02)	1.00 (0.98, 1.01)	0.99 (0.98, 1.01)	1.00 (0.98, 1.01)	0.99 (0.98, 1.01)	1.00 (0.98, 1.02)	0.99 (0.98, 1.01)
Crime rate					1.00 (1.00, 1.00)	1.00 (1.00, 1.00)	1.00 (1.00, 1.00)	1.00 (1.00, 1.00)	1.00 (1.00, 1.00)	1.00 (1.00, 1.00)	1.00 (1.00, 1.00)	1.00 (1.00, 1.00)
Individual-level												
Age												
18–24 years									1.00	1.00	1.00	1.00
25–44 years									0.31 (0.18, 0.54)	0.61 (0.39, 0.94)	0.32 (0.19, 0.54)	0.61 (0.39, 0.95)
45–64 years									0.22 (0.13, 0.39)	0.64 (0.37, 1.08)	0.22 (0.13, 0.38)	0.64 (0.37, 1.09)
65+ years									0.16 (0.08, 0.33)	0.43 (0.23, 0.80)	0.15 (0.07, 0.32)	0.43 (0.23, 0.81)
Household income												
≤ \$29,999									1.00	1.00	1.00	1.00
≥ \$30,000									1.41 (0.91, 2.18)	1.56 (1.10, 2.23)	1.39 (0.89, 2.16)	1.56 (1.10, 2.21)

Table 3. Cont.

	Null/empty model		Built environment		Social environment		Built and social environment		Built, social and individual model		Full model with season	
	Males	Females	Males OR 95% CI	Females OR 95% CI	Males OR 95% CI	Females OR 95% CI	Males OR 95% CI	Females OR 95% CI	Males OR 95% CI	Females OR 95% CI	Males OR 95% CI	Females OR 95% CI
Education												
did not graduate from high school									1.00	1.00	1.00	1.00
graduated from high school									1.13 (0.60, 2.13)	1.21 (0.72, 2.05)	1.11 (0.58, 2.13)	1.21 (0.71, 2.05)
some post-high school education									1.18 (0.62, 2.25)	1.27 (0.74, 2.19)	1.14 (0.58, 2.13)	1.28 (0.74, 2.20)
college / university diploma / degree									1.04 (0.64, 1.70)	1.02 (0.63, 1.64)	1.00 (0.60, 1.66)	1.01 (0.63, 1.63)
Smoking status												
Current smoker									1.00	1.00	1.00	1.00
Daily									1.04 (0.82, 1.33)	1.21 (0.95, 1.54)	1.01 (0.78, 1.29)	1.21 (0.95, 1.54)
Occasional									1.22 (0.66, 2.26)	1.16 (0.66, 2.05)	1.26 (0.69, 2.31)	1.15 (0.65, 2.04)
Former									1.03 (0.76, 1.39)	1.33 (0.91, 1.94)	1.04 (0.77, 1.40)	1.33 (0.91, 1.94)
Contextual (Season)												
Summer											1.00	1.00
Fall											0.71 (0.51, 0.99)	0.86 (0.67, 1.11)
Winter											0.44 (0.32, 0.60)	0.82 (0.60, 1.12)
Spring											0.66 (0.49, 0.88)	0.85 (0.64, 1.12)
ICC	0.01	0.01	0.01	0.01	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00

Table 4. Multivariate multilevel models for male and female overweight/obesity.

	Null/empty model		Built environment		Social environment		Built and social environment		Built, social and individual model		Full model with season	
	Males	Females	Males	Females	Males	Females	Males	Females	Males	Females	Males	Females
			OR 95% CI	OR 95% CI	OR 95% CI	OR 95% CI	OR 95% CI	OR 95% CI	OR 95% CI	OR 95% CI	OR 95% CI	OR 95% CI
Built Environment												
Number of indoor recreation facilities per 1000 people			1.67 (0.74, 3.77)	1.02 (0.45, 2.30)			1.65 (0.78, 3.49)	1.34 (0.60, 2.98)	1.50 (0.71, 3.19)	1.28 (0.55, 3.00)	1.50 (0.71, 3.16)	1.27 (0.54, 2.97)
Number of summer outdoor facilities per 1000 people			1.02 (0.93, 1.13)	1.09 (1.03, 1.16)			0.98 (0.89, 1.08)	1.09 (1.03, 1.15)	0.98 (0.89, 1.07)	1.08 (1.03, 1.10)	0.98 (0.90, 1.08)	1.08 (1.02, 1.14)
Number of winter outdoor recreation facilities per 1000 people			0.71 (0.22, 2.24)	1.08 (0.54, 2.19)			1.06 (0.38, 2.99)	1.09 (0.57, 2.10)	0.89 (0.30, 2.69)	1.00 (0.52, 1.90)	0.88 (0.29, 2.63)	1.06 (0.53, 2.10)
Park area (km ²) per 1000			1.00 (1.00, 1.01)	0.99 (0.99, 0.99)			1.00 (1.00, 1.01)	0.99 (0.99, 0.99)	1.00 (1.00, 1.01)	1.00 (1.00, 1.00)	1.00 (1.00, 1.01)	1.00 (0.99, 1.00)
Green space area (km ²) per 1000 people			1.09 (0.98, 1.22)	0.73 (0.63, 0.85)			1.12 (1.03, 1.23)	0.65 (0.53, 0.80)	1.10 (1.01, 1.21)	0.67 (0.50, 0.80)	1.10 (1.00, 1.20)	0.67 (0.54, 0.84)
Bike and walking path length (km) (total)			1.00 (0.98, 1.02)	1.01 (1.00, 1.02)			0.99 (0.98, 1.01)	1.01 (1.00, 1.02)	1.00 (0.98, 1.01)	1.01 (0.99, 1.00)	1.00 (0.98, 1.01)	1.01 (0.99, 1.02)
Number of grocery stores per 1000 people			1.84 (0.68, 5.01)	1.17 (0.51, 2.57)			1.87 (0.68, 5.17)	1.30 (0.55, 3.30)	1.40 (0.51, 3.86)	1.21 (0.50, 2.90)	1.40 (0.50, 3.90)	1.21 (0.49, 2.98)
Number of convenience stores per 1000 people			0.91 (0.66, 1.26)	1.19 (0.84, 1.69)			1.28 (0.84, 1.94)	0.90 (0.57, 1.50)	1.32 (0.90, 1.93)	0.97 (0.60, 1.60)	1.31 (0.89, 1.91)	0.96 (0.60, 1.56)
Number of fast food outlets per 1000 people			1.03 (0.92, 1.16)	1.14 (0.97, 1.34)			1.03 (0.90, 1.23)	1.10 (0.96, 1.40)	1.06 (0.91, 1.23)	1.14 (0.96, 1.30)	1.05 (0.90, 1.23)	1.14 (0.96, 1.35)
Number of restaurants per 1000 people			0.82 (0.67, 1.00)	0.78 (0.60, 0.99)			0.72 (0.56, 0.91)	0.80 (0.63, 1.00)	0.71 (0.56, 0.91)	0.78 (0.62, 0.99)	0.71 (0.56, 0.90)	0.78 (0.61, 0.99)
Number of specialty stores per 1000 people			1.15 (0.82, 1.61)	1.65 (1.06, 2.57)			1.39 (0.95, 2.03)	1.71 (1.11, 2.60)	1.32 (0.85, 2.04)	1.78 (1.15, 2.80)	1.33 (0.86, 2.07)	1.79 (1.16, 2.78)

Table 4. Cont.

	Null/empty model		Built environment		Social environment		Built and social environment		Built, social and individual model		Full model with season	
	Males	Females	Males	Females	Males	Females	Males	Females	Males	Females	Males	Females
	OR 95% CI	OR 95% CI	OR 95% CI	OR 95% CI	OR 95% CI	OR 95% CI	OR 95% CI	OR 95% CI	OR 95% CI	OR 95% CI	OR 95% CI	OR 95% CI
Social Environment												
t-score SES					0.98 (0.97, 1.00)	1.01 (0.99, 1.02)	0.97 (0.96, 0.99)	1.00 (0.98, 1.00)	0.98 (0.96, 0.99)	1.00 (1.00, 1.00)	0.98 (0.96, 0.99)	0.99 (0.98, 1.01)
Sense of Belonging					1.01 (1.00, 1.03)	1.00 (0.98, 1.02)	1.02 (1.00, 1.03)	1.00 (0.96, 1.00)	1.02 (1.00, 1.04)	0.98 (0.99, 1.00)	1.02 (1.00, 1.04)	0.98 (0.96, 1.00)
Councilor voting					0.98 (0.96, 0.99)	0.99 (0.98, 1.00)	0.97 (0.96, 0.99)	1.00 (0.97, 1.00)	0.98 (0.96, 0.99)	0.99 (0.99, 1.00)	0.97 (0.96, 0.99)	0.99 (0.97, 1.00)
Crime rate					1.00 (1.00, 1.00)	1.00 (1.00, 1.00)	1.00 (1.00, 1.00)	1.00 (1.00, 1.00)	1.00 (1.00, 1.00)	1.00 (1.00, 1.00)	1.00 (1.00, 1.00)	1.00 (1.00, 1.00)
Individual-level												
Age												
18–24 years									1.00	1.00	1.00	1.00
25–44 years									2.73 (1.56–4.78)	2.30 (1.41, 3.80)	2.80 (1.58, 4.95)	2.30 (1.40, 3.78)
45–64 years									3.32 (1.87–5.88)	3.57 (2.24, 5.70)	3.40 (1.90–6.09)	3.59 (2.25, 5.73)
65+ years									1.71 (0.87, 3.34)	4.44 (2.09, 9.40)	1.74 (0.88, 3.43)	4.60 (2.18, 9.71)
Household income												
≤ \$29,999									1.00	1.00	1.00	1.00
≥ \$30,000									1.43 (0.86, 2.39)	0.74 (0.52, 1.10)	1.45 (0.87, 2.41)	0.75 (0.52, 1.08)

Table 4. Cont.

	Null/empty model		Built environment		Social environment		Built and social environment		Built, social and individual model		Full model with season	
	Males	Females	Males OR 95% CI	Females OR 95% CI	Males OR 95% CI	Females OR 95% CI	Males OR 95% CI	Females OR 95% CI	Males OR 95% CI	Females OR 95% CI	Males OR 95% CI	Females OR 95% CI
Education												
did not graduate from high school									1.00	1.00	1.00	1.00
graduated from high school									1.14 (0.65, 2.00)	0.74 (0.41, 1.30)	1.11 (0.62, 1.98)	0.75 (0.42, 1.34)
some post-high school education									0.98 (0.52, 1.84)	0.84 (0.46, 1.60)	0.96 (0.51, 1.80)	0.86 (0.47, 1.57)
college/university diploma/degree									0.90 (0.51, 1.59)	0.53 (0.32, 0.90)	0.87 (0.49, 1.55)	0.54 (0.32, 0.90)
Smoking status												
Current smoker									1.00	1.00	1.00	1.00
Daily									1.90 (1.38, 2.62)	1.16 (0.93, 1.45)	1.90 (1.38, 2.62)	1.14 (0.91, 1.44)
Occasional									1.05 (0.64, 1.72)	1.26 (0.80, 1.99)	1.06 (0.65, 1.73)	1.25 (0.80, 1.95)
Former									1.18 (0.80, 1.75)	0.83 (0.55, 1.24)	1.20 (0.81, 1.77)	0.82 (0.55, 1.23)
Contextual (Season)												
Summer											1.00	1.00
Fall											1.28 (0.94, 1.73)	0.87 (0.66, 1.15)
Winter											0.99 (0.72, 1.38)	1.11 (0.81, 1.52)
Spring											1.28 (0.93, 1.75)	0.94 (0.73, 1.21)
ICC	0.05	0.02	0.04	0.02	0.02	0.00	0.00	0.00	0.00	0.00	0.00	0.00

For men, winter and spring months were associated with significantly lower levels of PA. Final models identified that no individual-level characteristics were significantly associated with male PA. However, final female models identified that those classified in the higher income group had a 50% greater likelihood of being active.

3.3.2. Overweight/Obesity Models

Null models (not shown) identified a significant variance in the likelihood of being overweight or obese across neighbourhoods. Although low, the ICCs in the null model tended to be slightly higher for overweight/obesity than they were for PA ($ICC_{male} = 0.05$ and $ICC_{female} = 0.02$) (Table 4). No significant associations were observed between any of the built environment characteristics and male overweight/obesity rates in built environment-only models. However, after the addition of the social environment variables, a higher proportion of restaurants was significantly associated with lower odds ($OR = 0.72$, 95% CI: 0.56, 0.91) and a higher green space ($OR = 1.12$, 95% CI: 1.03, 1.23) was significantly associated with higher odds of being overweight/obese. For males, a decreased likelihood of overweight/obesity was associated with living in neighbourhoods with higher voting rates in the social environment model. When the built environment variables were added to the social environment model, males were also more likely to be overweight/obese in neighbourhoods with a higher sense of community belonging and less likely living in neighbourhoods with a lower SES. The odds remained almost identical with the addition of season and individual-level covariates. Final models identified that increasing age above 24 years and being an occasional smoker compared to a daily smoker were associated with greater odds of being overweight or obese.

Initial female models with only the built environment variables showed that women were more likely to be overweight or obese if living in neighbourhoods with higher numbers of summer outdoor recreation facilities ($OR = 1.09$, 95% CI: 1.03, 1.16) and specialty stores ($OR = 1.65$, 95% CI: 1.06, 2.57) and greater bike and walk path length ($OR = 1.01$, 95% CI: 1.001, 1.02). They were less likely to be overweight or obese if living in neighbourhoods with more green space area ($OR = 0.73$, 95% CI: 0.58, 0.89), park area ($OR = 0.99$, 95% CI: 0.99, 0.99) and restaurants ($OR = 0.78$, 95% CI: 0.69, 0.99). All of these associations remained significant and in the same direction in the final model with the exception of bike and walk path length and park area which lost significance following the addition of the individual-level variables. No significant associations were observed between the social environment and female overweight/obesity. Final models identified that increasing age above 24 years was associated with greater odds and being a college/university graduate was associated with a lower likelihood of being overweight or obese.

4. Discussion

This study investigated the influences of objectively measured recreation, food and social environments as they relate to levels of PA and overweight/obesity in a large representative sample of adults living in the City of Ottawa. In addition to examining multiple environmental determinants concurrently, the study used neighbourhoods that are relatively homogeneous in terms of socio-economics. In contrast to census tract delineations usually seen in the Canadian literature on this topic, the ONS neighbourhoods are thought to better represent natural areas with which residents

identify and provided a scale that is adequate to study the differences in health outcomes within the urban environment.

The study's findings are similar to other Canadian studies in which significant differences were observed between neighbourhoods/areas for PA levels [39] and rates of overweight/obesity [40,41]. Findings identified that higher green space was negatively associated with PA and positively associated with overweight/obesity in males. A recent study in the Netherlands by Maas and colleagues also revealed a negative association between green space and walking and cycling in leisure time in both males and females. Interestingly, in that same study, green space was not significantly associated with meeting PA recommendations, playing sports or actively commuting [42]. The negative association in males may perhaps be attributed to low motivation for using green space. Green spaces lack specificity for use related to PA unlike bike/walk paths for commuting or parks for play and as such, their use for PA purposes may be lower than that of other facilities. In addition, it has been shown that women are more likely to visit areas like playgrounds where they can supervise children as opposed to men who use more formal facilities like basketball courts and soccer fields where they can engage in more vigorous types of PA [43].

