Active living environments, physical activity, and population health

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March 2021

A thesis submitted to McGill University in partial fulfilment of the requirements of the degree of Doctor of Philosophy

ABSTRACT

Place plays a central role in constraining and enabling our health-related actions and routine behaviours. It is increasingly understood that a modifiable proportion of obesity and chronic disease could be the consequences of living in neighbourhoods that are unsupportive of physical activity. Active Living Environments (ALEs), the extent to which our neighbourhoods are designed to promote active living, have been recognized as a promising environmental determinant of physical activity, obesity, and chronic disease. Whether built environments impact subsequent chronic disease-related hospital burden and mortality has not been fully evaluated. Moreover, there is a paucity of international comparative research that evaluates associations of neighbourhoods and chronic disease prevention across different geo-social, political, and economic contexts.

This dissertation gauges the potential for neighbourhoods to alter chronic disease and mortality patterns of populations in Canada and abroad. The aim of these studies is to provide insight into the relationship between neighbourhood environments, mortality, and hospitalization. I also assess and compare these associations in different demographic groups and focus specifically on those with or at risk of type 2 diabetes (T2D). The overarching hypothesis of this thesis is that neighbourhoods that are conducive to active living enable people to be physically active which reduces hospitalization and mortality burden. The research has four objectives:

1. To examine population-level associations between ALEs, physical activity, and mortality;
2. To examine population-level associations between ALEs, physical activity, and hospitalization;
3. To compare associations of ALEs and health in those without, at risk of, and diagnosed with T2D;
4. To advance our understanding of whether and to what extent associations between ALEs, health behaviours and health outcomes we observe in Canada are generalizable to other countries.

This dissertation consists of nine chapters based on four full-length manuscripts and two short communication pieces. I have organized the chapters first by geography – beginning with Canada and ending with Wales and Australia; then by outcome – beginning with mortality, moving on to hospitalization, and ending with a closer examination of walking outcomes. I begin with a review of foundational theories and concepts of ALEs, physical activity, and chronic disease health from the perspectives of health geography, population health, behavioural health research, urban

planning, and transportation. **Chapter 3** is the first manuscript of the dissertation and examines associations between ALEs and premature cardiometabolic death in groups stratified by sex (women, men) and age (middle-age, older). I showed that living in favourable neighbourhoods conferred a 22% reduction in the rate of death from cardiometabolic causes (hazard ratio [HR] 0.78, 95% confidence interval [CI] 0.63 to 0.97) for older women. I also showed that this cohort, regardless of age and sex, walked more in these neighbourhoods but did not necessarily perform more overall physical activity. **Chapter 4** examined effect measure modification of T2D status on the relationship between ALEs and premature cardiometabolic mortality. I used product terms between ALEs (less versus more favourable) and T2D groups (present, at risk, none) to show that older women with T2D living in less favourable ALEs had the highest cardiometabolic death rates. **Chapter 5** shifts the focus from mortality outcomes to morbidity outcomes and asks whether ALEs are associated with hospitalization for major cardiovascular disease events using a large population-based sample of Canadian adults. Living in neighbourhoods that are progressively more favourable for active living was associated with as much as a 24% reduction (odds ratio [OR] 0.76, 95% CI 0.65 to 0.90) in the odds of hospitalization for acute myocardial infarction (AMI) relative to the least favourable neighbourhoods. Using mediation analysis, I also provide evidence that a modest proportion of the relationship is attributable to leisure-time walking. **Chapter 6** assesses the artefactual impact of living close to hospital on the association between ALEs and hospitalization. I showed that living between 500 meters and six kilometers of a hospital was associated with modestly higher odds of cardiometabolic hospitalization (OR 1.10, 95% CI 1.02 to 1.18; 500 meters, OR 1.05, 95% CI 1.01 to 1.09; six kilometers). I then demonstrated that the relationship between favourable ALEs and lower odds of hospitalization for cardiometabolic disease are robust to living close to hospital. **Chapter 7** is the first of two international studies and examines the relationship between ALEs and hospitalization in Wales UK and Canada. While Canadian respondents living in favourable ALEs exhibited lower odds of obesity at baseline as well as lower odds of hospitalization over the study period, Welsh respondents living in favourable ALEs exhibited little difference in obesity prevalence and higher odds of hospitalization. Although T2D patients in both countries were more likely to be hospitalized than those without T2D, they were no more likely to benefit from favourable ALEs than those without T2D. The goal of the last manuscript in **Chapter 8** was to examine associations between ALEs and purpose-specific weekly walking, as well as assess the extent to which these relationships varied by T2D risk and status. I found that walking for errands emerged as both a frequent activity and the most strongly patterned outcome by ALE class. I also found that the relationship between favourable ALEs and walking for leisure was weaker for those with T2D or are at higher risk for T2D, while higher levels of transit walking and errand walking in favourable ALEs persisted regardless of T2D status.

My findings contribute substantive insight as to whether and how much neighbourhoods might support routine physical activity that will later translate into more favourable health outcomes. I provide evidence that favourable built environments for active living are linked with higher levels of walking in Canada and Australia, lower odds of hospitalization in Canada, and lower premature cardiometabolic rates for older Canadian women with T2D. Leveraging the multi-disciplinary strengths of health geography to understand place and health, as well as novel methodological approaches of using population-scale linked data, longitudinal health outcomes, GIS-derived measures of the built environment, as well as international comparative approaches, this dissertation helps build the case for active living-friendly neighbourhoods to be both a sensible and intervenable way to achieve population-wide reductions in physical inactivity, chronic disease death and hospitalization.

RÉSUMÉ

Le milieu joue un rôle central d'obstacle et de facilitateur quant à nos actions et nos routines liées à la santé. Il est de plus en plus reconnu qu'une proportion modifiable de cas d'obésité et de maladies chroniques pourrait être la conséquence du fait de vivre dans des quartiers mal adaptés à un mode de vie actif. L'accessibilité à la vie active dans les milieux de vie (AVA), une mesure de l'accessibilité des milieux de vie à la vie active, a été identifiée comme déterminant environnemental prometteur d'activité physique, d'obésité et de maladies chroniques. Cependant, la capacité des environnements bâtis d'influencer le fardeau hospitalier subséquent lié aux maladies chroniques n'a pas été évaluée entièrement. De plus, il y a peu de recherche comparative internationale évaluant les associations entre les milieux de vie et la prévention des maladies chroniques dans les différents contextes géosociaux, politiques et économiques.

Cette thèse mesure la capacité des milieux de vie de modifier les taux de maladies chroniques et de mortalité chez les populations au Canada et à l'étranger. L'objectif de ces études est de donner un aperçu du rapport entre les milieux de vie, la mortalité et l'hospitalisation. Ce rapport est également évalué et comparé dans de différents groupes démographiques avec une attention particulière portée aux personnes atteintes ou à risque du diabète de type 2 (DT2). L'hypothèse principale de cette thèse est que les milieux de vie favorables à un mode de vie active encouragent l'activité physique, favorisant ainsi une réduction des fardeaux d'hospitalisation et de mortalité. Cette recherche a quatre objectifs :

1. Examiner les associations au niveau de la population entre les AVA, l'activité physique et la mortalité;
2. Examiner les associations au niveau de la population entre les AVA, l'activité physique et les hospitalisations;
3. Comparer les associations entre les AVA et la santé dans les personnes non atteintes de DT2, les personnes à risque de DT2, et les personnes ayant reçu un diagnostic de DT2;
4. Faire progresser nos connaissances afin de mieux comprendre si – et, le cas échéant, dans quelle mesure – les rapports entre les AVA, les comportements de santé et les états de santé que nous observons au Canada sont généralisables à d'autres pays.

Cette thèse comprend neuf chapitres, basés sur quatre manuscrits complets et deux brèves communications. Les chapitres sont organisés d'abord par géographie, commençant par le Canada et terminant par le Pays de Galles et l'Australie. Les chapitres sont ensuite organisés par résultat, commençant par la mortalité, suivie par les hospitalisations, et terminant par les résultats de marche à pied. On commence par un examen des théories et des concepts de base des AVA, de l'activité physique et des maladies chroniques d'un point de vue de la géographie de la santé, la santé de la population, la recherche en santé comportementale, la planification urbaine et les transports. Le **Chapitre 3** est le premier manuscrit; il examine les rapports entre les AVA et les décès cardiométaboliques prématurés dans les groupes stratifiés par sexe (femme, homme) et par âge (moyen, avancé). Je démontre que le fait de vivre dans un milieu de vie favorable entraîne une réduction du taux de décès d'origine cardiométabolique de 22% (rapport des hasards 0.78, 95% CI 0.63 à 0.97) pour les femmes d'âge avancé. Je démontre également que les membres de cette cohorte pratiquent plus souvent la marche à pied dans ces milieux de vie, peu importe leur âge ou leur sexe, mais qu'ils ne pratiquent pas nécessairement plus d'activité physique en général. Le **Chapitre 4** examine la modification de l'effet du statut DT2 sur le rapport entre les ALE et la mortalité cardiométabolique prématuré. Les termes du produit entre les AVA (moins vs plus favorables) et les groupes DT2 (présent, à risque, non atteint) ont été utilisés pour démontrer que le taux de décès cardiométabolique le plus élevé touchait les femmes d'âge avancé atteintes de DT2 habitant dans les AVA moins favorables. Le **Chapitre 5** passe de la mortalité à la morbidité, cherchant à déterminer s'il existe un rapport entre les AVA et les hospitalisations pour accidents cardiovasculaires majeurs par moyen d'un large échantillon de la population générale d'adultes canadiens. Les milieux de vie progressivement plus favorables à un mode de vie actif ont été associés à une réduction de jusqu'à 22% (OR 0.78, 95% CI 0·66–0.91) de la probabilité d'hospitalisation liée à l'infarctus aigu du myocarde (IAM) par rapport aux milieux de vie moins favorables. En utilisant dés méthodes d'analyse de médiation, je présente également des indications que le rapport pourrait être, dans une faible mesure, attribuable à la marche à pied pour loisir. Le **Chapitre 6** cherche à évaluer l'impact artéfactuel de l'habitation à proximité d'un hôpital sur l'association entre les AVA et les hospitalisations. Je démontre que l'habitation à une distance de 500 mètres à 6 kilomètres était associée à une probabilité d'hospitalisation cardiométabolique légèrement supérieure (OR 1.10, 95% CI 1.02 à 1.18; 500 meters, OR 1.05, 95% CI 1.01 à 1.09;

six kilometers). Par la suite, je démontre que le rapport entre les AVA favorables et la probabilité réduite d'hospitalisation pour maladies cardiométaboliques sont robustes à l'habitation à proximité d'un hôpital. Le **Chapitre 7** présente la première de deux études internationales. Il examine le rapport entre les ALE et les hospitalisations aux Pays de Galles (Royaume-Uni) et au Canada. Alors que les répondants canadiens vivant dans les ALE favorables présentaient un taux réduit d'obésité au ligne de base, ainsi qu'une probabilité réduite d'hospitalisation au cours de l'étude, les répondants gallois vivant dans les ALE favorables ont un taux d'obésité et une probabilité d'hospitalisation similaire au reste de la population. Même si les patients atteints de DT2 dans les deux pays étaient plus susceptibles à être hospitalisés, ils n'étaient pas plus susceptibles à bénéficier des ALE favorables par rapport aux personnes non atteintes. Le but du dernier manuscrit dans le **Chapitre 8** était d'examiner les rapports entre les ALE et la marche à pied hebdomadaire pour raisons spécifiques, et de mesurer la variation dans ces rapports selon le risque et le statut DT2. J'ai constaté que la marche à pied pour faire des courses est une activité fréquente, et qu'elle est le résultat présentant l'association la plus forte selon la classe AVA. J'ai également constaté que le rapport entre les ALE favorables et la marche à pied pour loisir était plus faible pour les personnes atteintes de DT2 ou à risque élevé de DT2, tandis que le taux plus élevé de la marche à pied pour transports et pour faire des courses ne changeait pas selon le statut DT2.