In contrast to males, the females in our sample were less likely to be overweight/obese in neighbourhoods with high green space and more likely with a greater number of summer outdoor facilities. The sex differences in green space and facility association with overweight/obesity rates was not clear. It is possible that the preference for use of green space and facilities differs by sex, but unfortunately this study was unable to test this hypothesis. Another Canadian study showed that living in proximity to greater numbers of parks and parkland was more positively associated with PA among women than men [44]. It may be that the summer facilities are more geared towards young children and males. It is also possible that women visit these venues with their children where they in turn sit to watch them play. Controlling for the presence of young children may help to tease out this relationship, but this data was not available for this analysis. A review of parks and recreation settings identified that these settings are more commonly associated with walking with less clear relationships for moderate- and vigorous-intensity PA [45]. It is likely that the differences observed across studies are attributable to the variation in measurement used for both the environment and PA variables, and the definition of neighbourhood within a study.

Interestingly, while the food environment was originally intended as a proxy for food consumption for our covariates specifically in the overweight models, it emerged as a possible determinant of PA. In males, a higher number of convenience stores and in females, a higher number of restaurants in the neighbourhood were significantly associated with higher odds of PA. It is likely that these food outlets are more representative of the density of amenities in the neighbourhood and may act as a proxy for mixed-land use and walkability which has been previously shown to be associated with PA [9]. Future research would benefit from the use of a measure of land use for testing this hypothesis. The majority of research to date has focused on the food environment as it relates to BMI and body weight status [46]. In the present study, females had increased odds of being overweight/obese when living in neighbourhoods with a greater number of specialty food stores while males had lower odds living in neighbourhoods with a higher numbers of restaurants. The present findings are similar to those reported by Black and colleagues who used similar measures of the environment in their multilevel examination of New York City neighbourhoods and the odds of obesity. In their study, a greater

availability of restaurants was also significantly associated with lower odds of obesity [47]. The female findings were also similar to U.S. studies of adults looking at the relationship between various food outlets including convenience stores and BMI [48–50]. These previous studies demonstrated that the presence of convenience stores compared to no stores was significantly associated with a higher prevalence of overweight and obesity. While these studies did not perform sex-specific analyses they did control for sex in their models [48–50]. Perhaps the reason why there were no significant associations between the other food outlets like grocery stores and fast food outlets in our study was related to both their variability amongst neighbourhoods and the ratio of the poor nutrition resources such as fast-food restaurants and convenience stores to healthy resources such as supermarkets and specialty food stores. A recent Canadian study demonstrated that a lower ratio of fast-food restaurants and convenience stores to grocery stores and produce vendors near people's homes was associated with lower odds of being obese [51].

Surprisingly, the social environment had no impact on female PA or overweight/obesity status. However in males, a stronger neighbourhood sense of community belonging was significantly associated with being physically active and lower neighbourhood SES and higher voting rates were significantly associated with lower odds for overweight and obesity. Often, low individual level SES has been associated with lower rates of PA and higher rates of obesity [4,52]. Studies that have used aggregated indices, area-level measures of deprivation or area-level SES have reported positive associations between higher neighbourhood levels of deprivation and higher rates of inactivity [11] and higher BMI or rates of obesity [53]. However, the majority of research on this relationship has been conducted in the U.S. where the incline of the social gradient may be steeper than in Canada. In addition, there is evidence to suggest that sex-differences exist for area SES and health [52,54].

Harrington and Elliott reported on data from the Ontario Heart Health Survey collected in 1992, their analysis looked at both a combined and male and female specific models. Similar to the current study, factors in the social environment including proportion of homeowners *versus* renters, income inequality, neighbourhood education, average household income, proportion of households below the LICO, and unemployment rate were not significantly related to BMI in the combined or male-female specific models. Average dwelling value was the only significant social variable and was only significant in the female and combined models, identifying that lower average dwelling value was associated with higher BMI *versus* the highest average dwelling value [41]. Berry and colleagues also examined the issue of neighbourhood SES on BMI in a cross-sectional sample of combined male and female participants within the City of Edmonton, Alberta, Canada [55]. Their analysis also employed multilevel modeling and controlled for PA as assessed by the IPAQ, however, it included other factors not captured within the RRFSS such as fruit and vegetable consumption and reasons for neighbourhood selection (e.g., proximity to job, proximity to outdoor recreation resource, *etc.*). Findings identified that participants residing in low SES neighbourhoods had greater BMIs than those in the medium or high SES neighbourhoods [55]. It appears that an inverse relationship may exist between area level SES and BMI in Canadian populations and these relationships may be influenced by sex.

Lower neighbourhood SES was associated with lower odds of overweight/obesity in men only. In addition, men were more likely than women to be overweight or obese. It is possible that the higher prevalence of overweight/obesity is partially responsible for these findings, but it is also possible that

the lower SES scores are proxy measures of factors in the built environment such as increased reliance on active transportation. Previous research has also shown a positive association between public transit use and PA [56].

Few studies have examined the influence of social factors other than neighbourhood SES. Findings of the present study support the notion that high social cohesion or sense of community belonging is associated with a greater likelihood of PA [57–59]. Other research has shown that relationships between crime and PA may differ depending on whether the crime is perceived or objectively measured [22,60]. Similar to other objectively measured research [19,47], the present investigation identified no significant associations between crime and PA or overweight/obesity.

The present study has limitations that should be recognized. First, the neighbourhood-level indicators were all collected between 2006 and 2008 while the individual-level data comprised of the combination of five surveys spanning years 2003 to 2007. The temporality of the data collection periods may bias the results whereby individuals were not exposed to the same environments at every survey time point. While this bias may be present, Ottawa level estimates remained relatively stable across this time period (data were originally collected in 2006 and re-assessed in 2008). Second, the food outlet density variables used were based on a per capita measure, it is important to distinguish that defining food outlet density measures in per land area measures may produce a different estimated relationship between BMI and food outlet density as seen in previous research [61]. Thirdly, the study was unable to control for the fact that individuals may have responded in multiple cycles of the RRFSS resulting in an individual's over-representation, however, this bias is likely overcome by the large sample size. A fourth limitation is that the individual-level variables were self-reported and evidence suggests that self-report measures specifically for PA differ significantly from their objective measures [62]. While it would have been preferable to use direct measures to examine these relationships, there is no known large dataset for the Ottawa area and collection of these measures on such a large scale would be very time and cost intensive. The self-report measures allowed for the capture of data on a large scale and the use of the higher PA cut-point (level 3 *versus* 1 and 2) may have helped to identify individuals who are truly active.

One of the major limitations of this study is its cross-sectional nature; thus it was unable to capture causality in the relationships of the built and social environments with PA and overweight/obesity. Most of the previous research has also relied on cross-sectional designs due to the sheer costs associated with tracking such a large group of individuals over time. Due to the nature of our secondary data sources we were unable to control for several important individual variables including intrapersonal factors (e.g., intention and attitudes), interpersonal factors (e.g., social support for PA), diet, sedentary behaviour, and number of children. Lastly, it was not possible to assess neighbourhood preferences and the likelihood that people self-selected into their respective neighbourhoods. It is possible that individuals who are more active select to live in neighbourhoods that are supportive of their lifestyles. While the study did not assess preference, it was able to control for clustering at the neighbourhood level using the hierarchical modeling approach. Further, the aggregate-level unit of analysis (neighbourhoods) is distinct from the sampling units utilized in the survey sampling frame. While survey weights do adjust for the complex survey design, they fall short of accounting for differential sampling across neighbourhoods and may polarize them in a way that doesn't necessarily reflect the extent of the differences between them. In addition, the study was unable to account for the

fact that individuals were likely to cross neighbourhood boundaries to utilise other PA and food resources, and as such, neighbourhoods may not have truly represent their degree of exposure.

5. Conclusions

The results of this study suggest that in Ottawa, Canada variation in PA and overweight/obesity levels can be attributed to the neighbourhood of residence. Findings suggest that neighbourhood-level interventions that support PA and healthy weight control may need to be gender tailored. Furthermore, the recreation environment may play less of a role in PA levels, specifically higher intensity PA, than access to amenities in the food environment, a possible indicator of mixed land use. The social environment, specifically neighbourhood-level sense of belonging, voting participation and SES may play more important roles in male outcomes, while individual-level SES may be more important for females. Season, which had previously been ignored in many multilevel examinations of neighbourhood influences on PA, appears to play an important role for male PA, perhaps due to gender differences in preference for outdoor *versus* indoor location for PA. Age continues to be associated with a greater likelihood of being overweight or obese.

To our knowledge, this study is the first to have examined the multilevel associations between individual PA levels and rates of overweight/obesity with neighbourhood-level recreation, food and social environments and individual socio-demographics and season in a large random sample of urban-dwelling Canadians. Our findings provide support for the growing research identifying that physical inactivity and obesity may be partially explained by neighbourhood-level exposures. Future research in this area is necessary to identify whether the relationships differ with objectively measured PA and body composition, accounting for neighbourhood preferences and whether longitudinal associations exist.

Conflict of Interests

All of the authors declare no competing interests.

Authors' Contributions

SAP conceived the study, carried out the design, performed the analyses, and drafted and edited the manuscript. EAK is a principal investigator with the ONS and was responsible for the environmental data; she participated in this study's design and coordination, provided analytical input and helped draft and edit the manuscript. KR participated in the study's design, abstraction of data from the RRFSS, provided analytical input and aided with the editing of the manuscript. J-MB provided analytical advice and interpretation and helped edit the manuscript. MS is a principal investigator with the ONS and was responsible for the environmental data, specifically the GIS components; he also participated in the design of the study, provided methodological input, and assisted in the editing of the manuscript. AA participated in the study's design and coordination of data acquisition and edited the manuscript. MST and DP participated in the design of the study, provided methodological input, and assisted in the editing of the manuscript. All authors read and approved the final manuscript.

Acknowledgements

SAP received funding in support of her doctoral work from the Social Sciences and Humanities Research Council–Doctoral Award, Ontario Ministries of Ontario Graduate Scholarships and a University of Ottawa Excellence Scholarship and Doctoral Research Award. The Ottawa Neighbourhood Study was funded by the Canadian Institutes of Health Research (funding reference number 99345), the Champlain Local Health Integration Network, the Ottawa Coalition of Community Health, Resource Centres and United Way Ottawa. Randy Mar, Cameron Hopgood and the Ottawa Police Service are gratefully acknowledged for the crime data used in this research. This research is a contribution to the Ottawa Neighbourhood Study (www.neighbourhoodstudy.ca) and the authors would like to thank all those involved in its inception and maintenance including funders.

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Supplementary table. Bivariate correlations between neighbourhood variables.

	Indoor facilities	Summer Facilities	Winter facilities	Park area	Green space	Bike/path length	Grocery stores	Convenience stores	Specialty stores	Restaurants	Fast food	SES index	Sense of belonging	Voting rates	Crime rates
Indoor facilities	1.00	0.11 <.0001	-0.02 0.17 <.0001	0.13 <.0001	0.004 0.83	-0.21 <.0001	0.11 <.0001	0.33 <.0001	0.21 <.0001	0.22 <.0001	0.15 <.0001	0.11 <.0001	0.07 .0001	0.09 <.0001	0.10 <.0001
Summer facilities		1.00	0.58 <.0001	0.49 <.0001	0.10 <.0001	-0.06 .0006	-0.17 <.0001	-0.27 <.0001	-0.27 <.0001	-0.26 <.0001	-0.23 <.0001	-0.37 <.0001	0.14 <.0001	0.23 <.0001	-0.49 <.0001
Winter facilities			1.00	0.29 <.0001	-0.03 0.15 <.0001	-0.10 <.0001	-0.15 <.0001	-0.17 <.0001	-0.19 <.0001	-0.15 <.0001	-0.11 <.0001	-0.21 <.0001	0.10 <.0001	0.21 <.0001	-0.35 <.0001
Park area (km ²)				1.00	0.06 0.001	0.01 0.44	-0.17 <.0001	-0.19 <.0001	-0.18 <.0001	-0.14 <.0001	-0.15 <.0001	-0.29 <.0001	0.10 <.0001	0.20 <.0001	-0.28 <.0001
Green space area (km ²)					1.00	0.64 <.0001	-0.07 <.0001	-0.04 0.03	-0.07 <.0001	-0.05 0.003	-0.03 0.08	-0.08 <.0001	-0.02 0.16	0.03 0.11	-0.07 <.0001
Bike/path length (km)						1.00	-0.02 0.24	-0.24 <.0001	-0.16 <.0001	-0.08 <.0001	-0.02 0.16	-0.32 <.0001	0.05 .002	0.16 <.0001	-0.003 0.86
Grocery stores							1.00	0.43 <.0001	0.25 <.0001	0.05 0.002	0.20 <.0001	0.42 <.0001	-0.09 <.0001	-0.24 <.0001	0.29 <.0001
Convenience stores								1.00	0.49 <.0001	0.41 <.0001	0.38 <.0001	0.66 <.0001	-0.35 <.0001	-0.40 <.0001	0.46 <.0001
Specialty stores									1.00	0.88 <.0001	0.85 <.0001	0.30 <.0001	0.02 0.34	-0.12 <.0001	0.56 <.0001
Restaurants										1.00	0.93 <.0001	0.13 <.0001	0.04 0.03	-0.08 <.0001	0.57 <.0001
Fast food											1.00	0.15 <.0001	0.04 0.02	-0.10 <.0001	0.54 <.0001
SES index												1.00	-0.37 <.0001	-0.50 <.0001	0.32 <.0001
Sense of belonging													1.00	0.22 <.0001	-0.16 <.0001
Voting rates														1.00	-0.27 <.0001
Crime rates															1.00

Pearson correlation (p-value)

CHAPTER 6: MANUSCRIPT 4

This manuscript was written and submitted in accordance to the specifications for submission to the peer-reviewed journal *Obesity*.

Title:

Relationships between neighbourhoods, physical activity and obesity: A multilevel analysis of a large Canadian City.

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Suggested citation:

Prince S.A., Kristjansson E.A., Russell K., Billette J.-M., Sawada M., Ali A., Tremblay M.S., Prud'homme D. Relationships between neighbourhoods, physical activity and obesity: A multilevel analysis of a large Canadian City. *Obesity*. 2012 Jan 19. doi: 10.1038/oby.2011.392. [Epub ahead of print].

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Relationships Between Neighborhoods, Physical Activity, and Obesity: A Multilevel Analysis of a Large Canadian City

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In Canada, there is limited research examining the associations between objectively measured neighborhood environments and physical activity (PA) and obesity. The purpose of this study was to determine the relationships between variables from built and social environments and PA and overweight/obesity across 86 Ottawa, Canada neighborhoods. Individual-level data including self-reported leisure-time PA (LTPA), height, and weight were examined in a sample of 4,727 adults from four combined cycles (years 2001/03/05/07) of the Canadian Community Health Survey (CCHS). Data on neighborhood characteristics were obtained from the Ottawa Neighbourhood Study (ONS); a large study of neighborhoods and health in Ottawa, Canada. Binomial multivariate multilevel models were used to examine the relationships between environmental and individual variables with LTPA and overweight/obesity using survey weights in men and women separately. Within the sample, ~75% of the adults were inactive (<3.0 kcal/kg/day) while half were overweight/obese. Results of the multilevel models suggested that for females greater park area was associated with increased odds of LTPA and overweight/obesity. Greater neighborhood density of convenience stores and fast food outlets were associated with increased odds of females being overweight/obese. Higher crime rates were associated with greater odds of LTPA in males, and lower odds of male and female overweight/obesity. Season was significantly associated with PA in men and women; the odds of LTPA in winter months were half that of summer months. Findings revealed that park area, crime rates, and neighborhood food outlets may have different roles with LTPA and overweight/obesity in men and women and future prospective studies are needed.

Obesity (2012) doi:10.1038/oby.2011.392

INTRODUCTION

Physical activity (PA) is known to be protective against several chronic diseases and premature mortality (1). In spite of its protective abilities, average PA levels continue to fall short of recommendations. Self-reported data from the 2009 Canadian Community Health Survey (CCHS) showed that 51% of women and 44% of men were inactive (<1.5 kcal/kg/day) in their leisure time (2). Furthermore, 59% of Canadian men and 44% of women were at increased health risk from being overweight or obese (3).

Canadian rates of physical inactivity and obesity have continued to rise dramatically over the past several decades and individual factors are unable to explain these large increases (4,5). It has been suggested that the social and built environments are potential contributors to the current trends (4). To

date, most research has focused on perceived access to environments rather than objective measures of the environment (6). Objectively measured studies have mixed results, but have found positive associations between PA and availability of walking/bike paths, recreation/fitness facilities, and parks and green spaces (6–8). While results are mixed, studies suggest that overweight and obesity are generally related to limited access to environmental supports (9).

Social environmental factors can mediate the effects of the built environment and influence the adoption of healthy lifestyles. Studies using area-level socioeconomic status (SES) have reported associations between lower area SES and higher rates of inactivity (10,11) and obesity (12,13). Little is known as to the relationship between other neighborhood social factors like crime, civic participation and social cohesion, and individual PA

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Received 21 June 2011; accepted 7 December 2011; advance online publication 19 January 2012. doi:10.1038/oby.2011.392

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and body composition. In addition, most research investigating environmental influences on PA or obesity for adults has been conducted in the United States, Europe, and Australia with little on Canadian populations. Furthermore, sex-based analyses are often lacking (14,15). To address these research gaps, this study assesses built and social environmental factors and their relationships with self-reported leisure-time PA (LTPA) and overweight/obesity using sex-specific multilevel models while controlling for individual-level variables in a large sample of Canadian adults.

METHODS AND PROCEDURES

A multilevel framework was used to examine the association between individual- and neighborhood-level characteristics with LTPA and overweight/obesity in 86 neighborhoods in Ottawa, Canada. The study received ethical approval from the University of Ottawa's Health Science Research Ethics Board (#H10-08-11) and the City of Ottawa's Public Health Research Ethics Board (#128-09).

Data sources

CCHS. The CCHS targets Canadians ≥ 12 years that live in private dwellings in Canada. Four cycles of the CCHS (years 2000/01, 2003, 2005, 2007) were combined to create a dataset of respondents from Ottawa, Canada. The CCHS did not sample uniformly across Ottawa, but survey weights were applied. As the CCHS is a national probability sample with a typical overall sample response rate ranging from 70–80%, standard survey weights were provided by Statistics Canada's methodologists in order to adjust for regional nonresponse and unequal size of sampling units. Weights were derived based on the sampling frames used (16). These weights were further rescaled to the analytical sample size and incorporated in all analyses to achieve regional-level representativeness.

Ottawa Neighbourhood Study (ONS). Environment characteristics were collected by the ONS (<http://www.neighbourhoodstudy.ca>), a large study of neighborhoods and health outcomes in Ottawa. Neighborhoods were defined based on natural barriers, similarity in socioeconomic and demographics, Ottawa multiple listing services maps, and participatory mapping feedback from the steering group (17). Most neighborhoods contained $\geq 4,000$ people. Objectively measured environmental data were collected from 2006 to 2008 using the following data and methods: (i) 2006 Canadian census household data; (ii) geographical information system data from DMTI Spatial, the City of Ottawa, Ottawa, Ontario, Canada and the National Capital Commission (NCC); (iii) telephone contact with businesses; (iv) web-based research (e.g., Canada 411, websites, Google maps); (v) team knowledge of local resources; and (vi) field research and validation (e.g., car, walking, bicycle). A further in-depth description of methods related to the ONS and its variables is available elsewhere (17). **Figure 1** provides a visual representation of the ONS neighborhood delineations in the City of Ottawa.

Neighborhood environments

Recreation environment. Recreational facilities were defined using the North American Industry Classification System (NAICS) Code 71 (18) and were only included if they provided activity for free or minimal cost. Neighborhood recreation measures included total bike and walking path length (km), counts per 1,000 people of indoor recreation facilities, winter outdoor facilities, summer outdoor facilities, park area (km^2), and green space area (km^2). Green space managed by the City or the NCC was included in the area of parkland variable, while non-managed areas were considered green space. Facility density (per 1,000 people) was used to capture demand on the facilities. Recreation data were added to the models as continuous variables.

Social environment. The socioeconomic environment was assessed using a neighborhood SES index that was developed using principal components analysis. It included percent of households below the

low-income cut-off (19), average household income, percent of unemployed residents, percent of residents with less than a high school education, and percent of single-parent families. The SES index was t -scored to represent a mean of 50 with a s.d. of 10 for comparability across neighborhoods and was reverse coded with higher scores indicating lower SES. Social cohesion/participation was evaluated using councillor voting rates from the 2006 Ottawa municipal election and aggregated reporting of a strong sense of community belonging from the CCHS (cycles 1–4). Missing sense of belonging values were imputed using the mean values from the appropriate neighborhood SES quintiles. Neighborhood safety was evaluated using City of Ottawa Police 2006 crime incidence rates for each neighborhood aggregated to crimes against property and crimes against person following the Uniform Crime Reporting Survey version 2.2 (20). Social environment data were analysed as continuous variables.

Food environment. The food environment was included in the models as a neighborhood-level covariate to account for availability of food choices and as a proxy for density of neighborhood resources. Within the ONS, objective measures of the food environment were classified into five types of food retail outlets according to the NAICS (18). The food outlets were examined using density (number per 1,000 individuals) and included grocery stores, convenience stores, specialty food stores, fast food outlets, and full service restaurants. Food environment data were added to the models as continuous variables.

Individual-level data

LTPA. The CCHS captured LTPA using an interview-administered questionnaire. Respondents were asked to self-report participation, frequency and duration in LTPA (including walking for exercise, gardening/yard work, swimming, bicycling, popular/social dance, home exercises, ice hockey, ice skating, in-line skating/rollerblading, jogging/running, golfing, exercise class/aerobics, downhill skiing, bowling, baseball/softball, tennis, weight-training, fishing, volleyball, basketball, and up to three other categories) over the previous 3 months. Each activity was assigned a metabolic equivalent value for use in the derived PA index. The PA index is calculated as the sum of the average daily energy expenditures (kcal/kg/day) of all leisure time activities. Respondents were classified as follows: physically active (≥ 3.0 kcal/kg/day); moderately active (1.5–2.9 kcal/kg/day); and inactive (< 1.5 kcal/kg/day). LTPA was analysed as a binomial outcome with inactive and moderately active respondents (inactive; < 3.0 kcal/kg/day) compared to those who reported being physically active. This follows recommendations for distinguishing those at the population level who meet health recommendations (21).

Overweight and obesity. Height and weight were self-reported in the CCHS and used to calculate BMI as weight (kg) divided by height (m^2). BMI guidelines for adults (22) were used to group individuals into the following categories: underweight ($< 18.5 \text{ kg/m}^2$), normal weight (18.5–24.9 kg/m^2), overweight (25.0–29.9 kg/m^2), and obese ($\geq 30 \text{ kg/m}^2$). BMI was analysed as a binomial outcome with under-/normal weight compared to overweight/obese.

Individual-level covariates

The models controlled for age category (18–24, 25–44, 45–64, and ≥ 65 years); education level ($<$ high school, high school graduate, some post-secondary, post-secondary degree); household income ($\leq \$29,999$, $\geq \$30,000$), smoking status (daily, occasional, former, never); and season of data collection (summer, fall, winter, spring). In addition, LTPA or BMI category was controlled for when not used as the outcome of interest.

Statistical analysis

All analyses were conducted in the year 2010. All descriptive and comparative analyses were conducted using SAS version 9.1 (SAS Institute, Cary, NC) incorporating appropriate survey weights and bootstraps provided by Statistics Canada. Means and s.d. of all exposure and

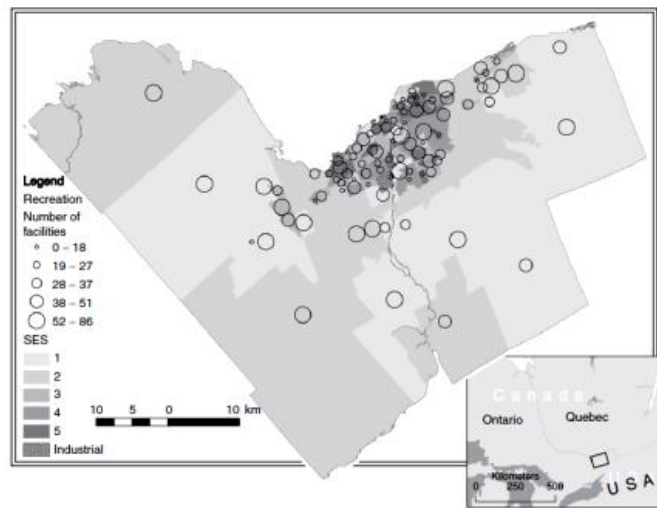


Figure 1 Ottawa Neighbourhood Study map including neighborhood delineations. SES, socioeconomic status.

outcome variables were calculated. *t*-tests and χ^2 tests were used to identify significant differences between males and females.

Sex-specific binary logistic regression models were used to assess the relationships of environmental and individual variables with the outcomes of LTPA and overweight/obesity. All of the neighborhood-level independent variables except for the already *t*-scored SES index were standardized ((independent variables – mean)/s.d.) to render them comparable. The models were built to distinguish between two levels: neighborhood and individual. A five-step modeling strategy was employed. The first step comprised identifying the null model or a description of the variance in the outcomes explained at the two levels as captured by the intraclass correlation coefficient. The second step involved the inclusion of all the built environment variables (recreation and food). Social environment variables were added in the third, season in the fourth and finally, all of the individual-level variables were added in the fifth step to produce final models. All regressions were estimated by the residual iterated generalized least squares and started with 1st order marginal quasi-likelihood then proceeded to 2nd order penalized quasi-likelihood methods using MLwiN (Version 2.21; Centre for Multilevel Modelling, University of Bristol, UK). Survey weights (standardized in MLwiN) generated from the CCHS were used at the individual level. Design weights were not available for the neighborhood level; therefore, level 2 weights were set to equal one. Standardized odds ratios (ORs) and their 95% confidence intervals (CIs) were estimated from regression coefficients and standard errors.

RESULTS

Sample characteristics

Upon combining the four cycles of CCHS data, a total of 6,564 respondents were identified from 89 neighborhoods. After excluding respondents who were <18 years ($n = 628$), pregnant ($n = 58$), had missing information on LTPA ($n = 164$), BMI ($n = 381$), education ($n = 62$), household income ($n = 388$) or smoking ($n = 2$), living outside the 89 predefined neighborhoods ($n = 19$), or residing in neighborhoods without voting rates ($n = 137$), the final unweighted sample used for analyses was 4,727

from 86 neighborhoods with a minimum of five respondents per neighborhood.

A sensitivity analysis revealed that those missing household income were more likely to be smokers, have a lower education, be classified in the youngest or oldest age categories, and less likely to be active and overweight/obese. As a result, the income data is not missing at random and study results should be interpreted in light of these potential biases.

Table 1 provides descriptive characteristics for the weighted sample. Half (51%) of the sample was female. Men were more likely to be classified as overweight/obese, highly active, report higher income, more post-secondary education, and be former smokers. Women were more likely to be seniors (65+ years), under-/normal weight, inactive, never smokers, and report lower income and education.

Neighborhood environments

Table 2 provides descriptive characteristics of the 86 neighborhoods. Figure 1 displays the neighborhood SES index values and the density of recreation resources per neighborhood.

Multilevel analysis

Table 3 provides final multilevel multivariate model results.

PA models. Null models (not shown) revealed significant variability in LTPA levels across neighborhoods. The intraclass correlation coefficient of the null model was 10% for females and 15% for males indicating that a significant but limited level of the variation in LTPA could be explained by neighborhood-level characteristics. The intraclass correlation coefficients decreased with each block of variables indicating that a proportion of the

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Table 1 Weighted sample characteristics

	Total (n = 494,800)	Men (n = 243,800)	Women (n = 251,000)
<i>Age category, n (%)</i>			
18–24 years	60,400 (12%)	30,500 (12%)	29,900 (12%)
25–44 years	215,500 (44%)	108,400 (44%)	107,100 (42%)
45–64 years	170,400 (34%)	83,700 (32%)	86,700 (35%)
65+ years	48,500 (10%)	21,100 (12%)*	27,400 (11%)*
<i>BMI category, n (%)</i>			
Underweight/ normal weight	257,100 (52%)	103,700 (43%)*	153,300 (61%)*
Overweight/ obese	237,800 (48%)	140,000 (57%)*	97,700 (39%)*
<i>Level of physical activity, n (%)</i>			
Inactive	363,000 (73%)	166,700 (68%)*	196,300 (78%)*
Active	131,900 (27%)	77,100 (32%)*	54,800 (22%)*
<i>Education, n (%)</i>			
Did not graduate from high school	43,800 (9%)	19,400 (9%)*	24,400 (10%)*
Graduated from high school	72,400 (14%)	32,500 (14%)*	39,900 (16%)*
Some post- high school education	47,500 (10%)	25,800 (10%)	21,700 (9%)
College/ university diploma/ degree	331,100 (67%)	166,100 (66%)	165,000 (64%)
<i>Household income, n (%)</i>			
≤\$29,999	61,100 (12%)	24,900 (10%)*	36,200 (14%)*
≥\$30,000	433,700 (88%)	218,800 (90%)*	214,900 (86%)*
<i>Smoking status, n (%)</i>			
Daily	74,400 (15%)	39,400 (18%)	35,000 (14%)
Occasional	26,800 (5%)	14,900 (6%)	11,900 (5%)
Former	226,000 (46%)	119,100 (47%)*	106,900 (42%)*
Never	167,600 (34%)	70,300 (30%)*	97,200 (39%)*
<i>Season of data collection, n (%)</i>			
Summer	118,900 (24%)	59,400 (27%)	59,500 (27%)
Fall	132,000 (27%)	68,000 (29%)	64,000 (27%)
Winter	119,400 (24%)	56,200 (17%)	63,200 (18%)
Spring	124,500 (25%)	60,200 (27%)	64,300 (28%)

Data are presented as frequencies and proportions unless otherwise stated.
Proportions are significantly different between males and females at * $P < 0.001$,
** $P < 0.05$.

variation of LTPA between neighborhoods was explained by the variables in the model.

There were no significant associations between LTPA and any of the built environment variables for men. In females, one standard deviation increase in the availability of park area (km^2) resulted in 17% higher odds of being active. For males,

Table 2 Neighborhood characteristics (N = 86)

	Mean $\pm$ s.d.	Range (min–max)
<i>Recreation environment</i>		
Indoor recreation facilities per 1,000 people	0.16 $\pm$ 0.16	0–0.64
Outdoor—winter per 1,000 people	0.29 $\pm$ 0.17	0–1.10
Outdoor—summer per 1,000 people	3.91 $\pm$ 2.02	0–13.98
Park area (km^2) per 1,000 people	39.47 $\pm$ 44.76	2.09–329.42
Bike/walking path length (km)	11.44 $\pm$ 16.17	0–140.83
Green space (km^2) per 1,000 people	0.62 $\pm$ 3.46	0.01–32.09
<i>Food environment</i>		
Grocery stores per 1,000 people	0.12 $\pm$ 0.15	0–0.87
Fast food outlets per 1,000 people	1.23 $\pm$ 2.19	0–17.94
Convenience stores per 1,000 people	0.53 $\pm$ 0.40	0–1.99
Restaurants per 1,000 people	0.96 $\pm$ 1.78	0–14.76
Specialty food stores per 1,000 people	0.38 $\pm$ 0.60	0–4.03
<i>Social environment</i>		
Socioeconomic index (t-score)	41.75, 48.69, 57.73 ^a	36.00–77.69
Strong sense of belonging (%)	56.08, 60.87, 63.70 ^a	36.70–77.90
Councillor voting rates (%)	46.55 $\pm$ 8.31	32.06–100.00
Founded offences of property and violent crime (counts in 2006)	451.15 $\pm$ 439.34	72.00–3,019.00

^aQ1, median, Q3.

every 1 s.d. increase in the crime rate resulted in a 14% increase in the odds of being physically active. For men, the winter and spring months, and for women winter months, were associated with significantly lower levels of LTPA compared to summer months. In males, increasing age was associated with lower LTPA levels and having higher income ($\geq \$30,000$) resulted in a 65% greater likelihood of LTPA. In females, increasing age and being classified as overweight/obese were associated with lower odds of LTPA.