Mes découvertes aident substantiellement à mieux comprendre si les quartiers peuvent faciliter un mode de vie actif bénéfique pour la santé, et, le cas échéant, dans quelle mesure. Je fournis des éléments de preuve démontrant un rapport entre les environnements favorables à un mode de vie actif et la fréquence de la marche à pied au Canada et en Australie, une probabilité réduite d'hospitalisation au Canada et un taux réduit de mortalité cardiométabolique chez les femmes d'âge avancé atteintes de DT2. Cette thèse utilise les forces multidisciplinaires de la géographie de la santé, ainsi que des approches méthodologiques novatrices quant à l'utilisation des données liées à l'échelle de la population, des résultats longitudinaux de la santé, des mesures de l'environnement bâti et des approches internationales comparatives, dans le but d'appuyer l'idée des quartiers favorable à un mode de vie actif comme façon raisonnable et intervenable de réduire l'inactivité physique, la maladie chronique et l'hospitalisation à l'échelle de la population.

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ABBREVIATIONS

ALE	Active Living Environment
AMI	Acute Myocardial Infarction
Aus-ALE	Australia Active Living Environments
AusDiab	Australian Diabetes, Obesity and Lifestyle Study
BMI	Body mass index
Can-ALE	Canadian Active Living Environments
CCHS	Canadian Community Health Survey
CHF	Congestive heart failure
CI	Confidence interval
CIHI	Canadian Institute for Health Information
CIQSS/QICSS	Centre interuniversitaire québécois de statistiques sociales/ Quebec inter-University Centre for Social Statistics (QICSS)
CMDB	Canadian Mortality Database
CRDCN	Canadian Research Data Centre Network
CVD	Cardiovascular disease
DAD	Discharge Abstract Database
DPoRT	Diabetes Population Risk Tool
EE	Energy expenditure
Geo-SDH	Geo-Social Determinants of Health Research Group
HR	Hazard ratio
IRR	Incidence rate ratio
MET	Metabolic Equivalent of Task
MVPA	Moderate-to-vigorous physical activity
OR	Odds ratio
OSM	OpenStreetMap
PA	Physical activity
PEDW	Patient Episode Database for Wales
SAIL	Secure Anonymised Information Linkage Databank
SD	Standard deviation
T2D	Type 2 Diabetes
Wal-ALE	Wales Active Living Environments
WHS	Welsh Health Survey

STATEMENT OF SUPPORT

I received funding for this PhD from the Fonds de Recherche du Québec Santé Doctoral Training Award, as well as the Canadian Institutes of Health Research - Institute of Population and Public Health, through the *Data Analysis Existing Databases* Operating Grant, grant #410289. I was also assisted by Professor Nancy Ross's funding from the Canadian Institutes of Health Research Canada Research Chairs Program.

The research related to chapters 4 through 8 was conducted at the Quebec Interuniversity Centre for Social Statistics (QICSS), which is branch of the Canadian Research Data Centre Network (CRDCN). These services are made possible by the support of the Social Sciences and Humanities Research Council (SSHRC), the Canadian Institutes of Health Research (CIHR), the Canada Foundation for Innovation (CFI), Statistics Canada, the Fonds de recherche du Québec – Société et culture (FRQSC) and the Quebec universities.

The research related to Chapter 8 was conducted within the secure research platform of the Secure Anonymised Information Linkage (SAIL) Gateway. SAIL is a Wales-wide databank containing information about the population of Wales UK, which receives core funding from the Welsh Government's Health and Care Research Wales and the Economic and Social Research Council. The SAIL Databank is a partnership with the NHS Wales Information service and is supported by Swansea University.

The research related to Chapter 9 was conducted with University of Melbourne, RMIT University, and the Baker Heart and Diabetes Institute. I was also granted additional funding by the Queen Elizabeth II Diamond Jubilee Scholarship *Common Threads through the Commonwealth* program, administered by the Institute for Health and Social Policy at McGill University.

ACKNOWLEDGEMENTS

Upon my arrival to McGill, I had the great fortune and privilege of meeting my supervisor Professor Nancy Ross, who has renewed my passion for academic research and scientific inquiry. Thank you for believing in me, thank you for believing in my work, and thank you for supporting my development as an independent scholar over the past eight years as your masters and PhD student. I would also like to thank my co-supervisor Professor Kaberi Dasgupta for her close attention and medical expertise that has made this work stronger and more relevant to health. My appreciations to my committee members Dr. Claudia Sanmartin and Professor Mylène Riva for their service to my Ph.D. program.

I also have a host of international collaborators to thank, including Dr. Richard Fry (Swansea University, Wales UK), Dr. Ashley Akbari (Swansea University, Wales UK), Dr. Rebecca Bentley (University of Melbourne, Australia), Dr. Billie Giles-Corti (RMIT University, Australia), Dr. Suzanne Mavoa (University of Melbourne, Australia), Dr. Manoj Chandrabose (Swinburne University of Technology, Australia), Dr. Neville Owen (Baker Institute), Dr. Dianna Maglianno (Baker Institute, Australia), and Dr. Jonathan Shaw (Baker Institute, Australia).

This dissertation would have been impossible without the work of the many data stewards and analysts who make it possible to do conduct research with linked data safely and securely. Special thanks to Mme. Danielle Forest at the McGill QICSS laboratory for her assistance. I would also like to acknowledge the staff of the SAIL Gateway that maintain the cutting-edge data linkage platform that was critical for this dissertation. Thanks also to the staff and scientists of the Healthy Liveable Cities Group at RMIT's Centre for Urban Research for helping me gain and maintain remote access to the Australian data used for this dissertation.

Many thanks to the long-term help and support from members of the Geo-Social Determinants of Health Research Group – Andrew Stevenson, Clara Kaufmann, Dr. Madeleine Steinmetz-Wood, Thomas Herrmann, William Gleckner, Megan Toth, Dr. Kelly-Ann Renwick, and to Dr. Samantha Hajna for her early guidance. I would also like to acknowledge the Geography Graduate Society and all the students that made room 427 a fixture of graduate student life. I would like to thank Professor Nigel Roulet, June Conolly, Marissa Mastroberardino, Nancy Secondo, Joseph Vacirca, Paula Kestelman, Filomena Fata, Catherine Klempa, Christian Favreau, for contributing to the amazing experience I had being a graduate student in the Department of Geography.

To my dearest of friends from epidemiology, Eva Graham, to whom I owe my thanks for her countless hours spent talking me through epidemiological concepts and methods and reading through early drafts of this document, as well as Christina Norris, Jennifer Murray, Leslie Norris, and Roland of course. I also owe my appreciations to my childhood friend, Alexandra Todd and her partner Simon Wallace, for their encouragement, help with statistics, and time spent reviewing a few of these chapters. Thanks also to the feminists I had rooting for me back home in Vancouver and abroad.

I want to extend my deepest gratitude to Jack Dixon, for his patience, sharp second opinions, and steadfast support. Thanks also for your help proofreading the manuscript and translating the abstract. We met on the third day of the comprehensive examination for this degree. I told him that I had just started a 'month-long test' and that I could be a bit stressed out - potentially for the next three years. To this day, he remains undeterred.

My parents, Liza and Stuart Mah, were raised to believe in higher education and have spent the better part of their lives committed to providing me, my sister and my brother with these opportunities. I have endless admiration for your perseverance in your own lives and pursuits, and I am endlessly grateful for your love, encouragement, and contributions to me as a professional and as a human being. Mom, Dad, Laura, Trevor – my love to you.

CONTRIBUTIONS OF AUTHORS

This dissertation is a collection of four full-length manuscripts and two short communications that are written for submission to peer-reviewed journals. My co-supervisors, Nancy Ross and Kaberi Dasgupta, were essential to the conceptualization of the goals and objectives of the dissertation. Details of author contributions follow.

Chapter 3, *Active living environments, physical activity and premature cardiometabolic mortality in Canada: a nation-wide cohort study*, was co-authored by Sarah M Mah, Claudia Sanmartin, Mylène Riva, Kaberi Dasgupta, and Nancy A. Ross. I performed the statistical analysis and drafted the manuscript. All co-authors contributed to the data interpretation and revised drafts of the manuscript for intellectual content.

Chapter 4, *Effect measure modification of type 2 diabetes status on the relationship between active living environments and Premature cardiometabolic mortality*, was co-authored by Sarah M Mah, Claudia Sanmartin, Mylène Riva, Kaberi Dasgupta, and Nancy A. Ross. I performed the statistical analysis and drafted the manuscript. All co-authors contributed to the intellectual content of the paper.

Chapter 5, *Assessing active living environments and hospital Burden using Canadian population based linked data*, was co-authored by Sarah M Mah, Claudia Sanmartin, Mylène Riva, Kaberi Dasgupta, and Nancy A. Ross. I performed the statistical analysis and drafted the manuscript. All co-authors contributed to the intellectual content of the paper. Thomas Herrmann, a research assistant with the Geo-Social Determinants of Health Research Group, is also acknowledged for his assistance with providing some of the geographic measures related to hospital proximity.

Chapter 6, *Does living near hospital obscure the association between favourable Active Living Environments and lower hospitalization?*, was co-authored by Sarah M Mah, Thomas Herrmann, Claudia Sanmartin, Mylène Riva, Kaberi Dasgupta, and Nancy A. Ross. I performed the statistical analysis and drafted the manuscript. All co-authors contributed to the intellectual content of the paper.

Chapter 7, *An International Comparative Study of Active Living Environments and Hospitalization for Wales and Canada*, was co-authored by Sarah M Mah, Nancy A. Ross, Ashley Akbari, and Richard Fry. I performed the statistical analysis and drafted the manuscript. Richard Fry derived the Wales Active Living Environment (Wal-ALE) measures, and Ashley Akbari assisted in the provision of survey and administrative health data for Wales. All co-authors contributed to the data interpretation and revised drafts of the manuscript for intellectual content.

Chapter 8, *Australia Active Living Environments and Walking for Purpose: The Australian Diabetes, Obesity and Lifestyle Study (AusDiab)*, was co-authored by Sarah M Mah, Richard Fry, Dianna Maglianno, Jonathan Shaw, Neville Owen, Nancy Ross, Rebecca Bentley, and Billie Giles-Corti. I performed the statistical analysis and drafted the manuscript. Richard Fry derived the Australia Active Living Environment (Aus-ALE) measures. Rebecca Bentley and Billie Giles-Corti helped conceptualize the study. All co-authors contributed to the data interpretation and revised drafts of the manuscript for intellectual content.

RESEARCH ETHICS

Analyses in Chapters 3 to 7 were conducted under project number 16-HAD-MCG-4802, *Relationships between walkability, health behaviours and chronic disease outcomes: Validation of the CCHS walkability measure,* at the McGill University site of the Canadian Research Data Centre Network, a secure laboratory which provides access to micro-data holdings of Statistics Canada, Canada's national statistical agency. Statistics Canada has in place a detailed protocol for protection of respondent confidentiality which was followed in these analyses (see http://www.statcan.gc.ca/eng/rdc/mitigation). These procedures supersede the authority of Research Ethics Boards at Canadian universities and so there is no additional certificate included for the linked survey analyses.

Analyses in Chapter 7 pertaining to the linked Welsh Health Survey and PEDW were conducted through the Secure Anonymised Information Linkage (SAIL) Databank, a remote desktop protocol and virtual environment enabling secure data access and analysis. The project was approved by the Information Governance Review Panel (IGRP), which reviews all proposals submitted to the SAIL Databank to ensure that they are appropriate and in the public interest. Analyses were carried out under the SAIL Feasibility Agreement #0715. Approval for these anonymised data was from the Welsh Government.

Analyses in Chapter 8 pertaining to the Australian Diabetes, Obesity and Lifestyle Study (AusDiab3) conducted from 2011-2012 were conducted via remote VPN access to RMIT University's servers. The study has been approved by the Alfred Health Human Ethics Committee no. 39/1 (project #1851818, *International comparisons of neighbourhood environments, type 2 diabetes, mortality, and hospital burden*) at the University of Melbourne, Australia. In accordance with McGill's policies on research ethics, further approval was obtained from McGill's Research Ethics Board 1 (REB file #21-02-029, *International comparisons of neighbourhood environments, type 2 diabetes, and hospital burden,* Supplementary Figure D.1).