Overweight/obesity models. Null models (not shown) identified a significant variance in the likelihood of being overweight or obese across neighborhoods. The intraclass correlation coefficient of the null model was higher for males (27%) than females (20%).

None of the built environment variables were associated with male overweight/obesity. In females, the odds of being overweight/obese increased by 15% for every 1 s.d. increase in

the amount of park area (km^2). In addition, increased density of convenience stores (OR = 1.17, 95% CI: 1.03–1.34) and fast food outlets (OR = 1.38, 95% CI: 1.11–1.72) were associated with greater odds of overweight/obesity. No significant associations between the food environment and male overweight/obesity were observed. For both males and females, every s.d. increase in the crime rate resulted in an 8–9% decrease in the odds of overweight/obesity. Final models showed that increasing age for both men and women was associated with greater odds of being overweight or obese. In addition, for women, higher education decreased the odds of being physically active and increased the odds of being overweight or obese. In men, higher income ($\geq \$30,000$) and being a former smoker increased their odds while being a college/university graduate decreased their odds of being overweight or obese.

DISCUSSION

This study is one of the first to examine multilevel influences of objectively measured recreation, food and social environments, and individual-level factors and season as they relate to rates of PA, and overweight/obesity in a large representative sample of Canadian adults. Furthermore, the study employed the use of neighborhoods that are relatively homogeneous in terms of socioeconomic status, contrary to the use of census tracts usually seen in Canadian research on this topic.

The main objective of this research was to understand and identify potential built and social environment characteristics, seasonal and individual correlates of LTPA and overweight/obesity in Ottawa neighborhoods. The results showed different relationships for men and women. Surprisingly, LTPA was significantly associated with park area in females and crime rates in males. The likelihood of females being overweight/obese was positively related to park area, convenience store, and fast food outlet density and negatively influenced by crime rates. Males' odds of overweight/obesity were only negatively related to crime rates.

Findings of this analysis are similar to other Canadian studies in which significant area variation was reported for PA (23) and overweight and obesity (24). However, while the area-level variation in PA and overweight/obesity has generally been low in previous studies (23–25), our models revealed a considerable degree of variation at the neighborhood level possibly attributable to our more natural definition of neighborhoods.

Surprisingly in our study, the only recreation variable associated with LTPA and overweight/obesity was park area for females. Our LTPA findings are similar to investigations of spatial access to built and natural facilities and associations with meeting PA recommendations in a sample of Australian adults by Giles-Corti and Donovan (11). They found no significant associations between the environment and PA, but did find that individual determinants had stronger relationships with PA (11) and that access differed by neighborhood SES (26). By controlling for neighborhood SES factors, we may be controlling for this effect. Our PA findings also agree with those found by Panter and colleagues (27) who studied six English neighborhoods of varying SES. Their results showed

that those living in the closest tertile to a park or green space were twice as likely to meet PA guidelines (27). Interestingly, in addition to greater park area being associated with higher odds of female LTPA, it was also associated with higher odds of female overweight/obesity. Although these findings appear counterintuitive they do support the idea that park area may not necessarily be linearly related to BMI (28). However, caution should be exerted when interpreting the present findings as a number of issues related to the conception and analysis of the data require further investigation. The measure of park area in the current study included various types of "parks" including children's playgrounds and maintained green spaces which affects the specificity of their use. Female use of park area is likely affected by parity (i.e., number of children) which was unfortunately not available in the current data. Further, it was not possible to ascertain from the data information on park quality. Seasonality is also another issue of importance in this North American city where a colder climate can render parks not usable for up to 6 months of the year. Therefore, while a park may be present in a neighborhood it is not necessarily accessible. Finally, information on dog ownership was not available, but could provide important covariate information for park use and BMI. Previous research has shown that dog ownership is associated with lower BMIs (29) and an increased use of parks (30).

Interestingly, none of the facility variables had significant associations with LTPA. There is evidence to suggest that the relationship between PA and the built environment may be modified by whether facilities are free or pay-for-use with a greater density of pay-for-use facilities associated with being physically active vs. inactive (31). It is also possible that reverse causality could occur whereby pay-for-use facilities may locate to areas of higher SES with more potential clientele. Our study included facilities that were free or available at a minimal cost, however, the inclusion of both neighborhood and individual SES potentially captures the possibility that higher cost facilities are associated with higher levels of LTPA.

Similar to our investigation, Poulou and colleagues examined associations of BMI from the 2003 CCHS with the density of food sources and recreation facilities within 1-km buffers of homes in two other Canadian cities; Toronto and Vancouver (32). They found that the density of fast food outlets, convenience stores, grocery stores, and recreation facilities were not significantly associated with BMI (32). It is possible that 1-km buffers are more meaningful from a walkability perspective, but these may not adequately capture an individual's exposure to food sources and recreational facilities which are dependent on the use of a car. In addition, several Canadian studies have identified that resource availability may be dependent on area-level SES (33) and area-level SES may mediate the uptake of PA (34,35) and access to food outlets (36). By controlling for neighborhood social factors in our analyses we are controlling for this effect and this is perhaps why the recreation and social environments did not have strong independent associations with LTPA or overweight/obesity.

Table 3 Final multivariate multilevel models for male and female physical activity and overweight/obesity status

Final models	Outcome: physically active		Outcome: overweight/obesity	
	Males, OR (95% CI)	Females, OR (95% CI)	Males, OR (95% CI)	Females, OR (95% CI)
<i>Built environment</i>				
Number of indoor recreation facilities per 1,000 people	0.99 (0.84, 1.15)	0.95 (0.84, 1.07)	1.03 (0.91, 1.17)	1.01 (0.92, 1.11)
Number of summer outdoor recreation facilities per 1,000 people	1.02 (0.83, 1.26)	1.07 (0.88, 1.31)	1.06 (0.86, 1.32)	0.84 (0.66, 1.07)
Number of winter outdoor recreation facilities per 1,000 people	0.97 (0.79, 1.19)	0.86 (0.72, 1.01)	0.98 (0.86, 1.11)	1.10 (0.91, 1.32)
Park area (km ²) per 1,000	0.91 (0.77, 1.06)	1.17 (1.03, 1.33)	0.97 (0.78, 1.20)	1.15 (1.00, 1.32)
Green space area (km ²) per 1,000 people	0.57 (0.27, 1.21)	0.94 (0.74, 1.21)	0.80 (0.63, 1.01)	0.86 (0.70, 1.05)
Bike and walking path length (km) (total)	0.88 (0.70, 1.10)	0.88 (0.68, 1.15)	1.09 (0.84, 1.41)	1.18 (0.95, 1.47)
Number of grocery stores per 1,000 people	1.05 (0.88, 1.24)	0.99 (0.87, 1.13)	1.07 (0.93, 1.23)	0.93 (0.79, 1.08)
Number of convenience stores per 1,000 people	0.90 (0.79, 1.04)	1.06 (0.91, 1.29)	0.92 (0.82, 1.04)	1.17 (1.03, 1.34)
Number of fast food outlets per 1,000 people	1.12 (0.72, 1.73)	0.95 (0.79, 1.15)	1.22 (0.97, 1.55)	1.38 (1.11, 1.72)
Number of restaurants per 1,000 people	0.87 (0.52, 1.44)	0.94 (0.72, 1.24)	0.78 (0.55, 1.11)	0.77 (0.57, 1.06)
Number of specialty stores per 1,000 people	1.00 (0.69, 1.43)	1.18 (0.96, 1.46)	1.04 (0.83, 1.30)	1.00 (0.84, 1.19)
<i>Social environment</i>				
SES index t-score	0.99 (0.98, 1.01)	0.99 (0.97, 1.00)	1.00 (0.99, 1.02)	1.00 (0.99, 1.02)
Strong sense of community belonging	0.93 (0.81, 1.07)	1.05 (0.94, 1.17)	0.95 (0.85, 1.07)	1.04 (0.92, 1.16)
Councillor voting rate	1.08 (0.97, 1.20)	0.97 (0.86, 1.10)	0.91 (0.82, 1.02)	0.99 (0.85, 1.14)
Crime rate	1.14 (1.05, 1.23)	0.97 (0.89, 1.06)	0.92 (0.86, 0.99)	0.91 (0.85, 0.98)
<i>Contextual (season)</i>				
Summer	1.00	1.00	1.00	1.00
Fall	1.01 (0.75, 1.36)	0.95 (0.74, 1.21)	0.99 (0.74, 1.33)	1.11 (0.87, 1.41)
Winter	0.56 (0.39, 0.79)	0.54 (0.39, 0.77)	1.07 (0.79, 1.45)	1.05 (0.76, 1.45)
Spring	0.48 (0.36, 0.64)	0.80 (0.58, 1.11)	1.12 (0.81, 1.55)	1.03 (0.76, 1.40)
<i>Individual-level</i>				
<i>Age</i>				
18–24 years	1.00	1.00	1.00	1.00
25–44 years	0.54 (0.37, 0.79)	0.68 (0.46, 0.99)	2.85 (1.88, 4.33)	2.75 (1.80, 4.21)
45–64 years	0.36 (0.23, 0.54)	0.71 (0.45, 1.14)	4.28 (2.82, 6.52)	4.81 (3.14, 7.37)
65+ years	0.43 (0.25, 0.71)	0.59 (0.38, 0.91)	2.43 (1.52, 3.87)	3.94 (2.47, 6.28)
<i>Household income</i>				
≤\$29,999	1.00	1.00	1.00	1.00
≥\$30,000	1.65 (1.19, 2.29)	1.00 (0.73, 1.36)	1.39 (1.05, 1.84)	0.96 (0.73, 1.26)
<i>Education</i>				
Did not graduate from high school	1.00	1.00	1.00	1.00
Graduated from high school	0.81 (0.51, 1.28)	1.13 (0.64, 1.98)	0.69 (0.47, 1.02)	0.67 (0.43, 1.03)
Some post-high school education	1.28 (0.72, 2.29)	1.01 (0.57, 1.81)	0.82 (0.51, 1.34)	0.93 (0.57, 1.51)
College/university diploma/degree	1.16 (0.74, 1.83)	1.52 (0.92, 2.52)	0.56 (0.38, 0.84)	0.55 (0.37, 0.83)
<i>BMI category (for PA models), PA level (for BMI models)</i>				
Under/normal weight or inactive	1.00	1.00	1.00	1.00

Table 3 Continued on next page

Table 3 Continued

Overweight/obese or active	1.09 (0.85, 1.39)	0.62 (0.49, 0.79)	1.09 (0.85, 1.40)	0.63 (0.50, 0.79)
Smoking status				
Daily	1.00	1.00	1.00	1.00
Occasional	1.59 (0.90, 2.79)	1.10 (0.55, 2.21)	1.29 (0.79, 2.10)	0.78 (0.42, 1.43)
Former	1.40 (0.97, 2.03)	1.45 (0.90, 2.33)	1.63 (1.18, 2.24)	1.17 (0.87, 1.58)
Never	1.26 (0.83, 1.92)	1.32 (0.84, 2.09)	1.25 (0.89, 1.75)	0.90 (0.65, 1.24)
	Coefficient (s.e.)	Coefficient (s.e.)	Coefficient (s.e.)	Coefficient (s.e.)
Individual-level variance	-0.68 (0.26)	-1.17 (0.28)	-0.98 (0.30)	-1.08 (0.28)
Area-level variance	0.05 (0.04)	0.06 (0.05)	0.05 (0.03)	0.02 (0.02)
Intraclass correlation coefficient	7.93%	5.41%	5.38%	1.89%

All neighborhood-level variables have been standardized ((independent variable - mean)/s.d.). Statistically significant findings are highlighted in bold. CI, confidence interval; OR, odds ratio; PA, physical activity; SES, socioeconomic status.

Results of the present study also found that higher crime rates were associated with greater odds of LTPA in males and lower odds of overweight and obesity in both males and females. It is likely that crime correlates strongly with greater population density acting as a proxy measure for this environmental factor. Population density has been shown to be associated with higher levels of PA and lower BMIs (37).

The present study has limitations that should be recognized. First, the neighborhood-level indicators were collected between 2006 and 2008 while individual-level data were derived from four surveys spanning 2000–2007. We had confidence in using multiple years of survey data as Ottawa level estimates were relatively stable across this time period. Second, the individual-level variables were self-reported and evidence suggests that self-report measures of PA and height and weight differ significantly from their objective measures (38,39). In addition, PA was recalled from the previous 3 months which also adds to the possibility of recall bias. While it would have been preferable to use direct measures to examine these relationships, there is no known large dataset for the Ottawa area and collection of these measures on such a large scale would be very time and cost intensive. The self-report measures allowed us to capture data on a large scale and the use of a high PA cut-point (active vs. moderate/inactive) may have helped to identify individuals who were receiving health benefits. It is also important to realise that our PA outcome is based on LTPA and does not measure energy expenditures from activities of daily living. In addition, the use of BMI as a measure of overweight/obesity may misclassify individuals with a high muscle mass (40).

Another limitation of this study is its cross-sectional design; this prevents assessment of causality. Most previous research has relied on cross-sectional designs due to the costs associated with tracking a large group of individuals over time; however, prospective studies are needed to establish the direction of relationships. Finally, we were unable to assess perceptions of the neighborhoods including preferences and the likelihood that residents self-selected into their respective neighborhoods or that they crossed boundaries to access resources. It would have been ideal to determine whether the relationships differed between perceived awareness of resources and LTPA and

overweight/obesity. Unfortunately, the CCHS does not capture this information. Furthermore, it is possible that individuals who are more active select to live in neighborhoods that are supportive of their behaviors. While we did not assess preference and travel, we did control for clustering at the neighborhood level through hierarchical modeling.

Conclusions

Our results suggest that in this large Canadian city there is significant individual variation in PA and overweight/obesity that can be attributed to the neighborhood. Findings suggest that the recreation and social environment may play less of a role in LTPA and BMI status than the availability of neighborhood amenities and food outlets. In addition, neighborhood-level interventions to support PA and healthy weight may need to be gender and season tailored.

This study is the first of which we are aware that examines the multilevel associations between individual PA and overweight/obesity with neighborhood-level recreation, food and social environments and individual socio-demographics, and season in a large sample of urban-dwelling Canadians. Our findings provide support for the growing research demonstrating that physical inactivity and obesity may be partially explained by neighborhood-level exposures. Although there were few significant associations between the environment variables and LTPA and overweight/obesity, we are confident that our large sample size had adequate power to assess these relationships. Future research in this area is necessary to determine whether the findings could be replicated and whether the relationships would differ with the use of objectively measured PA and body composition, accounting for neighborhood preferences, parity and dog ownership and whether longitudinal associations exist.

ACKNOWLEDGMENTS

SAP received funding in support of her doctoral work from the Social Sciences and Humanities Research Council–Doctoral Award, the Ontario Ministry of Training, Colleges and Universities–Ontario Graduate Scholarships, and the University of Ottawa–Excellence Scholarships and Doctoral Research Award. The ONS was funded by the Canadian Institutes of Health Research (funding reference number 99345), the Champlain Local Health Integration Network, the Ottawa Coalition of Community Health, Resource Centres, and United Way Ottawa. Randy Mar, Cameron Hopgood,

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and the Ottawa Police Service are gratefully acknowledged for the crime data used in this research. While the data used for this research are those of Statistics Canada, the views and opinions expressed by the authors do not necessarily reflect those of Statistics Canada. This research is a contribution to the Ottawa Neighbourhood Study (<http://www.neighbourhoodstudy.ca>) and the authors would like to thank all those involved in its inception and maintenance including funders.

DISCLOSURE

The authors declared no conflict of interest.

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CHAPTER 7: MANUSCRIPT 5

This manuscript was written and published in accordance to the specifications of the peer-reviewed *Open Journal of Preventive Medicine*. It appears here in its publication format.

Title: Neighbourhood differences in objectively measured physical activity and body mass index.

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Suggested citation:

Prince SA, Tremblay MS, Prud'homme D, Colley RC, Sawada M, Kristjansson EA. (2011) Neighbourhood differences in objectively measured physical activity and body mass index. *Open Journal of Preventive Medicine*, 1(3): 182-189.

Neighbourhood differences in objectively measured physical activity, sedentary time and body mass index

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Received 9 September 2011; revised 13 October 2011; accepted 23 October 2011.

ABSTRACT

Background: There is limited Canadian research examining whether directly measured physical activity (PA) and body mass index (BMI) differ between neighbourhoods with different objectively measured socioeconomic (SES) and recreation (REC) environments. **Purpose:** To determine whether mean adult PA levels, sedentary time and BMIs were different across four neighbourhoods with contrasting SES and REC environments in Ottawa, Canada. **Methods:** This study employed a cross-sectional design to collect pilot data of objectively measured height, weight and PA (using accelerometry) and self-reported covariates in 113 adults (≥ 18 years). Four contrasting neighbourhoods (high REC/high SES, high REC/low SES, low REC/high SES, and low REC/low SES) were selected based on data collected as part of the Ottawa Neighbourhood Study. Analysis of covariance and logistic regression were used to perform neighbourhood comparisons for PA, sedentary time and BMI, adjusting for age, sex and household income and possible interactions. Post-hoc comparisons using Tukey's test were performed. **Results:** Significant neighbourhood-group effects were observed for light intensity PA and sedentary time. Post-hoc tests identified that the low REC/high SES neighbourhood had significantly more minutes of light PA than the low REC/low SES ($M_{diff} = 56.05$ minutes-day, Tukey $p = 0.01$). Unadjusted BMI differed between the four neighbourhoods, but the differences were not significant after controlling for age, sex

and household income. **Conclusions:** This study demonstrates that light PA and sedentary time differ between neighbourhoods of varying REC and SES environments after controlling for differences in age, sex and household income. Findings also suggest that other area-level factors may explain these neighbourhood differences.

Keywords: Physical Activity; Sedentary Time; Obesity; Neighbourhood; Environment

1. INTRODUCTION

Despite the benefits of daily physical activity (PA) and a healthy body weight for the prevention of several chronic diseases and premature mortality, most adult Canadians continue to fall short of PA recommendations and are overweight or obese [1-3]. Evidence suggests a link may exist between the recreation and social environments and an individual's likelihood of being physically active or overweight/obese [4-6]. Historically, the majority of research in this area has focused on perceived access to environments (e.g. what an individual feels they have access to or what they perceive their environment to be like) rather than objective measures of their built and socioeconomic environment (e.g. the number of facilities in their neighbourhood or average income levels) [7]. Results from objectively measured studies are mixed, but generally report positive associations between greater access to recreation environments and PA while lower access tends to be associated with greater odds of overweight and obesity [7-10]. Importantly, fewer studies have linked objectively measured environments to directly measured PA, sedentary time and body mass index (BMI) and even fewer have done

so in a Canadian context [7,10]. While some research has examined the independent relationship of either the recreation or social environments with PA and BMI, less is known about the possible synergistic effects of these two determinants. Research looking at environmental factors associated with light PA and sedentary time is emerging, but remains limited. In Canada, availability of recreation resources may be lower among neighbourhoods of lower socioeconomic status (SES) and, as such, an area's SES may affect the relationship of the recreation environment on PA [11-14].

In light of the possible effect of neighbourhood SES on the relationship between the recreation environment and PA and BMI, and current gaps in the literature, the main aim of this study was to compare objectively measured mean PA levels, sedentary behaviour and BMIs across four neighbourhoods with contrasting SES and recreation environments in adults living in Ottawa, Canada. Our hypothesis was that the neighbourhood with the fewest recreation resources and lowest neighbourhood SES would have the lowest levels of PA, greatest amounts of sedentary time and largest BMIs.

2. METHODS

This study was carried out in Ottawa, a large Canadian city with a regional population of approximately 1.2 million residents. Mean minutes of directly measured light, moderate and vigorous PA, sedentary time, step counts, and BMI were compared between participants living in four pre-selected, contrasting neighbourhoods characterized by their objectively measured SES and recreation (REC) environments. The study received ethical approval from the University of Ottawa's Health Science Research Ethics Board and the Children's Hospital of Eastern Ontario (CHEO) Research Ethics Board.

2.1. Participants

The study population includes 113 adults (≥ 18 years) with complete PA and BMI data. Participants were recruited through community newsletters, bulletin board posters, mailbox flyers, mail postcards, and word of mouth. Respondents were required to speak and read English or French, agree to wear an accelerometer for a minimum of five weekdays and two weekend days, have their heights and weights measured, and live within the boundaries of one of the study neighbourhoods as determined by their residential address. One adult per household was eligible to participate. Participants were provided with a \$20 honorarium and a PA profile following participation in the study. Study measurement sessions took place in public facilities where written informed consent was obtained, height and weight mea-

surements were taken and instructions for accelerometer use were explained. Participants were provided with an Actical® accelerometer (Phillips-Respironics, Oregon, USA), an instruction booklet/questionnaire, and a pre-paid addressed envelope to return the study materials and accelerometer.

2.2. Study Neighbourhoods

Participants were recruited from four neighbourhoods within the City of Ottawa. The neighbourhood boundaries were defined by the Ottawa Neighbourhood Study (ONS; www.neighbourhoodstudy.ca), a large study examining associations between neighbourhood characteristics and health outcomes. Figure 1 provides a map of the ONS neighbourhoods with the four chosen study neighbourhoods highlighted. The neighbourhoods were chosen to represent four contrasting areas based on REC and SES environments. The neighbourhoods are as follows: 1) high REC/high SES; 2) high REC/low SES; 3) low REC/high SES; and 4) low REC/low SES.

2.3. Ottawa Neighbourhood Study (ONS)

In the ONS, neighbourhoods were defined based on natural boundaries, similarity in SES and demographics, Ottawa Multiple Listing Services maps, and participatory mapping feedback from community members and experts [15]. Objectively measured environmental data were collected from 2006 to 2008 using the following data and methods: 1) 2006 Canadian census household data; 2) GIS data from DMTI Spatial Inc., the City of Ottawa, and the National Capital Commission; 3) telephone contact with businesses; 4) web-based research; 5) team knowledge of local resources; and 6) field research and validation. A further in-depth description of methods related to the ONS and its variables is available elsewhere [15].

2.4. Recreation (REC) Environment

The REC environment was based on a REC Index that was created using principal components analysis; this served as a measure of the density of facilities for recreation in a neighbourhood [15]. The REC index includes meters of bike and walking paths per person, meters-squared of park space per person, and recreation facilities per thousand people per neighbourhood. The REC index was *t*-scored to represent a mean of 50 with a standard deviation of 10 for comparability across neighbourhoods. Recreational facilities were defined using the North American Industry Classification System—Canada (NAICS) Code 71 and were only included if they were free or had a minimal cost [16]. Green space managed by the City or National Capital Commission was included in the park variable.

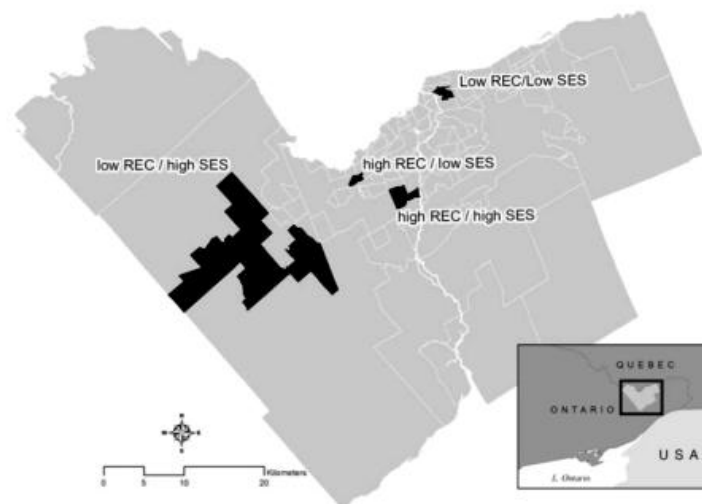


Figure 1. Ottawa neighbourhood study map and the four study neighbourhoods.

2.5. Socio-Economic (SES) Environment

The SES environment was assessed using a neighbourhood SES index developed using principal components analysis; it included percent of households below the low-income cut-off (LICO), average household income, percent of unemployed residents, percent of residents with less than a high school education, and percent of single-parent families [15,17]. The SES index was *t*-scored to represent a mean of 50 with a standard deviation of 10.

2.6. Individual-Level Outcomes

2.6.1. Physical Activity (PA) and Sedentary Time

PA was directly measured using Actical® accelerometers (Phillips-Respironics, Oregon, USA). The accelerometers are small, omni-directional, water resistant movement sensors able to capture all intensities of movement, including sedentary pursuits. The Actical® has been validated to measure PA and step counts in adults [18,19]. Participants were asked to wear the accelerometers on their right hip using an elasticized belt during their waking hours for a total of five week days and two weekend days. At midnight after the study meeting, data recording commenced. An epoch length of 60-seconds was used to capture movement in a count value per minute (cpm). Signals were also translated into steps per minute.

Valid accelerometer results were selected based on guidelines adopted for the data analyses of the Canadian

Health Measures Survey (CHMS) [2,20]. A valid day was defined as ≥ 10 hours of wear time and participants were required to have ≥ 4 valid days to be retained for the analyses. Data reduction and analysis was harmonized with the CHMS accelerometry data procedures. Further detail is available elsewhere [2,20].

The accelerometer data were downloaded using the Actical® software program and analysed in SAS. Data are presented as average daily minutes spent in moderate PA, vigorous PA, moderate-to-vigorous PA (MVPA), light activity, and sedentary time, and mean daily steps. PA intensity cut-points used in the identification of activity levels are provided in Table 1. PA was also analysed to assess those meeting current Canadian PA Guidelines and those who obtained an average of 10,000 steps per day versus those that did not [21,22]. If a participant had between four-to-six valid days, their weekly sum was calculated by multiplying the mean daily MVPA by seven.

2.6.2. Body Mass Index (BMI)

BMI was calculated using directly measured weight (kg) divided by height squared (m^2). Standing height was measured using a Seca 214 portable stadiometer (SECA, Hanover MD, USA) and recorded to the nearest centimeter and converted to meters. Weight was measured using a Life Source ProFit scale (A&D Medical, Milpitas, CA, USA) and recorded to the nearest 0.1 kg. BMI guidelines for adults were used to group individuals into the following categories: underweight (< 18.5

Table 1. Physical activity intensity cut-points for the actual as used by the Canadian Health Measures Survey [2,23,24].

Intensity	Metabolic Equivalent (METS)	Example	Accelerometer count range (CPM)
Sedentary	1 to less than 2	Car travel, sitting, reclining, standing	Less than 100*
Light	2 to less than 3	Walking less than 3.2 km/h, light household cleaning, cooking	100 to less than 1535
Moderate	3 to less than 6	Walking less than 3.2 km/h, cleaning (vacuuming, washing car), bicycling for pleasure	1535 to less than 3962
Vigorous	6 or more	Jogging, competitive team sport participation	3962 or more

CPM—counts per minute *including wear-time zeros.

kg·m²), normal weight (18.5 - 24.9 kg·m²), overweight (25.0 - 29.9 kg·m²), and obese (≥30 kg·m²) for descriptive purposes only [25]. BMI was analysed as a continuous outcome.

2.6.3. Individual-Level Covariates

Age and sex were forced into the models based on their known associations with PA and BMI. Household income was included based on its significant bivariate association with PA. Information on work, education, marital and smoking status and number of individuals per household were also collected, but were all significantly correlated with household income. To avoid multicollinearity and obtain the most parsimonious model given the sample size, they were not included. Season of data collection was also available; however, it was not significantly associated with either PA or BMI. All covariates were self-reported. Missing information for age or income was imputed based on regression parameter estimates from models using sex, neighbourhood and BMI as predictors. In total, three participants were missing information on age and an additional seven were missing information for income.

Age was included as a continuous measure. Sex was coded as male or female. Household income was considered as a two-level categorical variable that accounts for the number of people in the household and total household income from all sources in the 12 months before the interview: "lower" (<\$60,000 for 1 - 2 people; <\$80,000 for ≥3 people) compared to "upper" (≥\$60,000 for 1 - 2 people; ≥\$80,000 for ≥3 people).

2.7. Statistical Analysis

All analyses were conducted using SAS version 9.2 (SAS Institute Inc., Cary, NC, USA). Unadjusted descriptive statistics were performed to derive means ± standard deviations and frequencies of all demographic variables for each neighbourhood. Unadjusted between neighbourhood comparisons were analysed using one-way analysis of variance (ANOVA) for continuous variables and chi-square tests for dichotomous variables. Adjusted between neighbourhood comparisons were performed using analysis of covariance (ANCOVA) for continuous outcomes (using Proc GLM and LSMeans

for unequal designs) and logistic regression for binary outcomes (using Proc Logistic and Proc GLM). ANCOVA models allowed for the adjustment of differences in the covariates between neighbourhoods and between subjects in each neighbourhood. Interactions were tested between all covariates and neighbourhoods with no significant interactions observed. Post-hoc Tukey tests were used to perform pairwise comparisons for PA and BMI between the individual neighbourhoods.

3. RESULTS

3.1. Sample Characteristics

A total of 126 adults (≥18 years) were recruited from four neighbourhoods. From this sample, 113 had complete BMI and valid PA data and were used in the analyses. Table 2 provides descriptive characteristics of the participants by neighbourhood.

The participants were reasonably well distributed across the neighbourhoods. Compared to the general Canadian population as assessed by the CHMS, the study participants were leaner than a representative Canadian sample (53% versus 38% healthy weight), had similar proportions meeting step-per-day guidelines (35% versus 34%) and had a greater proportion of individuals meeting MVPA guidelines (31% versus 15%) [2,3].

3.2. Neighbourhood Differences in Physical Activity

Tables 3 provides comparisons of mean PA levels and proportions meeting the current Canadian PA guidelines [21]. Unadjusted comparisons showed that only mean daily minutes spent in light PA ($p = 0.01$) differed between participants living in the four neighbourhoods; this difference was stronger after adjustment for covariates ($p = 0.002$). Following adjustment, a significant group effect was observed for minutes of sedentary behaviour and light PA. The low REC/high SES neighbourhood had the most minutes spent engaged in light PA with post-hoc tests identifying average minutes were significantly higher than the low REC/low SES neighbourhood ($M_{diff} = 56.05$ minutes-day, Tukey $p = 0.01$).

Following adjustment, mean differences in average

Table 2. Participant characteristics by neighbourhood (n = 113).

Characteristics	High REC/ High SES (n=29)	High REC/ Low SES (n=29)	Low REC/ High SES (n=23)	Low REC/ Low SES (n=32)
Male sex, n (%)	8 (28%)	6 (21%)	4 (17%)	7 (22%)
Age, years	51.3 ± 13.7	48.1 ± 14.1	51.0 ± 14.1	45.8 ± 15.0
BMI category, n (%)				
Underweight	0	1 (3%)	0	0
Healthy weight	17 (59%)	19 (66%)	7 (31%)	17 (53%)
Overweight	9 (31%)	7 (24%)	12 (52%)	8 (25%)
Obese	3 (10%)	2 (7%)	4 (17%)	7 (22%)
Household income, n (%) ^a				
Low	2 (7%)	7 (24%)	7 (30%)	18 (56%)
High	27 (93%)	22 (93%)	16 (70%)	14 (44%)

Data are presented as mean ± standard deviations unless otherwise stated. REC – recreation index score, SES – socioeconomic status index score. ^aMean differences between neighbourhoods based on chi-square or ANOVA; $p < 0.001$.