Chapter 1
INTRODUCTION

The places where we live can profoundly impact our health by influencing our everyday behaviour. Some take the bus to work, while others sit in cars during rush-hour. Some spend their leisure time in a pedestrian-friendly neighbourhood, while others find themselves dissuaded from doing so in a traffic-oriented environment. Some walk to the nearby grocery store while others drive for twenty-minutes to run errands. To some degree, all of these habits and activities depend on the design, density, and destinations in our neighbourhoods. Where we live shapes whether and to what extent we achieve active lifestyles and could, in turn, reduce mortality and hospitalization rates related to chronic disease such as type 2 diabetes (T2D).

The purpose of this dissertation is to determine whether neighbourhoods that are built for active living support physical activity and improve health across the population. This research contributes to the growing literature linking *active living environments* (ALEs, also known as walkable environments) with physical activity (especially walking), lower obesity, and lower chronic disease incidence. However, we have not conclusively determined whether such environments influence mortality and hospitalization rates. This thesis combines information-rich survey and administrative data with objective spatial measures of neighbourhood environments. For this dissertation, I conducted population-based analyses linking place with behaviour and health outcomes. I show that living in more favourable ALEs is associated with lower cardiometabolic mortality rates for older women (Mah, Sanmartin, Riva, Dasgupta, & Ross, 2020), and further demonstrate that this association is especially meaningful for those with or at risk of T2D. I then show that living in incrementally more favourable ALEs is associated with lower odds of hospitalization for major cardiovascular disease (CVD) events and is modestly impacted by living close to a hospital. Using data from two countries (Canada and Wales UK), I demonstrate that the positive health impacts of ALEs demonstrated in Canada may not be easily generalizable to other countries. Finally, I use data from Australia to determine that ALEs are associated with substantial differences in purpose-specific walking for the general population and for those with or at risk of T2D.

1.1 RATIONALE

Our neighbourhoods have transformed dramatically over the last century. Around 90% of the world's population lived in rural environments in the early 1900s (Grimm et al., 2008). Today, we have reached an urban-dwelling population of 55% globally (United Nations, 2018), and we are on track to reach 68% by 2050. The urban-dwelling population rose from 751 million in 1950 to over five times this number by 2018 (4.2 billion). Canadians are among the most urbanized and suburbanized people in the world. According to the last census, over 80% lived in urban areas, and some of the highest population growth rates occurred in suburban areas (Statistics Canada, 2016). Urban environments have a reputation for concentrating innovation, supporting economic development and progressive civic participation, raising standards of living and prolonging life expectancies (Leon, 2008). Yet, the *urban penalty* of living in cities has been historically recognized since the mid-19th century with the growth of industrialized cities and their challenges of overcrowded housing, poor sanitation and air quality, and high mortality rates. While advances in medicine and hygiene have been instrumental in limiting the spread of infectious diseases in high-density cities, there is now a need to address a different sort of urban penalty. The ways in which we have engineered our societies and environments have not kept pace with our physiological need for physical activity.

Our lifestyles have transformed as dramatically as the places we live. Transportation has become largely motorized. Our daily activities are increasingly assisted by labour-saving technologies and automation and have contributed to producing sedentary lifestyles. There have been reductions in both the allocation of time and energy expenditure required for different domains of physical activity (Ng & Popkin, 2012). Our neighbourhoods, rural and urban, are where we live and where many of us spend much of our time. Many of our neighbourhoods have failed to evolve around our needs. Instead, they have been structured around the needs of cars, industry, and technology. As a result, many environments are built in ways that make it difficult to conduct our daily activities in ways that enhance physical activity. Sedentary lifestyles and the conditions that impose such lifestyles have begun to erode the gains in life expectancy achieved with advances in medicine, public health, and standards of living (Olshansky et al., 2005). Many aspects of our daily lives – occupation, household activities, recreation, and transportation, require less effort and physical labour. One study from the United States found that the proportion of jobs involving at least moderate physical activity was reduced from 50% in 1960 to 20% by the early 2000s, and linked these trends to net reductions in energy expenditure and increases in average body weight (Church et al., 2011)

Around 28% of the world's population was considered insufficiently physically active in 2001, and showed no improvement in 2016 (Guthold, Stevens, Riley, & Bull, 2018). Global analyses suggest that physical inactivity is a significant determinant for a range of non-communicable diseases and premature mortality (Lee et al., 2012), generating health care costs that reached an estimated $53.8 billion worldwide in 2013 (Ding et al., 2016). In 2016, an estimated 41 million people died of non-communicable diseases – 1.6 million of which were related to diabetes, and 17.9 million of which were related to CVD (World Health Organization, 2020).

As had been the case for the infectious diseases of the *first* urban penalty, medicine and public health have risen to the challenge. Both public and private sectors have invested substantial resources toward developing novel pharmaceutical therapies in response to the non-communicable diseases of the *second* urban penalty. These innovations have likely been a factor in the declines observed for certain conditions such as CVD (Mensah et al., 2017). However, the already high costs of pharmaceutical development continue to rise, and tend to be much higher for certain diseases such as T2D (DiMasi, Grabowski, & Hansen, 2016). Targeting lifestyle factors such as physical inactivity, diet, and smoking are also likely to have contributed to CVD declines (Mensah et al., 2017), and continue to inform the design and implementation of lifestyle interventions. However, individual-level approaches to chronic disease prevention rely on accurately identifying those at risk, and they tend to be resource-intensive. In general, these programs are limited in their ability to impact whole populations. Biomedical and behavioural approaches to chronic diseases depend, in part, on the conditions shaping our health and behaviours.

Place plays a central role in our ability to practice health behaviours. *Active Living Environments* (ALEs), the extent to which our neighbourhoods are designed to promote active living, are increasingly being recognized as a key environmental determinant of physical activity (especially walking), obesity, and chronic disease. Built environments show promise as a potential policy area for supporting physical activity and preventing chronic disease. However, we do not know whether or to what extent living in less favourable ALEs necessarily results in greater hospitalization or morbidity, nor have we assessed whether living in more favourable ALEs is preventive of premature mortality, particularly among individuals living with T2D or at higher risk for T2D. From a health systems and policy perspective, the answers to these questions are important if we pursue and invest in creating neighbourhoods built for active living with the aim of reducing premature chronic disease death and hospital burden. Furthermore, the concept of ALEs has gained international traction. A single international cohort has signaled that these environments are generally associated with physical activity and obesity outcomes (Sallis et al., 2020). A growing number of jurisdictions, beyond those in which studies of ALEs have been conducted, have expressed interest in making their neighbourhoods active-living friendly. Moreover, there is paucity of comparably derived measures for ALEs and for many places, which limits our ability to assess how well ALEs may perform across different geographic contexts. Lastly, few groups have access to individual-level health data for different countries that would allow for parallel studies on neighbourhoods, behaviour and chronic disease across a variety of geo-social, political, and economic conditions.

1.2 Objectives

The purpose of this dissertation is to assess whether, and to what extent, favourable ALEs are associated with population-wide gains in physical activity-related health. The overarching hypothesis of this thesis is that neighbourhoods that are conducive to active living enable people to be physically active and thereby enable people to achieve favourable cardiometabolic health outcomes. This hypothesis is explored through four objectives:

1. To examine population-level associations between ALEs, physical activity, and mortality;
2. To examine population-level associations between ALEs, physical activity, and hospitalization;
3. To compare associations between ALEs and health in those without, at risk of, and diagnosed with T2D;
4. To advance our understanding of whether and to what extent associations between ALEs, health behaviours and health outcomes we observe in Canada are generalizable to other countries.

1.3 Dissertation Structure

This dissertation consists of nine chapters based on four full-length manuscripts and two short communication pieces. I have organized the chapters first by geography – beginning with Canada and ending with Wales and Australia; then by outcome – beginning with mortality, moving on to hospitalization, and ending with a closer examination of walking outcomes. Each chapter is prefaced with an introduction that explains how the section fits within the broader scope of the dissertation's objectives, and contains a focused literature review, methodology, results, and discussion that are tailored to the research question.

Chapter 2 situates this dissertation within the sub-discipline of Health Geography. I also introduce several other related disciplines and fields of study, including social epidemiology, population health, and urban planning. I provide a broad overview of the concepts that are foundational to studies of neighbourhood health from geography and epidemiology. I then describe population health approaches to chronic diseases and physical inactivity, with a focus on T2D. Dominant behavioural models are key to understanding interventions for increasing physical activity, and I explain why a social ecological approach is helpful for identifying and understanding environmental determinants of behaviours. I introduce the concept of the ALE from the urban planning and transportation fields and provide an overview of the evidence linking ALEs to population-wide health and behaviour. I also introduce the Canada Active Living Environments (Can-ALE) measure that will be used throughout this dissertation. Then, I briefly review the disease progression of T2D and links to physical inactivity and to neighbourhoods. I present a summary and conceptual framework unifying this work. The final segment consists of an overview of record linkage, the primary tool enabling my research for this dissertation.

Chapter 3 is the first of six empirical manuscripts and addresses objective 1. The aim of this study was to use Canadian record-linked data to determine whether we could observe ALE-associated gains in physical activity and lower mortality rates for people living in more favourable ALEs across a large population-based sample. There are two main ways in which this work differs from previous approaches. Firstly, I focused specifically on mortality related to cardiometabolic diseases (T2D and CVD) because these are among the deaths that are etiologically linked with physical inactivity. Secondly, this study was sufficiently powered for analyses stratified by age group and sex – which was necessary to account for the different mortality experiences by age and sex. To target the cardiometabolic deaths that 'ought' to be avoided, I focused on premature deaths. I separated the sample into middle age and older adults and defined premature cardiometabolic death separately for these groups. I also defined endpoints for premature death for older women and men in accordance with sex-specific life expectancies in Canada. I detected a protective effect of ALEs for premature cardiometabolic death in older women.

Chapter 4 is a follow-up study to Chapter 3 and the second manuscript of this dissertation. The research question objective 1, and additionally relates to objective 3. After the analysis from Chapter 3 revealed a protective association in older women only, I examined this subpopulation further and asked whether the association between ALEs and premature cardiometabolic death varies by T2D status and risk. I employed population-based algorithms designed to identify those at risk of T2D and those who have T2D based on survey items, and observed effect modification of the relationship between living in favourable ALEs and risk of premature cardiometabolic mortality based on T2D status.

Chapters 5 through 7 consider hospitalization as an outcome. The risk, frequency, and intensity of hospitalization are recognized indicators used to monitor the health status of the population over time and across regions, and are also informative as indicators of population health and disease morbidity (Canadian Institute for Health Information, 2020). Yet, there is almost no evidence on whether built environments might have the capacity to reduce hospitalization. Reducing hospital burden is a desirable goal given the large share of gross national product spent on healthcare in most nations. **Chapter 5** describes rates of all-cause hospitalizations and those related to major CVD events for Canadians living in each of the five ALE classes (1 being the least favourable and 5 being the most), and addresses objective 2 of this dissertation. My findings suggest that living in neighbourhoods that are progressively more favourable for active living is associated with lower odds of all-cause hospitalization, and more specifically – lower odds of being hospitalized with acute myocardial infarction and congestive heart failure. I also found that this relationship could be partly mediated through walking, however there was little evidence for mediation through overall physical activity.

The relationship between living close to hospital and higher hospital use has been shown previously (Goodman, Fisher, Stukel, & Chang, 1997; Lin, Allan, & Penning, 2002; Rudge et al., 2013). Living close to a hospital could confound associations between ALEs and hospitalization because favourable ALEs tend have more destinations – which includes health care facilities. **Chapter 6** examines the extent to which living closer to a hospital confounds the protective relationship between favourable ALEs and odds of hospitalization found in Chapter 5. A single composite measure of hospitalization that included both CVD- and diabetes-related events was used to capture a broad range of hospitalizations that could potentially be sensitive to physical inactivity. We derived a measure of distance to hospital for each neighbourhood using open-source data on points of interest (OpenStreetMap Contributors, 2018). I then tested the impact of different distances on the change estimates relating ALE to the odds of hospitalization for cardiometabolic disease. The study suggests that living within six kilometers of a hospital is associated with a small increase in the likelihood of hospitalization and modestly attenuates the association between living in more favourable ALEs and lower odds of hospitalization.