Table 3. Unadjusted and adjusted* average daily and weekly minutes of activity at various levels of intensity, average daily step counts, percent meeting physical activity guidelines, and body mass index by neighbourhood (total n = 113).

	Unadjusted				p-value	Adjusted*				p-value
	High REC/ High SES (n=29)	High REC/ Low SES (n=29)	Low REC/ High SES (n=23)	Low REC/ Low SES (n=32)		High REC/ High SES (n=29)	High REC/ Low SES (n=29)	Low REC/ High SES (n=23)	Low REC/ Low SES (n=32)	
Activity intensity										
Daily minutes of sedentary	581 ± 13	602 ± 13	570 ± 15	596 ± 13	0.39	591 ± 16	611 ± 15	576 ± 16	599 ± 13	0.05
Daily minutes of light	98 ± 12	87 ± 12	114 ± 14	57 ± 12	0.01	88 ± 14	76 ± 13	105 ± 15	49 ± 12	0.002
Daily minutes of moderate	15 ± 4	13 ± 4	14 ± 4	20 ± 4	0.52	13 ± 4	12 ± 4	13 ± 5	20 ± 4	0.82
Daily minutes of vigorous	4 ± 1	2 ± 1	1 ± 2	3 ± 1	0.67	3 ± 2	2 ± 2	1 ± 2	3 ± 1	0.24
Daily minutes of MVPA	19 ± 4	16 ± 4	17 ± 5	23 ± 4	0.59	17 ± 5	14 ± 5	15 ± 5	23 ± 4	0.82
Weekly minutes of MVPA	134 ± 29	112 ± 29	115 ± 32	161 ± 27	0.59	118 ± 35	100 ± 33	105 ± 36	159 ± 30	0.82
Daily step counts	9446 ± 682	8518 ± 682	8596 ± 766	8413 ± 649	0.69	9208 ± 815	8227 ± 768	8436 ± 841	8217 ± 696	0.57
Met weekly MVPA guidelines, n (%)	10 (34%)	9 (31%)	6 (26%)	10 (31%)	0.94	8 (31%)	8 (27%)	6 (22%)	12 (29%)	0.97
Met daily step guidelines, n (%)	12 (41%)	9 (31%)	8 (35%)	9 (28%)	0.75	10 (38%)	12 (27%)	6 (32%)	12 (25%)	0.34
Body mass index, kg·m ⁻²	24.7 ± 0.8	23.9 ± 0.8	27.0 ± 0.9	26.3 ± 0.8	0.045	24.8 ± 1.0	24.2 ± 0.9	27.3 ± 1.0	26.7 ± 0.8	0.13

All activity is reported in average minutes except for step counts. All results shown as mean ± standard error. P -value for ANOVA/ANCOVA or chi-square/logistic regression models. MVPA—moderate-to-vigorous physical activity. *Adjusted for age, sex, household income.

steps per day remained non-significant between neighbourhoods. Furthermore, no significant differences in the proportion of participants meeting the current PA guidelines either by weekly minutes of MVPA or daily step counts were observed. The data were also analysed using percentage of wear time spent in the various levels of PA in order to adjust for the fact that individuals with longer wear times may have subsequently higher minutes of time spent in light and sedentary pursuits. Both the unadjusted and adjusted results were virtually identical to those found for the mean minutes spent at the various PA intensities.

3.3. Neighbourhood Differences in Body Mass Index (BMI)

Table 3 provides comparisons of mean BMIs across

the four neighbourhoods. Unadjusted comparisons identified that BMI differed between participants living in the four neighbourhoods ($p = 0.045$); this difference lost significance following adjustment ($p = 0.13$). Participants from the two low REC neighbourhoods had the highest average BMIs. Post-hoc tests identified that the low REC/high SES had a higher average BMI than the high REC/low SES neighbourhood, but this difference only approached significance ($M_{diff} = 3.09 \text{ kg·m}^2$, Tukey $p = 0.06$).

4. DISCUSSION

This study aimed to investigate whether PA levels, sedentary time and BMI differed between adults living in four Ottawa neighbourhoods with contrasting SES and REC environments. To the best of our knowledge,

this is the first study to use objective measures of the neighbourhood environment and directly measured PA, sedentary time and BMI in a Canadian population. Furthermore, it is one of the first to look at objective measures of the REC environment, rather than previously examined land-use mix and walkability characteristics, along with SES on directly measured PA levels, sedentary time and BMI. The results support the notion that PA, sedentary time and BMI may differ by factors in the built and social environments and that these differences can be independent of individual-level determinants. The findings do not support our original hypothesis that individuals living in a neighbourhood with a combination of low SES and low availability of recreation facilities would have the lowest amounts of daily PA, greatest amount of sedentary time and highest BMIs.

Interestingly, we found that minutes spent in light PA were significantly greater in the low REC/high SES neighbourhood compared to the low REC/low SES neighbourhood. Research on impacts of the environment on light PA is limited and as mentioned, especially using objective measurements. Research on a small sample of Belgian adults ($n = 120$) demonstrated that adults living in a 'high walkable' neighbourhood took more steps per day and walked more for transport than those living in a 'low walkable' neighbourhood [26]. Research has also shown that higher mixed-land use is associated with greater levels of PA, possibly due to increased use of active transport [8]. While walkability and mix-land use factors were not used to select our study neighbourhoods, they do offer a reasonable explanation for why light PA was higher in the low REC/high SES neighbourhood.

Area zoning measures were calculated for all four neighbourhoods as a proxy for land use variety. The low REC/low SES neighbourhood had the greatest number of different zonings at 114 compared to the high REC/high SES neighbourhood with 34 and the high REC/low SES neighbourhood with 30. The low REC/high SES neighbourhood had 113 different zonings; however, as can be seen in Figure 1, this neighbourhood is one of the largest in Ottawa and naturally would have a greater distribution simply due to its geographical size. The density of the zonings would therefore be lower than in the low REC/low SES neighbourhood.

While walkability was not assessed in the current study, the low REC/high SES neighbourhood is rural compared to the urban and more walkable low REC/low SES neighbourhood. Forms of active transportation are often included as MVPA, therefore, the light PA may be capturing more incidental movements associated with lower intensity activities of daily living such as house and yard work [23]. It is also likely that the low REC/high SES neighbourhood has larger homes and

properties, possibly resulting in greater time spent in light household chores. Research has also shown that possible urban-suburban-rural differences exist for PA with rural neighbourhoods more likely to be inactive [27-29]. It is possible that a lower land-mix use and decreased walkability may provide an explanation for why daily light PA was higher in the low REC/high SES neighbourhood compared to the low REC/low SES neighbourhood. Furthermore, research on neighbourhood SES has also shown that adults living in areas described as lower SES are more likely to use active transport and less likely to use motorized transport [30].

Research on the impact of neighbourhood environments on sedentary behaviour is very limited. Recent work by Van Dyck and colleagues looked at the effect of neighbourhood walkability on accelerometer measured sedentary time in adult men and women from Belgium [31]. Their study identified that contrary to general hypotheses, living in a highly walkable neighbourhood was associated with greater amounts of time spent in sedentary pursuits [31]. Interestingly, neighbourhood SES was not significantly associated with daily inactivity and neighbourhood SES did not modify the relationship between walkability and sedentary time [31]. These findings are similar to those seen in the current study whereby our more urban and walkable neighbourhoods had higher amounts of sedentary time compared to our rural and less walkable (low REC/high SES) neighbourhood.

In another investigation the current authors examined the multilevel associations of the recreation and social environments on self-reported PA and BMI across all of the neighbourhoods in the City of Ottawa using data from the Canadian Community Health Survey (Prince SA, Kristjansson EA, Russell K *et al.* Relationships between neighbourhoods, physical activity and obesity: A multilevel analysis of a large Canadian City. Unpublished). Findings from that study indicated that leisure time PA and overweight/obesity were not significantly associated with any recreation resources or social environment variables. In light of these findings and that our neighbourhoods were only selected based on REC and SES, it is likely that other environmental characteristics are influencing PA levels. The relative influence of where people live and work on their PA and BMI may differ by population density characteristics and/or other factors and requires further study. Finally, it is possible that more robust, direct measures may produce fundamentally different results than self-reported measures, and indeed that convention thinking of the influence of built and social environments needs to be challenged and perhaps there are other factors yet to be identified/measured that are impacting upon the environment's

relationship with PA and BMI.

The present study has limitations that should be recognized. The study's sample size may have been too small to see possible differences and clear trends. It must be noted that recruitment for this study was onerous likely due to the nature of the direct measurement of PA and BMI and the constraints placed on location and times of participant meetings by the Research Ethics Boards. This likely resulted in a biased sample of highly motivated individuals, a common bias in research of this nature. The population was also highly educated (23% had a graduate-level degree e.g. masters, doctorate) and affluent (70% had a high household income) and the results are therefore not generalizable. The study should therefore be treated as pilot-level information to challenge other researchers to employ more rigorous measurement methodologies.

It is also important to realize that the accelerometers provide objective measures that remove self-report biases, but they are unable to capture all forms of PA accurately (e.g. weight lifting, rowing, cycling). Participants were also asked to remove the monitors during water activities and as a result swimming was not captured in the PA data.

5. CONCLUSIONS

This is the first known Canadian study to examine whether objectively measured neighbourhood recreation and SES environments are associated with levels of directly measured PA and BMI. Results of this study identify that minutes of light intensity PA and sedentary behaviour differ between neighbourhoods of varying recreation and SES environments after controlling for differences in age, sex and income. Findings also suggest that other area-level factors such as mixed-land use and degree of urbanism may explain these neighbourhood differences. Future research into the impact of the neighbourhood on PA and BMI should concomitantly assess multiple aspects of the environment including, but not limited to recreation, amenities, walkability, mixed-land use, population density, SES, social support, social cohesion, crime, and perceptions and preferences of the neighbourhood.

6. ACKNOWLEDGEMENTS

The authors are grateful to Travis Saunders for his efforts in participant recruitment, data collection and verification and to Dr. Jean-Michelle Billette and Ms. Megan Carter for their statistical and methodological advice. Support for the ONS was provided by the Canadian Institutes of Health Research (funding number 99345), the Champlain Local Health Integration Network, the Ottawa Coalition of Community Health, Resource Centres and United Way Ottawa. Funding for the

collection of individual data was provided by a Faculty of Health Sciences and CHEO Partnership Research Grant. S. Prince received funding in support of her doctoral work from the Social Sciences and Humanities Research Council of Canada-Doctoral Award, Ontario Ministries of Ontario Graduate Scholarships and a University of Ottawa Excellence Scholarship and Doctoral Research Award.

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CHAPTER 8 GENERAL DISCUSSION

8.1 Bridging the manuscripts – A summary of key findings

The overall purpose of this thesis was to examine the associations between objectively measured built and social environments and self-reported and directly measured PA and BMI in adults living in Ottawa, Canada. A component of this thesis examined the differences between self-reported and directly measured PA in adult populations to assess the level of agreement between the two measures. The first manuscript discussed population health frameworks for obesity and served as a primer for the analyses that followed in the subsequent papers. The second manuscript is a systematic review of the literature that compared self-reported and directly measured PA in adult populations. The third manuscript examined the relationships between objectively measured built and social environment variables with *self-reported total PA* and overweight/obesity in Ottawa adults using data from the RRFSS. The fourth manuscript used the same objective measures of the environment, but examined associations with *self-reported LTPA* and overweight/obesity in Ottawa adults using CCHS data. The fifth and final manuscript reported on the primary collection of *directly measured intensities of PA, sedentary behaviour* and BMI data from a convenience sample of adults living in four Ottawa neighbourhoods that differed based on their built and social environmental characteristics.

The results of the systematic review contribute to the existing literature concerning the measurement of PA and identifies that self-report and direct measures do not agree. These results are important and need to be considered in the interpretation of studies examining associations with factors in the neighbourhood environment.

The three analytical manuscripts provide knowledge that is otherwise absent in the Canadian literature regarding the built recreation and social environments and adult PA levels. They identify the potential for PA and BMI to differ by neighbourhood, but also suggest that other factors in the environments may affect behaviours and outcomes. Finally, the lack of clear and consistent findings challenges the conventional thinking that the neighbourhood built recreation and social environments are strong influences on Canadian adults' PA and BMI and perhaps there are other factors yet to be identified and measured, or existing outside of the residential neighbourhood, that impact the environment's relationship with PA and BMI.

8.2 Revisiting the objectives

In order to satisfy the objectives, this thesis conducted a systematic review of the literature surrounding the validity and reliability of PA measurements in adults, performed two secondary analyses using self-reported data from the RRFSS and CCHS linked to objectively measured built and social environment variables from the ONS, and a cross-sectional analysis of directly measured PA and BMI data collected for the purpose of this thesis in four contrasting neighbourhoods classified using data from the ONS. The following is an examination of the objectives of the thesis and the subsequent findings as they relate to the objectives.

Objective 1: *To perform a systematic review of the literature to compare the agreement between self-report and direct measures in assessing PA in adult populations.* The second manuscript of this thesis reports on the results from a systematic review comparing self-reported and directly measured PA in adults. Results from the review generally indicate a

poor level of agreement between self-report and direct measures of PA, with trends differing based on the measures of PA, the level of PA examined and the sex of the participants. Findings of the review suggest that the measurement method may have a significant impact on the observed level of PA and that caution should be exerted when comparing studies' results based on different measures of PA. Based on these findings, it is clear that relationships between PA behaviours and measures of the built and social environments will differ significantly depending on measurement methodology.

Objective 2: *To determine the associations between the built recreation and social environments and self-reported total PA and BMI in the City of Ottawa adult population.*

The third manuscript of this thesis discusses the findings of a secondary data analysis looking at the cross-sectional relationships between self-reported total PA and overweight/obesity from the RRFSS with objectively measured variables in the built recreation and social environments of adults living in City of Ottawa neighbourhoods. The study found that the level of variation in PA or overweight/obesity attributed to the neighbourhood level was low. Results identified that only two built recreation variables were significantly associated with PA. Green space was associated with PA among males, but in the counter-intuitive direction with higher green space associated with lower odds of PA. Greater park area was associated with higher PA in females, however the findings were borderline significant. Further to the PA findings, the study identified that women were more likely to be overweight or obese with every additional summer outdoor facility and less likely with greater green space area. The opposite was found in men, as they were more likely to be overweight or obese with greater green space area. Findings identified that the social environment had a greater impact on outcomes among males. Higher aggregated

sense of community belonging for males was associated with a greater likelihood of PA and being overweight or obese. In addition, men were less likely to be overweight or obese when residing in neighbourhoods with lower socioeconomic scores and higher voting rates.

Further to the recreation environment, factors in the food landscape were significantly associated with male and female PA and overweight/obesity. It is possible that in adults the recreation environment is less important for all-domain PA than area access to other amenities related to walkability.

Objective 3: *To determine the associations between the built recreation and social environments and self-reported LTPA and BMI in the City of Ottawa adult population.* The fourth manuscript of this thesis discusses findings of a secondary data analysis looking at similar relationships between self-reported leisure-time PA and overweight/obesity from the CCHS with the same objectively measured variables in the built recreation and social environments used in objective 2. This manuscript used LTPA rather than total PA, which was hypothesized to be more greatly influenced by factors in the recreation environment. Surprisingly, findings revealed that the only significant recreation variable was park area. Greater park area was significantly associated with increased odds of female LTPA and overweight/obesity. While these findings seem contradictory, it is important to understand that they are two separate outcomes which may not represent the same relationship. Individuals who are more physically active in a given neighbourhood are not necessarily those with the highest BMIs. Furthermore, people with BMI scores $> 25 \text{ kg/m}^2$ can be physically active, it is not a contradiction. It is also possible that, because of the methodology used to measure LTPA in this study, the self-reported data may have lead to a misclassification of PA levels and BMI status.