The remaining substantive chapters are devoted to studies of ALEs, health and behaviours using internationally sourced population data from the UK and Australia. Innovative data linkage efforts that parallel Canadian initiatives allowed me to construct analogous samples and variables for individual-level characteristics and health outcomes for Wales. Moreover, the flexibility of the Can-ALE methodology as well as its derivation from open-source data (Herrmann et al., 2019) enabled the construction of comparable ALE measures for Wales (the Wales Active Living Environments measure, Wal-ALE) and for Australia (the Australia Active Living Environments measure, Aus-ALE). These studies serve, in part, to validate these novel measures of ALEs.

The first is a comparative study of Wales and Canada in **Chapter 7.** Cross-national comparative studies expand the range and variability of exposures under study, and also allow us to examine how certain neighbourhoods operate in different regional contexts. The International Physical Activity and Environment Network (IPEN) studies suggest neighbourhoods which favour active lifestyles may be advantageous to physical activity and to health in wide range of geographical contexts (Sallis et al., 2020). However, the extent to which the impacts of ALEs are generalizable across to places where less is known about built environments and health has not been fully explored. Wales is distinct from Canada in its population, history, and landscape, but shares some of the same challenges, including rising chronic disease rates, low active transport prevalence, as well as being host to an ageing population. Neither Wales nor Canada were among the countries included in the IPEN cohort. The goal of this chapter is to compare the relationship between ALEs and hospital burden in the general population and those with T2D in Wales and Canada, and addresses objectives 2 to 4.

Chapter 8 examines in greater detail the influence of the built environment on walking for different purposes. This chapter addresses objective 4 of this dissertation and makes use of purpose-specific walking variables available from the Australian Diabetes, Obesity and Lifestyle Study. The approach of this study is also novel in that it distinguishes between the potential for ALEs to influence how often people walk from whether they walk at all. This chapter also addresses objective 3 by leveraging the availability of survey information on T2D risk and status. I used these data to assess whether the relationships between ALEs and walking for different purposes might vary in those who have T2D or are at higher risk for T2D.

Research findings are reviewed and summarized in relation to the broader objectives and hypotheses in a concluding chapter, **Chapter 9**. References are listed at the end of each chapter, and all literature cited is listed at the end of the dissertation.

Chapter 2

CONTEXT AND FRAMEWORK

This chapter reviews the overarching theory, concepts, and evidence linking active living environments (ALEs), physical activity, and health outcomes that form the foundation of this dissertation. First, I describe the place of research on neighbourhoods and health within the sub-discipline of health geography and introduce some of the theoretical underpinnings that have informed this dissertation. I then take a population health lens to the state of chronic diseases in Canada, and discuss life-course perspectives as well. Second, I review the theories of health behaviour that have influenced both our understanding of physical activity and health, as well as our interventions for increasing physical activity. I introduce the application of social ecological models to physical activity and focus on walking as a means of physical activity that is routine and widely accessible. Third, I discuss the emergence of ALEs from the field of transportation and urban planning and provide a broad overview of the major population-based evidence that has strengthened our understanding of how these types of neighbourhoods have been linked with behaviour and downstream health outcomes. Fourth, I discuss type 2 diabetes (T2D) as a major modifying factor in this dissertation. I then present a conceptual framework and summary of the overarching gaps in knowledge of ALEs with respect to health outcomes (morbidity and mortality), the relevance of these environments to those who already have T2D or are at high risk of developing T2D, and the international generalizability of the health benefits associated with living in ALEs. Last, I provide an overview of record linkage as well as a rationale for using linked survey, administrative and environmental data to study built environments and population-wide health patterns.

2.1 NEIGHBOURHOODS AND CHRONIC DISEASE

Chronic disease in Canada looks like a 'good news story' in some ways. Data from the Canadian Chronic Disease Surveillance System (CCDSS) reveal immense reductions between 2000 to 2018 in age-standardized death rates of major cardiovascular (CVD) disease and incidence rates for hypertension, and appreciable reductions in incidence rates for congestive heart failure (CHF), acute myocardial infarction (AMI), and stroke (Public Health Agency of Canada, 2020). These decreases have been attributed to improvements in primary care, as well as better diagnostics, clinical treatment, and prevention strategies. However, Canada has both a growing population and an aging population. This means that reductions in disease incidence may not necessarily translate into reductions for prevalence rates (Figure 2.1, panel A). CVD remains a leading cause of death, second only to cancer (Figure 2.1, panel B). Diabetes prevalence has increased from 5% to 8% over 16 years, without appreciable reductions in incidence or mortality rates. Moreover, diabetes-related deaths are often underestimated because diabetes is often not considered the primary cause of death (McEwen et al., 2006). Presently, T2D affects 2.5 million Canadians (Statistics Canada, 2020b).

A striking characteristic of chronic diseases are the extent to which rates vary across regions. Geographic differences in diabetes and CVD have been widely documented in Canada. Across provinces, age-standardized prevalence rates for diabetes can range from 6.8% in Quebec to 9.1% in Manitoba (Public Health Agency of Canada, 2020). Incidence rates for AMI can be as high as 300 cases per 100,000 people in the Northwest Territories to nearly half that in British Columbia (Public Health Agency of Canada, 2020). Chronic diseases as well as their antecedent risk factors have been found to vary across health regions (Figure 2.1, panel C). Lee and colleagues demonstrated that although provincial trends for six risk factors for CVD (which included hypertension, diabetes, current smoking, obesity, low physical activity, and low-income adequacy) were similar to national trends, the distribution of these risk factors varied considerably across health regions within provinces (Lee et al., 2009). Spatial disparities in chronic disease are also observed at local scales (Figure 2.1, panel D). Diabetes prevalence in the city of Toronto can change from 4.9% in the neighbourhood of Leaside-Bennington to over 12.8% in the adjacent neighbourhood of Thorncliffe Park located less than three kilometers away (Ontario Community Health Profiles Partnership, 2021).

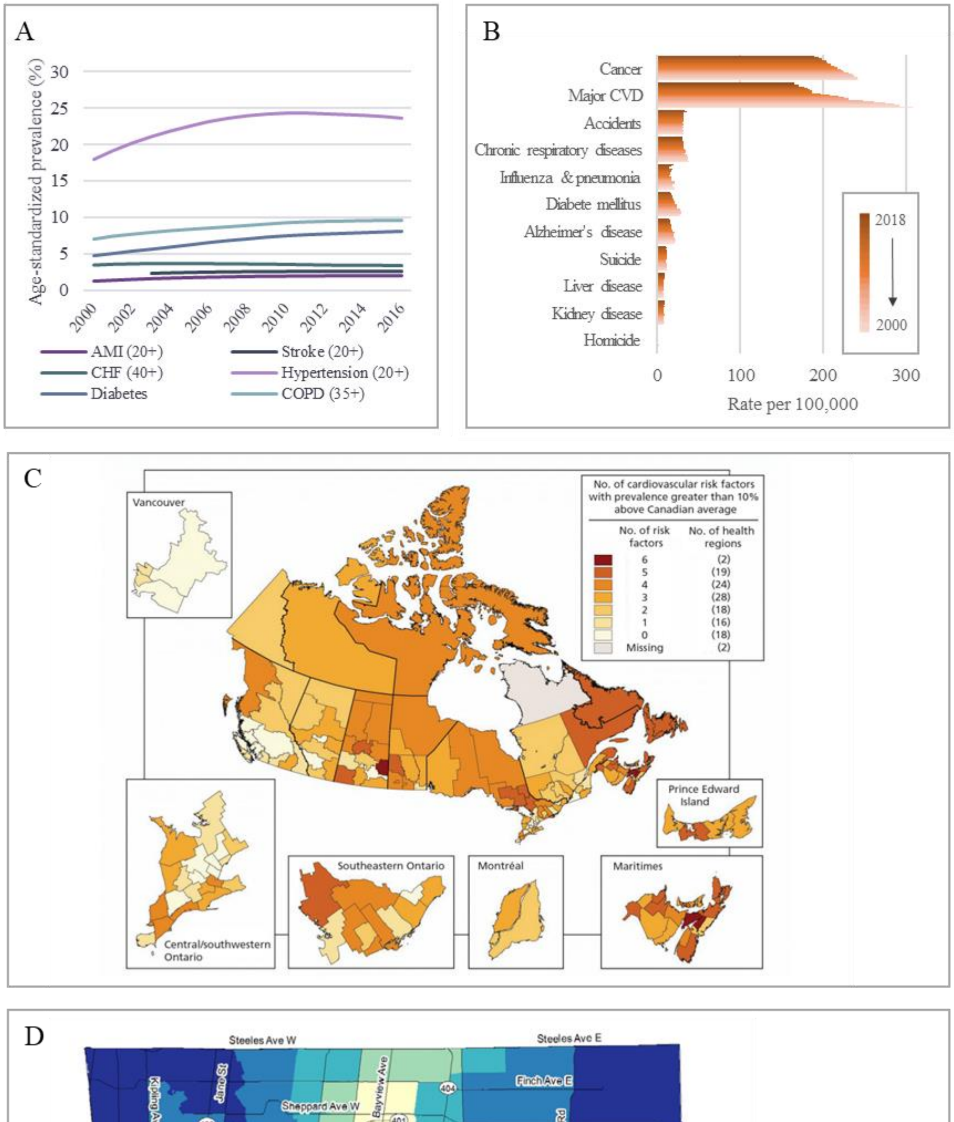

Figure 2.1 Chronic disease in Canada and neighbourhoods.

A. Age-standardized prevalence of major chronic diseases among Canadians, 2000/03–2016. Data source: Canadian Chronic Disease Surveillance System 2018. AMI, acute myocardial infarction; CHF, congestive heart failure; COPD, Chronic Obstructive Pulmonary Disease. **B.** Age-standardized mortality rates per 100,000 standard population. [1]Rates are age-standardized using the 2011 population. Data source: Statistics Canada, Canadian Vital Statistics, Birth and Death Databases and Appendix II of the publication "Mortality Summary List of Causes" (catalogue number 84F0209XIE). **C.** Distribution of risk factors for cardiovascular disease across health regions in Canada. Risks factors with a prevalence exceeding the national average by at least 10% were counted (Lee et al., 2009). **D.** Age-standardized diabetes prevalence by neighbourhood in Toronto from 2014 (Toronto Public Health, 2017).

Geographic disparities in chronic disease rates have motivated researchers from a variety of disciplines to consider the potential role that neighbourhoods themselves may play. Several health-related fields began to broaden their research interests to include determinants of health within and across different environmental contexts. Epidemiologists Susser and Susser advocated for an "eco-epidemiology" approach which acknowledges that multiple interacting levels of determinants influence health (Susser & Susser, 1996a, 1996b). Another epidemiologist, A. J. McMichael, warned that an ever-narrowing focus on biomedical risk factors for disease might eventually reduce our view of the causes of disease to individual physiology and genetics, rendering us "prisoners of the proximate" (McMichael, 1999). Medical sociologists Link and Phelan pointed out that some causes of health inequalities, such as poverty, persist not only because of how widespread and pervasive they are, but also because these causes tend to also impact individuals' access to resources that are instrumental for avoiding or minimizing disease (Link & Phelan, 1995). In many ways, neighbourhoods fit these criteria: where we live contains exposures that can impact our health through multiple pathways (such as air pollution, noise, crime), but also affects our access to health-promoting amenities such as health care, services, schools (Duncan & Kawachi, 2018).

Studies of neighbourhoods are understood to be comprehensive because they encompass both physical and social factors of disease across groups of people. However, studies of neighbourhood health and chronic disease bear important challenges (Diez Roux & Mair, 2010). How neighbourhoods are conceptualized and measured in ways that are relevant to chronic disease are vast and often complex. Identifying the characteristics of neighbourhoods that are driving chronic disease and testing their associations with a strong theory of their mechanism is a necessary but complicated task, because many of these characteristics are interrelated and influence each other. Furthermore, neighbourhoods are more than the sum of the characteristics relevant to health or those which we select for study. Places are complex and unique in their interactions with people - shaped by people and shaping people over time. Fundamentally, we need the perspective of health geography to fully understand the relationship between place and our health.

Health Geography

As a subdiscipline with cross-disciplinary and intersectoral collaborations with epidemiology, public health, medicine, and psychology, *health geography* seeks to understand the relationship between place, health, and wellbeing. It is a field that is devoted to examining how people interact with place, and accounts for characteristics of space and place that other health-related fields may overlook. Health geography has its roots in medical geography, a subdiscipline that has traditionally focused their scholarly work in spatial epidemiology and health care research (Mayer, 1982; Paul, 1985), and draws extensively from disease ecology and spatial analytic approaches. Dialogue between the two subdisciplines has resulted in both a pluralistic approach toward adopting and advancing a range of interdisciplinary theories and methodologies (Meade & Emch, 2010) as well as attention toward more holistic conceptions of health and well-being beyond those of traditional medicine (Kearns & Moon, 2002). Health geography has brought both substantive and methodological assets to public health policies already in play, since so many aspects of health, behaviours, and health care are influenced by exposures that are fundamentally environmental or geographic in nature (Dummer, 2008).

There are three uniquely geographic aspects of neighbourhoods and chronic disease that health geographers have identified and worked to address. **First, the conceptualization of neighbourhoods and place is a priority of health geography.** Health geography has been characterized as having an explicit use of theory to explain relationships between health and place, as well as encompassing a more critical view and awareness of health disparities and the upstream forces that drive them (Cutchin, 2007). Importantly, health geography has broadened conceptions of place beyond "geometric constructions of space" (Kearns & Joseph, 1993) composed of geographical coordinates, toward an understanding of place as "an operational and living construct which matters" (Kearns & Moon, 2002). How we perceive, experience, and understand place, its historical significance, and the social structure and qualities of the physical environment enriches our understanding of place and have become key qualities of interest in the subdiscipline (Gesler, 1992). Engagement with the other disciplines of human geography has contributed to a fulsome understanding of neighbourhoods. For instance, the health fields' interest in the *urban-rural divide* has been a normative concern regarding differential access to health care services and resources (Sibley & Weiner, 2011). However, many fields of geography recognize the urban-rural divide as a central concept that carries social, political, economic, and cultural significance. Understanding 'urban' and 'rural' characteristics of place, and how these characteristics relate to and overlap with physical and social environmental determinants of health can deepen our understanding of neighbourhood health. The care taken in how health geographers conceptualize *place* has uniquely catalyzed the advancement of both our understanding of neighbourhoods, as well as our analysis of neighbourhoods.

The second aspect of studying neighbourhoods and chronic disease is the need for tools and analytic methods to understand spatial information. Health and medical geographers, as well as spatial epidemiologists, have a tradition of developing methods for determining spatial and temporal patterns of disease occurrence. Fundamental to the discipline has been the geographic information systems (GIS) framework which has enabled the storage, management and visualization of spatial data, as well as the development of objective neighbourhood exposure measures (Cromley & McLafferty, 2011). For example, the geocoding capabilities, buffer and network-based analyses and spatial statistics afforded by GIS have been instrumental in studies of obesity and environment (Jia, Cheng, Xue, & Wang, 2017). Moreover, the development of sophisticated spatial analytic methods to, for instance, address privacy concerns or improve small area estimates, are active areas of research and development (Kirby, Delmelle, & Eberth, 2017). Health geographers have a practice of bringing together both quantitative and qualitative approaches to understand relationships between place and health (Dummer, 2008).

The third challenge of neighbourhoods and chronic disease is the need to innovate our measures of environmental exposures. Although neighbourhood environments, as determinants of chronic disease, can be powerful exposures that permeate our behaviours that impact health, determining an individual's *actual* exposure to certain neighbourhood features, and linking these exposures to behaviours and health outcomes is difficult. Administrative boundaries and spatial scales relevant to specific health boutcomes are routinely used to produce neighbourhood measures and are often robust to sensitivity analyses. However, there remains a desire for more precise measures of neighbourhood exposures in space and time (Muller-Riemenschneider et al., 2013; Ross, Tremblay, & Graham, 2004; Villanueva et al., 2014). First articulated by Mei-Po Kwan as the *Uncertain Geographic Context Problem* (Kwan, 2012), both misclassifying spatial and temporal exposure can lead to inferential errors. For example, working-age residents may spend a significant proportion of their time near their place of employment and seek amenities in neighbourhoods away from home. This problem has led to an array of new approaches aided by GIS and Geographic Positioning Systems (GPS) that characterize *activity spaces* – the collection of places that people encounter and travel through over the course of their daily activities. Such studies, while promising in the level of detail and precision they offer, often entail sensor-based geospatial data collection from small samples that is both costly and computationally intensive to analyze. Nevertheless, this is a growing area of research that complements studies of residential neighbourhoods.

Population Health

There are two other approaches to neighbourhoods and health that are instrumental to this dissertation's overarching framework. The first is *population health.* The medical and public health fields recognized that preventing chronic disease across populations would require a different approach. Although the seeds for such an approach were sown in late 18th century Europe with the growth of urban populations of the Industrial Revolution and infectious diseases (Szreter, 2003), our modern-day approach to population health can be traced back to Canada's history of public health promotion, beginning with *A New Perspective on the Health of Canadians*, also known as the Lalonde Report. Twelve years later, the Ottawa Charter for Health Promotion emerged from the World Health Organization's First International Conference on Health Promotion, and in 1989 the Canadian Institute for Advanced Research (CIAR) introduced the widely endorsed 'population health approach' (Health Canada, 1994).

Contemporaneous with Canadian interests in population health, Geoffrey Rose articulated his theory of population health in his seminal work which proposed two approaches to disease prevention (Rose, 1985). First, he described the *high-risk strategy* as targeting for intervention those most likely to develop a disease.

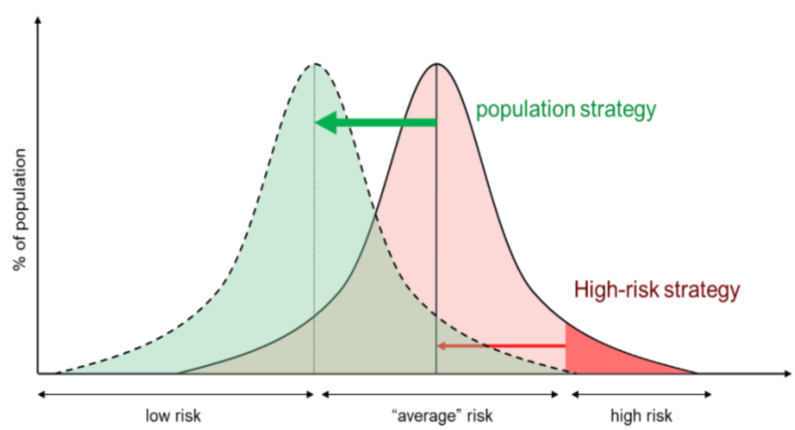

Figure 2.2 Rose's population strategy for preventive health (Rose, 1985).

This approach is often seen as the most consistent with the traditional biomedical model. High risk approaches are effective because they are tailored to the needs of individuals. They are also efficient, in the sense that only those identified as high-risk are targeted for intervention and treated (Figure 2.2). However, the high-risk approach 1) assumes that our screening/diagnostic methods accurately identify those truly at risk, 2) relies on individual-level adherence to medical regimens and in health behaviours, and 3) is limited in its potential to intervene to the scale of populations. He reasoned that a "larger number of people at a small risk may give rise to more cases of disease than the small number of people who are at high risk." This idea has been applied to body mass index (BMI) as a risk factor for diabetes incidence (Manuel et al., 2010): the majority of new diabetes cases are predicted to come not from those with the highest BMI, but those in the middle of the distribution (Figure 2.3).

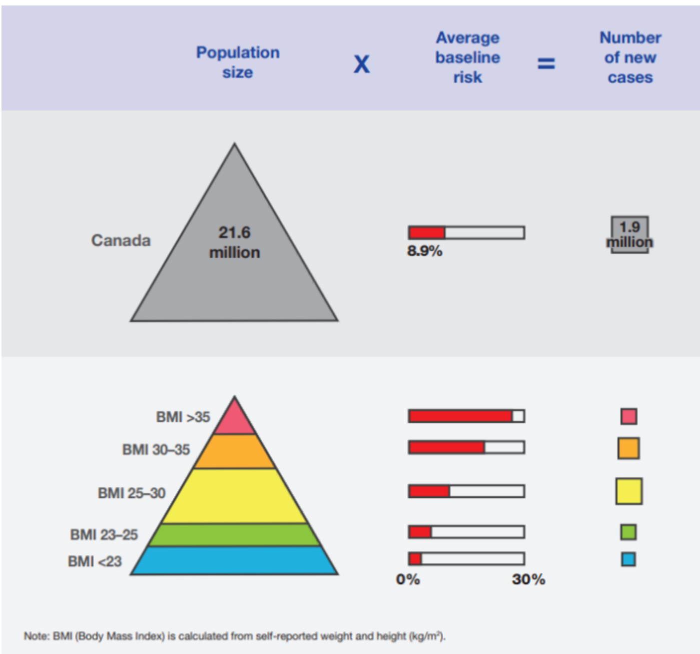

Figure 2.3 Predicted diabetes cases 2007 – 2017 in Canada.
Illustration of the predicted total number of new diabetes cases between 2007 and 2017 using the Diabetes Population Risk Tool (DPoRT) algorithm, Canadians' Body Mass Index (BMI) and risk factors in 2007. The largest number of people will come from the middle of the distribution with BMIs between 25-30 (yellow). Figure from *How many Canadians will be diagnosed with diabetes between 2007 and 2017? Assessing population risk ICES Investigative Report (Manuel, Rosella, Tuna, & Bennett, 2010).*

Rose advocated for a second approach, which he called the *population strategy*. This approach involves a focus on the determinants of incidence in the population and in doing so, has the potential to 'shift the curve' by reducing risk across the entire distribution. Population strategies typically focus on widespread exposures that are environmental or social in nature and attempt to modify these exposures. The idea is to achieve modest changes in the individual habits and behaviours of many individuals, resulting in large net effects across the population. While mass environmental interventions are often of minimal benefit to individuals, the population strategy is scaled to benefit everyone - including the many who are not identified as being at high risk of disease but often make up the majority of cases (Figure 2.2). The approach also relies much less on individual adherence to changes in behaviour, because it tends to focus on modifying the factors that influence behaviour. Rose argued that the population strategy is fundamentally radical because it "attempts to remove the underlying causes that make the disease common" (Rose, 1985).

Life Course Perspectives

To identify and target mass causes of disease across populations, Rose acknowledged that most diseases "are in a state of flux" and that it would be necessary to track changes in exposures, risk factors, and disease incidence over time. *Life course approaches* examine the "long-term effects on chronic disease risk of physical and social exposures during gestation, childhood, adolescence, young adulthood, and later adult life" (Kuh & Shlomo, 2004) and have become essential for understanding health exposures and outcomes over time - particularly in the study of chronic diseases (Ben-Shlomo & Kuh, 2002; Lynch & Smith, 2005). There are three main concepts brought forward by the life course approach. First, the approach posits that environmental exposures may have a *greater* impact health during certain periods of time and less in others (called sensitive periods) or may *only* impact health during certain periods of time (called critical periods). Although this is most often applied to developmental processes in early life, the concept can be applied to exposures across the life course. For example, there is evidence that certain health-promoting aspects of neighbourhoods, such as access to healthy food outlets and recreational areas are beneficial for youth, while local services, daily activities, and destinations that promote social connectedness grow in importance as individuals age (Nathan et al., 2018). Second, the life course framework hypothesizes that sustained exposure to different environments over time has additive consequences on health down the road (called the accumulation of risk model). Third, life course studies consider the potentially long latency period between exposure onset and the occurrence of health outcomes (Aboderin et al., 2002; Forouhi, Hall, & McKeigue, 2004). For example, associations between built environments and physical activity may not be very strong for recent arrivals to the neighbourhood, for whom the environment has not had time to influence behaviors.