Crime rates were the only significant social environment variable associated with the outcomes. Contrary to the original hypothesis, higher crime rates were associated with greater odds of male LTPA and a lower likelihood of males and females being overweight or obese. Within the ONS higher crime rates have shown to cluster in the more urban and population dense neighbourhoods. Higher population density has been consistently shown to be associated with higher levels of PA and lower BMIs in adult studies (1;2).

Objective 4: *To determine whether adult directly-measured PA levels, sedentary time and BMIs were different across four neighbourhoods with contrasting socioeconomic and recreation environments in the City of Ottawa.* The fifth and final manuscript of this thesis reports on a cross-sectional analysis of directly measured PA, sedentary time and BMI data collected for the purpose of this thesis in four City of Ottawa neighbourhoods with contrasting socioeconomic and built recreation environments classified using data from the ONS. The study found significant neighbourhood-group effects for light intensity PA and sedentary time after adjustment for age, sex and household income. The low REC/high SES neighbourhood had on average 56 more minutes of light PA than the low REC/low SES neighbourhood. The more urban and walkable neighbourhoods had higher amounts of sedentary time compared to the rural and less walkable (low REC/high SES) neighbourhood. Moderate and vigorous levels of PA did not differ between the four neighbourhoods, however, the majority of the sample accrued very few minutes at these intensity levels, limiting the variation in these outcomes. BMI did not differ significantly between the four neighbourhoods following adjustment.

The four neighbourhoods were selected based on the combination of the composite recreation and socioeconomic indices. As such, the neighbourhoods do not necessarily

represent the highest/lowest recreation or highest/lowest socioeconomic neighbourhoods in Ottawa and subsequently the greatest variation in levels of exposure. It is also likely that other neighbourhood-level factors not accounted for in our neighbourhood selection such as population density, rural/urban status, walkability, crime rates, and social capital may further explain the findings. It is also possible that individual-level factors could be more dominant than previously thought.

Objective 5: *To determine whether any difference in these relationships existed between males and females.* Gender differences were examined using male and female specific multilevel models in the third and fourth manuscripts and by testing a gender interaction term in the pilot study (fifth manuscript). Within the built recreation environment, only green space and park area showed any significant associations with either male or female outcomes. Park area was significantly associated with both total PA and LTPA in females only. Green space defined as unmaintained land; was significantly associated with a reduced likelihood of total PA in males only and associated with higher odds of males and lower odds of females being overweight or obese. The negative association in males may be attributed to low motivation for using green space. Green spaces lack specificity for use and men are more likely to prefer more formal facilities where they can engage in more vigorous types of PA (e.g. sports) (3). The positive association of park area with female PA may be attributed to the fact that women are more likely to visit areas like playgrounds with their children. Total PA and LTPA were self-reported and may therefore be subject to recall and social desirability bias with women reporting greater levels of activity than if PA had been directly measured. The gender differences in green space associations with overweight/obesity rates are not clear.

Gender differences in the associations between the social environment and PA and overweight/obesity were also observed. In general, the social environment was more strongly related to outcomes among males. It is possible that other factors in the social environment such as social support or intrapersonal factors are stronger determinants of female PA. Unfortunately this thesis was unable to test these theories.

Within the pilot study gender was not identified as a significant effect modifier of the neighbourhood environment on directly measured PA, sedentary time or BMI. Important to note however, is that that only 22% of the sample was male.

8.3 Revisiting the conceptual framework

Providing an environment that maximizes an individual's opportunity to be physically active and maintain a healthy body weight is an important population health goal. As such, this thesis was organized around a socio-ecological framework for PA and obesity (**Chapter 1, Figure 2**). The framework recognizes individual behaviours may be dependent on the dynamic relationships between the structure and function of the environment and an individual's interaction with these features (4). Within the framework, individuals are influenced by multiple health determinants including their environments across multiple levels of interaction (intrapersonal, interpersonal, community, etc.) over the lifespan. Findings from this thesis recognize just how complex the relationships are between individuals and their environments. The data employed were all cross-sectional and as such it is not possible to understand in which direction and order these relationships occur. For example, do individuals choose to move into a neighbourhood that supports their enjoyment of PA, or does their environment determine how active they are? This poses a 'chicken or egg' discussion over the causality of PA and obesity. Furthermore, is the neighbourhood

recreation environment useful for increasing adult PA or is this more of a factor for children who are more likely to engage in more playful forms of PA? It is possible that built environmental factors related to neighbourhood walkability have a greater influence on adult PA through means of increasing active transportation and enabling PA to be integrated into daily functions? Does location of employment and the built environment at work have a significant effect on daily PA? Regardless, it is important to realise that children need positive role modeling and as such it is essential that families and communities are provided with supportive environments to create opportunities for teaching children how to actively engage in their environments. It is also possible that a myriad of other factors in the environment may affect adults' use of the recreation environment, such as knowledge of the facilities, social norms around their use, time factors, safety of the facilities, and other factors. Unfortunately, this thesis was not able to delve into understanding all of these complexities, but it did help me to understand that the mere presence of these resources does not appear to be enough to be associated with adult PA especially in leisure time.

In the City of Ottawa, a gradient exists whereby neighbourhoods with higher socio-economic levels possess more opportunities and facilities for recreation. Interestingly, in the direct measures study no clear pattern emerged regarding the combination of these two environmental factors and their relationship with PA or BMI. Furthermore, lower neighbourhood SES was only significantly associated with a reduced likelihood for being overweight or obese in males in the RRFSS paper. It is possible that within Ottawa, the area-level social gradient often observed in U.S. studies is not as steep for the outcomes of PA and overweight/obesity. It is also possible that the belief that “if you build it they will come” is untrue.

Individual-level indicators of SES (i.e. household income, education) were significantly associated with PA and overweight/obesity. Individual SES has been repeatedly shown in the literature to be an important influence on health behaviours and outcomes (5) and has the capacity to impact how an individual interacts with their environment. Further, individual SES is likely related to area SES making the relationship difficult to tease apart. Applying the socio-ecological framework requires consideration of context when examining health outcomes and their environments. Within the City of Ottawa, low SES neighbourhoods do not exist in isolation from high SES neighbourhoods and with individuals not only influenced by their area of residence, but also where they work and play! It is also likely that while this thesis was original in its use of several neighbourhood-level indicators of the social environment it was unable to assess the relationships between several other important social factors with PA and BMI. These factors include the policies in place to support the use of the recreation environments, social norms for being physically active and eating healthily, and residents' actual perceptions of the environment.

While the findings of this thesis do not present a clear picture regarding the neighbourhood recreation and social environments' relationships with PA and BMI, it does challenge some existing beliefs and provide a launching point for future research. As demonstrated by the circles in the conceptual framework, environments are complex and future work is still necessary to understand how individual determinants (or characteristics) influence how people interact with their environments, which environmental factors are the most important and in what context, and at what level should future interventions be targeted (i.e. nation, province, municipality, neighbourhood, or individual). In light of the complexity of these relationships, creating healthy community environments that provide health

promoting opportunities and the social support needed to enable Canadians to achieve healthy lifestyles should remain a public health goal, but understanding how to create these environments remains an important research question.

8.4 Overall limitations of the thesis

There are several limitations to this thesis. The major limitation of the systematic review was related to its sample which was limited to studies that included directly comparable data between self-report and direct measures (same units for both measures) or a comparison by way of correlation. Access to primary data from each study was not feasible; therefore, the review relied upon reported comparisons and the means of measured PA. This ultimately reduced the number of studies and limited the capacity to accurately assess the degree of agreement between self-report and direct measures, however, when possible non-comparable units were converted to increase the number of studies used. The review was also not able to discern between differences in study protocols related to calibration, cut-points, or collection of the measurements and other population specific characteristics which would be important factors to consider for repeatability and use within population-based studies.

The two multilevel model studies had limitations that should be recognized. First, the neighbourhood-level indicators were all collected between 2006 and 2008 while the individual-level data comprised of the combination of surveys spanning years 2001 to 2007. The temporality of the data collection periods may have biased the results as individuals were not exposed to the same environments at every survey time point. While this bias may be present, it was suggested that Ottawa level estimates remained relatively stable across this time period (data were originally collected in 2006 and re-assessed in 2008) [Personal communication with Elizabeth Kristjansson and Michael Sawada; Principal Investigators of

the Ottawa Neighbourhood Study]. Secondly, these studies were unable to control for the fact that individuals may have responded in multiple cycles of the RRFSS and CCHS resulting in the capacity for an individual to be over-represented. While this is a potential source of bias, it was likely overcome by the large sample sizes used. A third limitation of these studies is that the individual-level variables were self-reported and as the systematic review evidence suggests; self-report measures specifically for PA differ significantly from their objective measures (6). While it would have been preferable to use direct measures to examine these relationships, there is no known large dataset for the Ottawa area and collection of these measures on such a large scale would have been very time and cost intensive. This limitation also served as rationale for using a higher PA cut-point (high PA versus low and moderate PA) in the self-reported data in an attempt to identify individuals who were truly active. The disagreement between self-reported and directly measured PA found in the systematic review was a motivating factor for the collection of directly measured PA in the pilot study (manuscript 5). However, even with the use of direct measures, there remain challenges to data interpretation. It is important to realize that while the accelerometers provided objective measures that removed self-report biases, they were unable to capture all forms of PA accurately (e.g. weight lifting, rowing, cycling). Participants were also asked to remove the monitors during water activities and as a result swimming and water sports, which did occur, were not captured in the PA data.

Several important individual variables including intrapersonal factors (e.g. genetics, motivation, intention and attitudes), interpersonal factors (e.g., social support for PA), diet, and movement out of the neighbourhood were not captured. The data also did not capture neighbourhood preferences and the likelihood that people self-selected into their respective neighbourhoods. It is possible that individuals who are more active select to live in

neighbourhoods that are supportive of their lifestyles. While the studies did not assess preference, they controlled for clustering at the neighbourhood level. It would have also been ideal to determine whether the relationships differed between perceived awareness of resources and PA and BMI or to have accounted for the fact that individuals were likely to cross neighbourhood boundaries to utilize other resources, and as such, the studies' natural neighbourhoods may not truly represent the correct level of exposure. Unfortunately, none of the studies captured this information.

The pilot study's sample size may have been too small to see possible differences and clear trends. It must be noted that recruitment for this study was onerous likely due to the nature of the direct measurement of PA and BMI and the constraints placed on location and times of participant meetings by the Research Ethics Boards. This likely resulted in a biased sample of highly motivated individuals, a common bias in research of this nature. The population was also highly educated and affluent and the results are therefore not generalizable.

One of the major limitations of all the analyses conducted in this thesis was the cross-sectional study design. This design rendered it impossible to assess the causality of the relationships of the built and social environments with PA and overweight/obesity. Most of the previous research has also relied on cross-sectional designs due to the sheer costs and complexity associated with tracking such a large group of individuals over time. Intervention research may provide a means of assessing causality without the need to collect data on such a large scale.

8.5 Strengths of the thesis

This thesis topic is timely and important due to the high prevalence of physical inactivity and overweight/obesity in Canada. Prior to this thesis, no attempt had been made to synthesize the literature to determine the comparability of PA measures in adult populations. Results from the systematic review suggest that measurement methods of PA may have a significant impact on the observed levels. Self-report measures generally differed from directly measured levels of PA, which poses a problem for reliance on self-report measures. The review revealed the need to exert caution when interpreting study results based on self-report methods and a requisite for the use of valid, accurate and reliable measures when examining relationships between exposures of interest and PA.

At the onset of the thesis planning stages, research examining the influences of the built and social environments on rates of PA had largely occurred in non-Canadian populations (mostly US) (7) and the majority had involved perceived environments and self-reported PA and BMI measures. Furthermore, sex-based analyses were often lacking in these studies (8) creating a knowledge gap on whether possible sex differences in these relationships existed (9). To address gaps in previous research this thesis used objectively measured built and social environmental factors with both self-reported and objectively measured PA and BMI while applying sex-specific analyses and testing for sex interactions in samples of adults within Canada's capital city.

Several previous studies had also relied on single-level analyses creating an ecological fallacy and ignoring that individuals are nested within their environments. By applying a population health and socio-ecological framework, this thesis acknowledged the interaction of individuals within their environments through the use of multilevel modeling techniques. While this analytical approach was not possible for the pilot study (due to the

small sample size), between group comparisons acknowledged the capacity for PA and BMI to cluster by neighbourhood group.

8.6 Population health and research implications

Results of this dissertation show that the quantity of PA can differ based on its method of measurement (i.e. between self-report and direct methods) with implications for the interpretation of study findings. It also identifies that PA and BMI can differ by neighbourhood and recognizes that the relationships between neighbourhood environments and PA and body composition are complex, may differ between males and females, and may not always follow intuitive relationships. Furthermore it suggests that other factors in the environment not examined in this dissertation may influence adult PA and BMI and that longitudinal and intervention studies are needed.

This work has made an important contribution to understanding the potential biases present in the measurement of PA, especially given that the majority of previous Canadian surveillance studies (other than the CHMS which was initiated during this thesis) and environmental research has relied on self-reported PA. The systematic review has already become a highly cited and accessed piece of literature and provides background material for justification of the CHMS and the use of direct measures of PA in surveillance and research.

To summarize, this dissertation presents a series of recommendations that will help improve future population health research on environments, PA and obesity. The recommendations are as follows:

1. When possible and appropriate collect direct measures of PA and height and weight as self-report measures have been shown to introduce bias. When direct

measurements are not feasible findings should be interpreted with these biases in mind.

2. Use directly measured PA and BMI data in large Canadian studies examining the relationships with objective and perceived environment-level factors.
3. Simultaneously investigate walkability and the recreation environment in order to identify which is a more important determinant of adult PA.
4. Simultaneously investigate perceptions of the environment along with objective measures to identify which is a more important determinant of adult PA.
5. Assess the level of agreement between perceived and objectively measured environments for use in future studies and in interpretation of study findings.
6. Investigate other area-level factors including area social support for PA, PA policies, spending on PA resources and programs, and quality of environmental resources that may impact population levels of PA and overweight/obesity with the potential for intervention.
7. Compare adults and children where possible to identify how environmental determinants of PA and BMI likely differ.
8. Conduct longitudinal studies following individuals over time while controlling for movement out of their neighbourhood, access of resources outside of the neighbourhood, and changes in PA and BMI over time.
9. Conduct intervention studies (e.g. install new bike paths or update, add signage to pre-existing parks, or increase municipal spending on recreation infrastructure) at the neighbourhood or area level to examine whether changes in the built or social environments can positively impact population PA levels and decrease the risk for overweight and obesity.

Results of this thesis also add to the growing Canadian literature looking at the relationships between the built recreation and social environments and PA and BMI. They identify that in a Canadian context the objective measures examined from the built recreation and social environments may not be as strongly associated with PA and BMI as in the American literature and ultimately challenges conventional thinking on these relationships. The findings also suggest that perhaps there are other factors yet to be identified/measured that are impacting upon the environment's relationship with PA and BMI and that future research is needed to identify these factors and to assess causality in the relationships.

8.7 References

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APPENDIX A. ETHICS APPROVAL



Université d'Ottawa University of Ottawa

Service de subventions de recherche et déontologie Research Grants and Ethics Services

Ethics Approval Notice

Principal Investigator(s) / Supervisor:	Denis Prud'homme [REDACTED]
Co-Investigator(s):	Stephanie Prince [REDACTED]
File Number:	H 10-08-11
Title of Research Project:	Built and social environmental determinants of physical activity, overweight, and obesity in City of Ottawa neighbourhoods
Type of Project:	☐ Professor's research ☒ Use of Secondary data ☐ Course outline
Department and Institution:	Department of Human Kinetics, University of Ottawa
Research Ethics Board:	☐ Social Sciences and Humanities Chair: Dr. Peter Beyer ☒ Health Sciences and Sciences Chair: Dr. Daniel Lagarec
Ethics Approval Date:	December 17, 2008
Expiry Date:	December 16, 2009
Documents Reviewed and Approved:	Protocol
Approval Granted:	☒ Ia (Approval) ☐ Ib (Approval for initial stage only) ☐ II (Delayed approval) ☐ III (Decision deferred)
Special Conditions:	

This is to confirm that the University of Ottawa Research Ethics Board identified above, which operates in accordance with the Tri-Council Policy Statement and other applicable laws and regulations in Ontario, has examined and approved the application for ethical approval for the above named research project as of the Ethics Approval Date indicated above and subject to the conditions listed the section above entitled "Special Conditions".