2.2 Achieving Physical Activity

So far, I have described health geography's interdisciplinary contributions toward characterizing and explaining relationships between neighbourhoods and chronic disease. I also presented some of the merits of incorporating both population health and life course perspectives into those investigations. This section focuses on how we understand physical inactivity as a widespread risk factor for chronic diseases, and how we might examine neighbourhoods as a means of achieving population-level increases in physical activity to address chronic disease.

Physical Inactivity and Chronic Disease

There is overwhelming evidence that physical activity is essential for preventing chronic disease and related mortality (Lee et al., 2012). Physical activity is important in both primary prevention as well as secondary prevention strategies for those already diagnosed with T2D or CVD (Alves et al., 2016; Durstine, Gordon, Wang, & Luo, 2013). One meta-analysis of 17 studies estimated that an increase of 1 MET-hour/day[1] in physical activity was associated with a 9.5% reduction in all-cause mortality risk and a 7.9% reduction in CVD risk (Kodama et al., 2013). In spite of these benefits, only 16.4% of Canadian adults achieve the recommended physical activity guidelines (Center for Surveillance and Applied Research, 2020) of at least 150 minutes of moderate-to-vigorous physical activity per week (Tremblay et al., 2011) – a guideline that is theoretically sufficient to achieve meaningful reductions in chronic disease risk and death in Canada (Warburton, Nicol, & Bredin, 2006). That a modest 20 minutes of physical activity per day could prevent longstanding illness and disability may seem difficult to believe. However, systematic review evidence suggests that the most important relative risk reductions are observed when comparing no or limited physical activity to small amounts of physical activity (Warburton & Bredin, 2017). This may even be the case for non-vigorous physical activity (Woodcock, Franco, Orsini, & Roberts, 2011).

The health benefits of physical activity are known, but the challenge is how to effectively achieve increases in physical activity across populations for whom being physically inactive has become ingrained in daily life. The 2016 census revealed that 74% of Canadians commute to work by car, while the proportion of people traveling by public transit have increased slightly. Canadians are spending more time engaging in sedentary activities (Prince, Melvin, Roberts, Butler, & Thompson, 2020). The full-time working population spends most of their day (69%) in sedentary occupations (Prince, Roberts, et al., 2020).

Theories of Health Behaviour

There are many theories and models that have helped explain health behaviours and guide our efforts to achieve changes in health behaviours. Rhodes and colleagues (2019) have identified four overarching approaches that have been used to understand physical activity as a health behaviour:

[1] MET: Metabolic equivalent of task. 1 MET is the resting rate of energy expenditure.

humanistic, dual process, social cognitive, and socioecological (Rhodes, McEwan, & Rebar, 2019). I will review each briefly, with greater emphasis on the last two approaches (social cognitive, socioecological) as the two dominant approaches in this field.

Humanistic approaches are premised on the idea that people possess innate desires for growth and fulfillment of various intrinsic needs (called *self-actualization*) which drive whether we perform physical activity or not. While this approach has not been as extensively applied to physical activity interventions as social cognitive approaches, Alfonso and colleagues (2005) adapted Maslow's hierarchy of needs framework (Maslow, 1943) to explain walking (Figure 2.4). In their model, a series of aspects contribute toward an individual's decision to walk, each necessary for higher-order aspects to become influential to the decision. The most fundamental aspect (feasibility) is seen as a function of personal limits such as physical mobility, while higher-order needs (accessibility, safety, comfort, pleasure) are seen as a function of urban form and environment (Alfonzo, 2005).

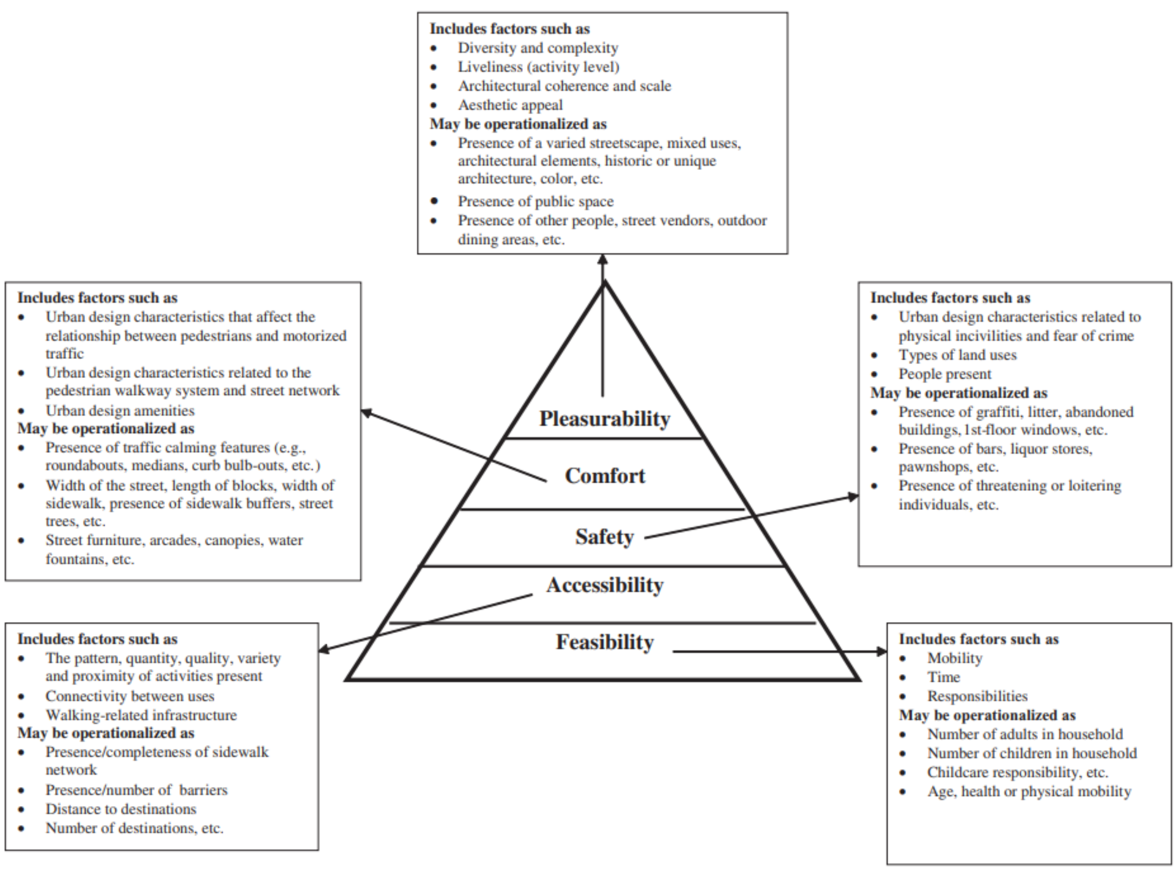

Figure 2.4 Hierarchy of Walking Needs (Alfonzo, 2005).

Dual process approaches propose that human behaviours are dictated by two cognitive processes: one that is *reflexive,* faster and requires little voluntary effort, and a second process that is *reflective,* slower, and demands more deliberate and conscious processing (Hagger, 2016; Strack & Deutsch, 2004). These two processes have also been referred to as "System 1" and "System 2," respectively (Kahneman, 2011). The interest here is to influence the first set of processes that have to do with non-conscious or *automatic behaviours*, which can be difficult to change because we tend to fall back on actions that are easier, more efficient, and familiar. This approach is useful for thinking about physical activity as *habit*, and how habits can be formed and changed by structuring environments in a way that cues or *nudges* individuals toward choosing certain activities over others (Lally & Gardner, 2013). For example, neighbourhoods that have well-run transit systems could obviate tendencies toward car travel in favour of walking or cycling for transportation. Dual process approaches are relatively new to research on health behaviours and have yet to be extensively applied and tested.

Social cognitive approaches presume human behaviour is primarily driven by individual-level knowledge, learning, and motivations. Three social cognitive models have been employed extensively to physical activity (Glanz & Bishop, 2010). The *Health Belief Model* hypothesizes that individuals are likely to engage in a particular health behaviour if: 1) they believe they are susceptible to a disease, and 2) engaging in this health behaviour will effectively prevent the disease (Hochbaum, 1958; Rosenstock, 1974). Interventions that are crafted from the Health Belief Model often centre on public education approaches, 'cues to action' (similar in concept to ideas of dual process above) and mass-media campaigns. The *Transtheoretical Model* conceptualizes individuals as being at varying stages or "readiness" for changes in health behaviour (Prochaska & DiClemente, 1992), while the *Social Cognitive Theory* (Bandura 1986) suggests that people learn from the actions and outcomes of each other in reciprocal ways (often referred to as *reciprocal determinism*). Central to Social Cognitive Theory is the idea that behaviours are impacted by an individual's self-control and self-efficacy. Social cognitive models are the foundation of many lifestyle programs and behaviour change techniques which aim to increase walking (Bird et al., 2013).

Social cognitive models are the dominant theories of health behaviour that have influenced both the objectives and design of physical activity interventions (Glanz, Rimer, & Viswanath, 2015).

Both the Transtheoretical Model and Social Cognitive Theory have provided the rationale for the techniques used in many individual-level interventions to increase physical activity, such as goal setting, self-monitoring, action planning, prompting practice or self-rewards. These approaches have shown success (Conn, Hafdahl, & Mehr, 2011; Greaves et al., 2011; Hankonen et al., 2014; Howlett, Trivedi, Troop, & Chater, 2018). A systematic review from Ogilvie and colleagues (2007) found that the most effective interventions for promoting walking to-date were those that were tailored to the individual and were targeted to sedentary people or to very motivated individuals. Aside from the mass media campaigns inspired by the Health Behaviours Model, which have yielded mixed results in terms of achieving sustained population-wide increases in physical activity (Abioye, Hajifathalian, & Danaei, 2013; Conn et al., 2011; Lira, Elaine, Younghan, Allison, & Tanya, 2017; Marcus, Owen, Forsyth, Cavill, & Fridinger, 1998), many health promotion efforts have targeted individuals as opposed to populations. Ogilvie and colleagues caution that although such interventions may produce increases in walking within the circumstances of the study (*efficacy*), the benefit of these interventions in real-world conditions (*effectiveness*) is often less clear (Ogilvie et al., 2007). Individual-level behavioural interventions also remain relatively resource-intensive, may be difficult to scale up, and as previously raised, rely on identifying those at risk and the adherence of individuals to the program (Rose, 1985). Reaching individuals in the 'middle' of the risk distribution remains a challenge, who, despite not being at the highest risk for disease, would eventually comprise the largest proportion of those who develop the disease. 'Lower risk' individuals are also likely to benefit from physical activity interventions (Howlett et al., 2018). Lastly, lifestyle change programs may have limited impact on diabetes-related complications and death for those who already have T2D (Schellenberg, Dryden, Vandermeer, Ha, & Korownyk, 2013).

Socioecological approaches acknowledge that there are multiple levels of influence extending from intrapersonal factors toward interpersonal, institutional, community, and policies which encompass the individual to collectively shape health behaviours (McLeroy, Bibeau, Steckler, & Glanz, 1988; Stokols, 1992). These approaches emphasize the role of mutual human-environment interactions occurring across different groups of people. Unlike the individual-level focus of the humanistic, dual process, and social cognitive approaches (Rhodes et al., 2019), socioecological approaches consider factors beyond the individual. They accommodate broad neighbourhood exposures and are also well-suited to understanding outcomes like chronic disease which stem from many causes. With their emphasis on identifying "high leverage" factors that have the maximal potential to affect behaviour through multiple levels of influence (King, Stokols, Talen, Brassington, & Killingsworth, 2002), socioecological models are highly compatible with the population health approach (Rose, 1985). These approaches also help to explain why existing behavioural interventions could be challenging in the absence of material, social and environmental conditions that are supportive of health behaviours. Socioecological approaches are not without limitations however, and share many of the challenges that are inherent to research on neighbourhood health (Diez Roux & Mair, 2010). Broadening the range of potential factors often comes at the cost of lower specificity about the relative importance of these factors and their theoretical mechanism of influence. As a result, hypotheses tend to be difficult to test, compared with the well-defined constructs and mechanistic explanations of social cognitive models (Sallis & Owen, 2015). Nevertheless, the socioecological approach uniquely highlights environmental context as a significant determinant of behaviour among multiple layers of influence, and have been particularly helpful for understanding relationships between neighbourhoods and behaviours.

Neighbourhoods and Physical Activity

The Ecological Model of Active Living (Sallis et al., 2006) is one of the most explicit applications of the socioecological approach to physical activity and is highly relevant this dissertation (Figure 2.5). As part of the model, Sallis and colleagues developed the concept of *active living*, a broad consideration of how physical activity is integrated into leisure, active transportation, occupational and household activities (Sallis, Linton, & Kraft, 2005). At the core of the model are intrapersonal characteristics of the individual. Each 'domain' of active living divides the model, and specifies the environmental perceptions, settings, and policies that are most relevant to certain behaviours. For example, whether one perceives a neighbourhood as being closely located and well-connected to public transit and service points is likely to influence active transport and utilitarian behaviours but could be less relevant to recreational activities. Neighbourhood aesthetics and public investment in parks are meaningful for leisure-time activities. However, these characteristics may not influence an individual's active transport, or have little impact on household or occupational activities. The model has encouraged researchers to consider the ways in which physical activity is programmed into everyday life, and how one might reinforce and create new ways to do so as potential avenues for population-level physical activity interventions.

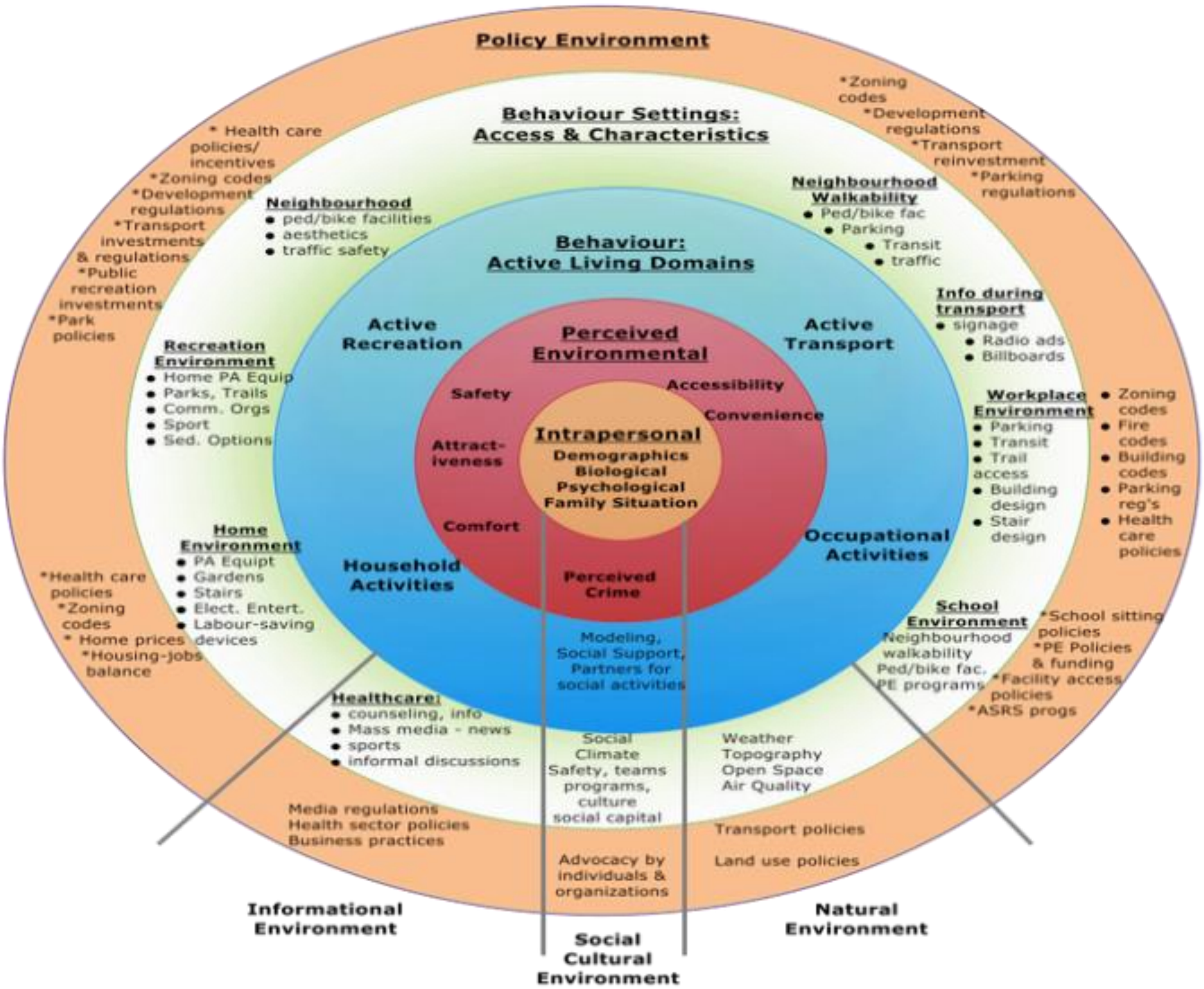

Figure 2.5 Ecological model of four domains of active living (Sallis et al., 2006).

Across the layers of policy and behaviour settings in the model, one of the central concepts is the *built environment*, defined as the physical environment that is built or designed by humans where we carry out our daily lives (Public Health Agency of Canada, 2014). The built environment includes all buildings, transportation, community spaces, layout and other infrastructure that comprise our surroundings. Identifying aspects of the built environment's physical structure that enable or constrain active living can be informative for neighbourhood policies and interventions that seek to alter population-wide behaviour. For example, the presence and variety of amenities in a neighbourhood that can be reached by walking or cycling provides opportunities for active transport to residents and is also likely to affect how residents perceive their own neighbourhood's accessibility and convenience. In thinking about the policies and interventions that could increase neighbourhood-based activities, one could consider, for example, how zoning bylaws that restrict the establishment of stores in residential neighbourhoods might influence both the quantity and type of amenities that are within walking distance of residents.

A scoping review of 46 systematic reviews and meta-analyses examining relationships between the built environment and physical activity, diet and obesity found consistent support for active-living friendliness as an important factor for physical activity (Dixon, Ugwoaba, Brockmann, & Ross, 2020). I cover active living-friendliness in more detail in the next section (2.3 Built Environments for Active Living). Many studies of the built environment have focused on walking as a central behavioural outcome – and with good reason. First, walking is a prevalent form of exercise that is embedded in daily activities. Since nearly all domains of living involve walking, it could be amenable to intervention through many different environmental and policy pathways. Physical activity derived from leisure-time activities (Arem et al., 2015) and active transport (Celis-Morales et al., 2017; Patterson, Webb, Hone, Millett, & Laverty, 2019) can be of substantial benefit to health outcomes. A second reason that follows is that built environment attributes have been found to relate to walking across many studies (Barnett, Barnett, Nathan, Van Cauwenberg, & Cerin, 2017; Owen, Humpel, Leslie, Bauman, & Sallis, 2004; Saelens & Handy, 2008). Lastly, the benefits of walking to cardiometabolic health and mortality are clear (Gregg, Gerzoff, Caspersen, Williamson, & Narayan, 2003; Hall et al., 2020; Murtagh et al., 2015). Walking is a simple, practical, and convenient form physical activity that is attainable for much of the population (Morris & Hardman, 1997), and warrants particular attention in socioecological studies of the built environment and health.

Even at the time of its publication, Sallis and colleagues (2006) advised readers that their model represented an ambitious research agenda. They cautioned that many of the variables they considered in the model had not been tested. However, the Ecological Model of Active Living is limited in other ways as well. First, the model does not specify the relative importance of each domain of active living to overall physical activity. For example, it is unclear whether walking trips for transit, for leisure, or for other purposes contribute most to overall physical activity attained. Second, the extent to which various factors interact with each other and confound associations of interest cannot be feasibly specified in broad socioecological frameworks. In the case of built environments, neighbourhoods for which high levels of investment in safety infrastructure for pedestrians and cyclists may also be higher-income neighbourhoods that have more resources and social capital. Last, the components in each layer of the model and their relative importance are likely to vary for different demographic groups. For example, school-based exercise programs are only relevant to children and youth, while adults are the likely audience for roadway billboards promoting physical activity. Nevertheless, the Ecological Model of Active Living is a useful framework for thinking about the interface between built environments and the daily activities of people. The model serves as a starting point for examining how relationships between neighbourhoods and physical activity may in turn, contribute to chronic disease outcomes (Sallis, Floyd, Rodriguez, & Saelens, 2012).

2.3 BUILT ENVIRONMENTS FOR ACTIVE LIVING

The conceptualization of built environments and its potential impacts on heath began in the transportation, urban planning, and urban design fields (Handy, Boarnet, Ewing, & Killingsworth, 2002). Transport planners have been interested in how land use could be leveraged to shape travel behaviours, reduce automobile use and increase the share of non-motorized trips (Cervero & Kockelman, 1997). Recognizing the challenges posed by climate change and the need for sustainable transit, planners have increasingly shifted their attention from motorway construction and maximization of road capacity to the design and optimization of public transit infrastructure as well as transit-oriented development. Parallel to these changes, key thinkers in urban planning were moving away from city plans that were often suburban and car-centric, toward designs that focused on the creation of functional, well-used public spaces and sustainability. These ideas would later pave the way for the 'New Urbanism' movement by the late 1980s – in large part a reaction to the post-war suburban sprawl that took over much of North America and was accompanied by increased traffic, pollution, and a lack of investment in public transit and pedestrian-oriented infrastructure. Designing neighbourhoods "to be compact, pedestrian-friendly, and mixed-use" in which "many activities of daily living (are) within walking distance" (Leccese & McCormick, 2000) was one of the ideas that gained widespread support in the field. This concept remains a central ambition for modern urban planners.

In step with the pursuits of the urban planning and transportation fields, as well as the health fields (Sallis, 2009), researchers became interested in defining the aspects of the physical built environment that encourage active living. These aspects were first conceptualized in a study of transit demand. Cervero and Kockelman (1997) aimed to "test the propositions of the new urbanists and others that compact neighbourhoods, mixed land uses, and pedestrian-friendly designs 'degenerate' vehicle trips and encourage residents to walk, bike, or take transit as substitutes for automobile travel, particularly for non-work purposes". They proposed that a combination of three built environment characteristics – density (compactness), diversity (a mix of land uses), and design (pedestrian-oriented features) – comprise the main elements that promote and make possible active travel (Cervero & Kockelman, 1997). Measures of these three elements and their composite measures are among the most widely employed for investigating relationships between built environment exposures and health (Chandrabose, Rachele, et al., 2019; den Braver et al., 2018; Feng, Glass, Curriero, Stewart, & Schwartz, 2010; Nieuwenhuijsen, 2018).

These elements are often referred to as neighbourhood *walkability*, 'the extent to which characteristics of the built environment and land use may or may not be conducive to residents in the area walking for either leisure, exercise or recreation, to access services, or to travel to work' (Leslie et al., 2007). However, the use of this term in health research has been criticized because it does not account for the built environment's ability to facilitate other forms of physical activity aside from walking (Gauvin et al., 2005), such as running and cycling. Moreover, to frame this research as relating to 'walkable neighbourhoods' presumes that individuals do, in fact, *walk* more in these neighbourhoods (Hajna, Ross, Griffin, & Dasgupta, 2017). In acknowledgement of the shortcomings of the current terminology, and to account for the multiple physical activity domains that these neighbourhood characteristics are likely to impact, this dissertation uses the phrase, *active living environments* (ALEs) to describe neighbourhoods that are conducive to routine physical activity.