During the course of the study the protocol may not be modified without prior written approval from the REB except when necessary to remove subjects from immediate endangerment or when the modification(s) pertain to only administrative or logistical components of the study (e.g. change of telephone number). Investigators must also promptly alert the REB of any changes which increase the risk to participant(s), any changes which considerably affect the conduct of the project, all unanticipated and harmful events that occur, and new information that may negatively affect the conduct of the project and safety of the participant(s). Modifications to the project, information/consent documentation, and/or recruitment documentation, should be submitted to this office for approval using the "Modification to research project" form available at: http://www.rges.uottawa.ca/ethics/application_dwn.asp



Université d'Ottawa University of Ottawa

Service de subventions de recherche et déontologie Research Grants and Ethics Services

Please submit an annual status report to the Protocol Officer 4 weeks before the above-referenced expiry date to either close the file or request a renewal of ethics approval. This document can be found at: http://www.rges.uottawa.ca/ethics/application_dwn.asp

If you have any questions, please do not hesitate to contact the Ethics Office at [REDACTED]
mail at [REDACTED]

[REDACTED]

Gilles Morier
Director, Research Grants and Ethics for Chair of the REB



Université d'Ottawa
Bureau d'éthique et d'intégrité de la recherche

University of Ottawa
Office of Research Ethics and Integrity

Ethics Approval Notice

Health Sciences and Science REB

Principal Investigator / Supervisor / Co-investigator(s) / Student(s)

<u>First Name</u>	<u>Last Name</u>	<u>Affiliation</u>	<u>Role</u>
Denis	Prud'homme	Health Sciences / Human Kinetics	Supervisor
Betsy	Kristjansson	Social Sciences / Psychology	Co-investigator
Mark	Tremblay	Health Sciences / Others	Co-investigator
Stephanie	Prince	Medicine / Medicine	Student Researcher

File Number: H12-08-01

Type of Project: PhD Thesis

Title: Neighbourhood Physical Activity Study

Renewal Date (mm/dd/yyyy)	Expiry Date (mm/dd/yyyy)	Approval Type
02/11/2011	02/10/2012	Ia
(Ia: Approval, Ib: Approval for initial stage only)		

Special Conditions / Comments:
N/A



Université d'Ottawa **University of Ottawa**
Bureau d'éthique et d'intégrité de la recherche Office of Research Ethics and Integrity

This is to confirm that the University of Ottawa Research Ethics Board identified above, which operates in accordance with the Tri-Council Policy Statement and other applicable laws and regulations in Ontario, has examined and approved the application for ethical approval for the above named research project as of the Ethics Approval Date indicated for the period above and subject to the conditions listed the section above entitled "Special Conditions / Comments".

During the course of the study the protocol may not be modified without prior written approval from the REB except when necessary to remove subjects from immediate endangerment or when the modification(s) pertain to only administrative or logistical components of the study (e.g. change of telephone number). Investigators must also promptly alert the REB of any changes which increase the risk to participant(s), any changes which considerably affect the conduct of the project, all unanticipated and harmful events that occur, and new information that may negatively affect the conduct of the project and safety of the participant(s). Modifications to the project, information/consent documentation, and/or recruitment documentation, should be submitted to this office for approval using the "Modification to research project" form available at:
http://www.rges.uottawa.ca/ethics/application_dwn.asp

Please submit an annual status report to the Protocol Officer 4 weeks before the above-referenced expiry date to either close the file or request a renewal of ethics approval. This document can be found at:
http://www.rges.uottawa.ca/ethics/application_dwn.asp

If you have any questions, please do not hesitate to contact the Ethics Office at extension [REDACTED] by e-mail at:
[REDACTED]

Signature:

[REDACTED]

Catherine Paquet
Director
For Barbara Graves, Chair of the Social Sciences and Humanities REB

[REDACTED]

**APPENDIX B. NEIGHBOURHOOD PHYSICAL ACTIVITY STUDY
QUESTIONNAIRE**

Physical Activity Study Adult Questionnaire



**Please return your completed questionnaire and
accelerometer in the enclosed stamped and addressed
envelope.**

**If you have any questions please contact
Stephanie Prince**

Telephone [REDACTED]

Email: [REDACTED]

**This study has been approved by the University of Ottawa
Research Ethics Board. If you have any questions or concerns you
may contact:**

Protocol Officer for Ethics in Research, University of Ottawa

Tel.: [REDACTED] Email: [REDACTED]

This section of the survey will collect basic information about who you are and some of your health practices. We will be using this information along with the information from the activity monitor. Please answer the following questions as best you can. Thank you for your help.

1. What is your date of birth?

_____ Day _____ Month _____ Year

2. Are you male or female? Please check the box that applies.

☐ Male ☐ Female

3. What is your postal code? _____

4. Are you currently married, living with a partner, widowed, divorced, separated, or have you never been married? Please check the box that best describe your current relationship status.

☐ Married

☐ Living with a partner

☐ Widowed

☐ Divorced

☐ Separated

☐ Never been married

5. How many people currently live in your household?

6. What is the highest level of education that you have completed? Please check the box that best describes your education.

- | | |
|--|-------------------------------------|
| ☐ Did not graduate from high school | ☐ Don't know |
| ☐ Graduated from high school | |
| ☐ Some post-high school education | |
| ☐ College / university diploma / degree | |
| ☐ Graduate level degree (e.g. MA, MSc, MEd, MBA, PhD) | |

7. Could you please tell me how much money you and other members of your household (total household income) received in the year ending in December 2008, before taxes. Please include income from all sources such as savings, pensions, rent, as well as wages. Please check the box that best describes your total household income from all sources:

- | | |
|---|---|
| ☐ less than \$20,000 | ☐ \$80,000 to \$90,000 |
| ☐ \$20,000 to \$30,000 | ☐ \$90,000 to \$100,000 |
| ☐ \$30,000 to \$40,000 | ☐ \$100,000 to \$120,000 |
| ☐ \$40,000 to \$50,000 | ☐ \$120,000 to \$150,000 |
| ☐ \$50,000 to \$60,000 | ☐ \$150,000 or more |
| ☐ \$60,000 to \$70,000 | ☐ Don't know |
| ☐ \$70,000 to \$80,000 | |

8. What is your **current work status**? Please check the box that best applies to your current work status.

- | | |
|---|--|
| ☐ Employed for wages | ☐ Taking care of a family |
| ☐ Self-employed | ☐ A student |

- ☐ Been out of work for less than one year ☐ Retired
- ☐ Been out of work for more than 1 year ☐ Unable to work

9. If you are currently working what is your **current occupation** (e.g. student, lab technician, office clerk, house keeper, etc)?

10. If you are currently working are you working full time or part time, and do you work during weekdays, weeknights, weekends, or rotating shifts? Please check the boxes that best apply to your current work status.

- ☐ Full-time ☐ Part-time
- ☐ Weekdays ☐ Weekends
- ☐ Weeknights ☐ Rotating shifts

11. Please indicate your **smoking behaviour**. Please check the box that best describes your smoking habits.

- ☐ Current smoker
- ☐ Everyday
- ☐ Some days (occasional/sometimes)
- ☐ Former smoker
- ☐ Not at all
- ☐ Don't know

This section of the survey will provide you with instructions for wearing your physical activity monitor. Thank you for agreeing to wear the accelerometer. Please read over the instructions carefully.

What is an accelerometer?

An accelerometer is a motion sensor that is similar to a pedometer or step counter, but instead of measuring the number of steps you take, it measures physical activity by recording how often and how quickly you move. It is **not** a tracking device and cannot record where you go. They are worn on a belt around the waist and do not interfere with your daily activities or function.

When should you wear your accelerometer?

Your accelerometer has been programmed to start recording your physical activity from the day you receive it. We would like for you to wear it for **8 consecutive days**. Please put on the accelerometer when you wake up on the day after you receive it and wear it continuously (except for when you sleep, swim or bath) until when you go to sleep on the last day. For example if you receive the accelerometer on Tuesday, please wear it Wednesday, Thursday, Friday, Saturday, Sunday, Monday, Tuesday and Wednesday.

What happens when you are done wearing the accelerometer?

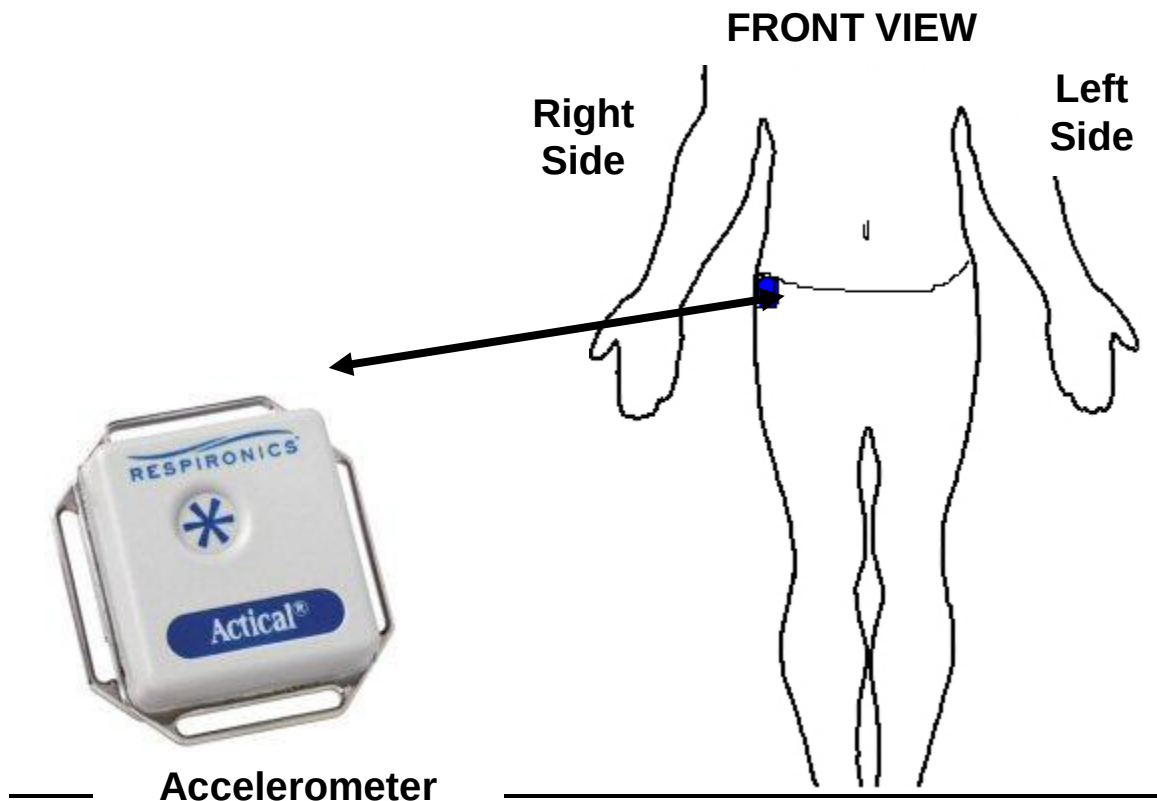
When you take the accelerometer off after the 8 days, please put it in the pre-addressed stamped envelope provided to you along with this survey and place it in the mail.

How do you use the accelerometer?

An instruction sheet is provided in this booklet to show you how to wear the accelerometer. The accelerometer should be worn snugly on the right side of your waist near your hip, over or under your clothing. Each day report when you put the accelerometer on, any time it was removed and reasons for removing it, any physical activities you were involved in, and when you took the accelerometer off at night in the log sheet provided.

Instructions for Wearing Your Accelerometer

1. The accelerometer should be worn snugly on your **right hip**, over or under your clothing (see picture below).
2. Start wearing the accelerometer as soon as you get dressed each day.
3. The accelerometer is waterproof but please remove during water activities such as swimming.
4. In the attached log sheet please write down when you put on the accelerometer, any times during the day when you took it off and the reason for removing it, and any specific activities you did that day. These include things like walking, biking, running, sports, etc.
5. Remove the accelerometer each night before going to sleep.



Study Number _____

Daily Activity Log Sheet

Name _____

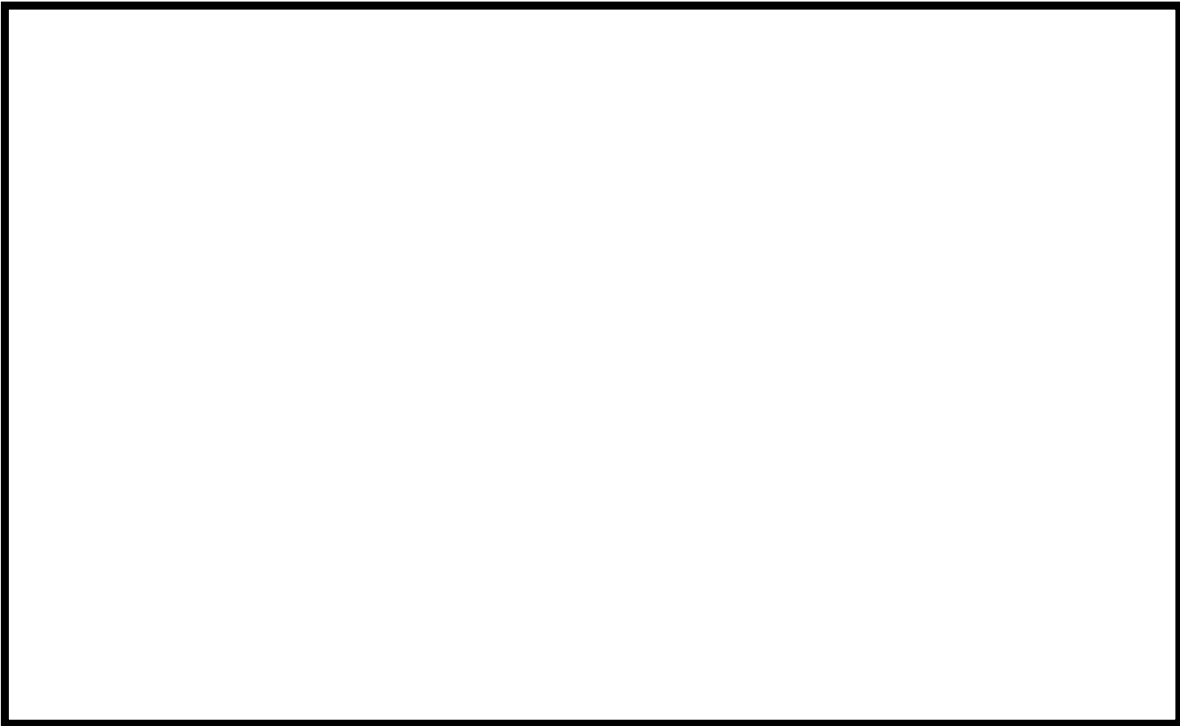
Start date _____

End date _____

Please fill in the times when you put the accelerometer on, any times you took it off and the reason, any activities you did, and when you took it off to go to bed over an 8-day period (2 weekend & 6 week days).

	Example	Day 1	Day 2	Day 3	Day 4	Day 5	Day 6	Day 7	Day 8
Time monitor was put on	8:30 am								
Any times monitor was removed and reason(s)	9:00am shower								
Daily physical activity	10:00am Bike ride 45 mins								
Time monitor was removed (bed time)	10:00pm								

Your comments and feedback are valued, please feel free to use the space provided here or on a separate piece of paper.



Please return your completed questionnaire in the enclosed stamped and addressed envelope.

**If you have any questions please contact:
Stephanie Prince**

Telephone: 

Email: 