Canadian Active Living Environments (Can-ALE) Measure

There are various ways that ALEs have been measured and different composite measures that exist, including those which require proprietary data sources, and others for which the measure and its derivation are themselves, proprietary ("Walk Score Methodology," 2020). The proprietary nature of such measures can limit 1) the ability for future investigates to fully understand and adapt these measures to suit their research questions; 2) the replicability of such measures across different regional contexts and time periods; and 3) the potential to derive comparable measures across regions. To overcome these limitations, maintain flexibility of the measure's derivation, as well as optimize the measures to explain walking rates in Canada, the Geo-Social Determinants of Health Research Group developed a procedure for deriving new measures of ALEs from open-source data. Below is an introduction to this measure, some key design decisions, as well as a description of how this procedure was applied to open data from two other countries.

The Canadian Active Living Environments (Can-ALE) Database is a national set of built environment measures for active living friendliness that were derived from open data (Figure 2.6). The full description of the design of these measures, details of their derivation, and their performance against other proprietary measures have been described in detail (Herrmann et al., 2019). The Can-ALE is a composite classification made up of three components: street connectivity, residential density, and destinations. Three-way intersection density of roads and footpaths derived from OpenStreetMap (OSM) data was selected as the street connectivity component facilities (OpenStreetMap Contributors, 2017). Weighted dwelling density measures were derived using Statistics Canada's DA-level dwelling counts for the 2016 census. Dwelling counts of each DA within the buffer were aggregated and divided by the area of the buffer. In cases where the buffer partially covered more than one DA, dwelling counts were proportionally adjusted to the area of the DA that fell within a given buffer. Points of interest from OSM were counted in each buffer area and were themselves were highly correlated with 2016 census walking rates. Transit measures were also derived, but only for census metropolitan areas (CMAs) and were not included in the measures used for this dissertation, because the sample population included Canadians who resided outside of CMAs. Scores for the three components (street connectivity, residential density, and destinations) were clustered into five categories using a k-medians clustering approach, representing environments that are very active living-*un*friendly (ALE class 1) to those that are very highly active living-friendly (ALE class 5). CCHS respondents were then linked with their corresponding neighbourhoods using their reported postal code. The Statistics Canada Postal Code Conversion File Plus (PCCF+) is a program that assigns spatial coordinates based on population-weighted random allocation (Wilkins & Peters, 2012). Once interpolated, these coordinates were overlaid with DAs in a Geographic Information System (GIS, ArcGIS v.10, ESRI 2010), and assigned their corresponding Can-ALE classification.

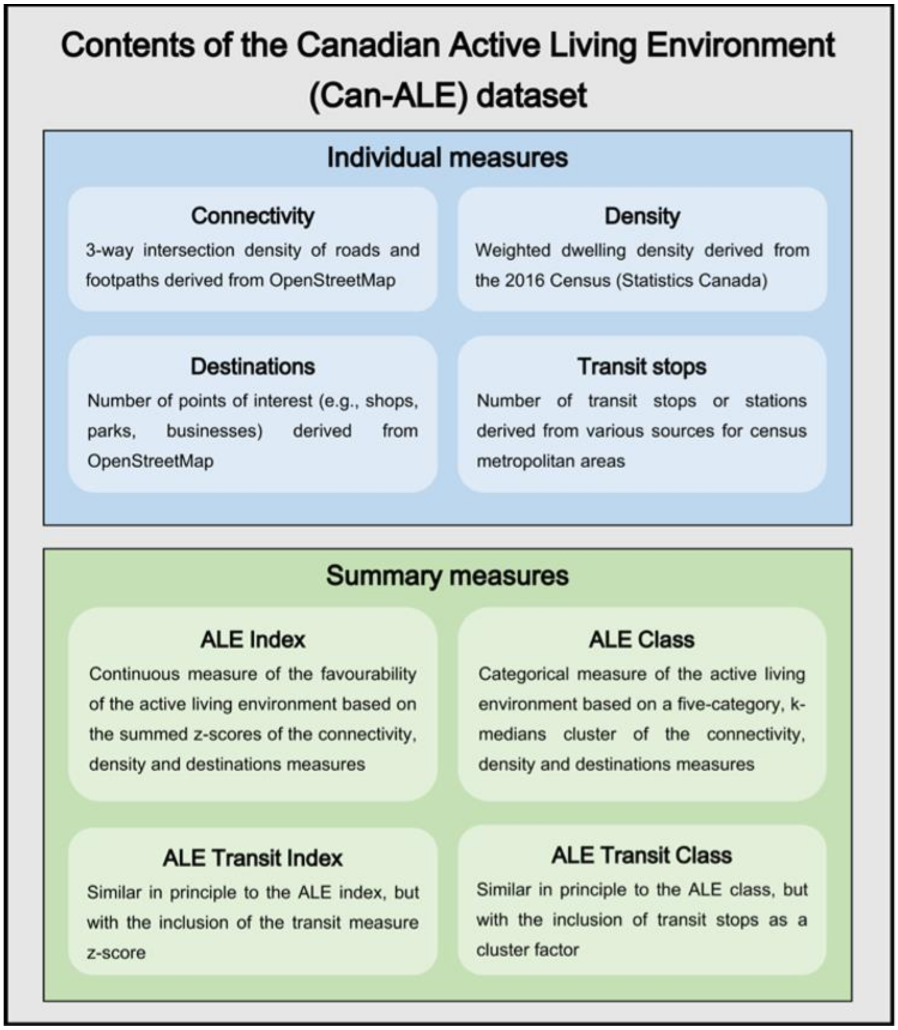

Figure 2.6 The Canadian Active Living Environments measures (Herrmann et al., 2019).
Eight built environment measures were derived as part of the Can-ALE 2016 dataset. This dissertation focuses on *ALE class*, a combined summary measure comprised of connectivity, density, and destinations.

ALEs, Physical Activity and Population Health

There are several studies that examine the relationship between objective measures for ALEs and physical activity behaviours for adults in Canada (Chiu et al., 2015; de Sa & Ardern, 2014; Farkas, Wagner, Nettel-Aguirre, Friedenreich, & McCormack, 2019; Glazier et al., 2014; Hajna, Ross, Joseph, Harper, & Dasgupta, 2015; McCormack, 2017) and elsewhere (Barnett et al., 2017; Hajna, Ross, Brazeau, et al., 2015; McCormack & Shiell, 2011; Saelens & Handy, 2008). ALEs tend to be more strongly linked with walking in adults compared with children (Colley, Christidis, Michaud, Tjepkema, & Ross, 2019a), consistent with the findings of a systematic review of life-course environmental determinants for physical activity (Carlin et al., 2017). ALEs also vary in their associations with physical activity by activity type and domain. Relationships between environmental characteristics and specific physical activity domains are often stronger than associations with total physical activity (Wendel-Vos, Droomers, Kremers, Brug, & van Lenthe, 2007), particularly with respect to leisure-time versus utilitarian or transport activities. Canadian evidence has shown greater utilitarian walking for those living in more walkable neighbourhoods (Hajna, Ross, Joseph, et al., 2015), while longitudinal evidence demonstrates increases in utilitarian walking for men who move to more walkable neighbourhoods (Wasfi, Dasgupta, Eluru, & Ross, 2016). Active transport is particularly influenced by ALEs (Grasser, Van Dyck, Titze, & Stronegger, 2013) and tends to be more strongly related to ALEs than leisure-time activity (Chiu et al., 2015; Creatore et al., 2016; Farkas et al., 2019; McCormack & Shiell, 2011; Saelens & Handy, 2008; Thielman, Rosella, Copes, Lebenbaum, & Manson, 2015). This difference is widely understood to reflect the utility of more highly connected streets with a greater density and diversity of destinations for utilitarian purposes, relative to recreational purposes (Saelens & Handy, 2008; Sugiyama et al., 2013). 8.1 Preamble describes this literature in more detail. Although it is tempting to dismiss leisure-time physical activity altogether as being sensitive to ALEs, a recent review of 72 studies found consistently positive associations between walkability and leisure-time walking, but not overall leisure-time physical activity (Van Cauwenberg et al., 2018). While it is true that ALEs are not likely to be as highly relevant to leisure-time walking as they are to transport walking, their role for promoting leisure-time walking is likely still important.

Much of the research that points to a protective association between ALEs and chronic disease risk factors has been conducted in Canada. This work has demonstrated associations with physical inactivity (McCormack et al., 2019), reduced overweight and obesity (Chiu et al., 2015; Colley, Christidis, Michaud, Tjepkema, & Ross, 2019b; Creatore et al., 2016; Glazier et al., 2014; Pouliou & Elliott, 2010; Ross et al., 2007; Wasfi, Dasgupta, Orpana, & Ross, 2016), diabetes (Booth et al., 2019; Booth et al., 2013; Creatore et al., 2016; Glazier et al., 2014), and hypertension (Chiu et al., 2016). Improving upon less direct measures of health outcomes, recent studies have shown associations between ALEs and objectively assessed biomarkers for cardiometabolic disease risk (Howell, Tu, Moineddin, Chu, & Booth, 2019; Loo, Greiver, Aliarzadeh, & Lewis, 2017). One study used both objectively assessed physical activity and directly measured cardiometabolic markers to show that favourable ALEs were associated with lower BMI, systolic blood pressure, and higher moderate-to-vigorous physical activity (Hajna, Dasgupta, & Ross, 2018). These findings reinforce those of wider systematic reviews and meta-analyses that find consistent relationships between built environments, physical activity (Barnett et al., 2017; Karmeniemi, Lankila, Ikaheimo, Koivumaa-Honkanen, & Korpelainen, 2018; Van Cauwenberg et al., 2018) and cardiometabolic risk (Chandrabose, Rachele, et al., 2019; den Braver et al., 2018; Dendup, Feng, Clingan, & Astell-Burt, 2018).

Whether neighbourhood environments are powerful enough to seed the prevention of downstream adverse health outcomes, such as premature chronic disease mortality and hospitalization, is unclear. With regard to mortality, a handful of ecological studies (Fecht, Fortunato, Morley, Hansell, & Gulliver, 2016; Gaglioti et al., 2018; Hamidi, Ewing, Tatalovich, Grace, & Berrigan, 2018) provide inconsistent evidence for an association with ALEs. Two individual-level studies of urban sprawl and land use mix suggest ALEs may indeed be protective for risk of mortality (Griffin et al., 2013; Hankey, Marshall, & Brauer, 2012; Wu, Prina, et al., 2016). In terms of hospitalization, there have been two ecological studies in Australia. One showed that living in neighbourhoods with a higher Walk Score® was associated with a modest reduction in the risk and frequency of hospitalization for AMI (Mazumdar et al., 2016), while the other demonstrated these neighbourhoods were linked with both lower hospitalization frequency and calculated costs of hospitalization (Yu et al., 2017). No previous studies have examined individual-level relationships between living in more favourable ALEs, physical activity, and subsequent hospital use. In addition, no studies have accounted for the fact that hospitals within destination-rich neighbourhoods of active living-friendly places may confound associations between ALEs and hospitalization.

International Studies of ALEs

The rise in physical inactivity and chronic diseases such as T2D is taking place globally. Rapid urbanization with ecological links to physical inactivity, obesity, and diabetes prevalence (Gassasse, Smith, Finer, & Gallo, 2017) motivates an international approach to built environments and health. The role of walkable environments for physical activity is likely to vary between different countries, but most studies are limited to samples from single regions and are therefore unable to interrogate these differences. However, international systematic reviews as well as two international studies may provide clues as to how universal these associations between ALEs and health may be. To date, there is a single international cohort of roughly 14,000 participants from 12 countries which has driven the International Physical Activity and Environment Network studies (Sallis et al., 2020). These studies have found consistent associations between built environments, higher accelerometer-assessed total physical activity, higher self-reported walking for transport and leisure, as well as lower overweight and obesity. One other ecological study used large-scale step count data collected from cellular phones of individuals from 111 countries to show that physical activity *inequality* was a predictor of increased country-level obesity prevalence, particularly for women (Althoff et al., 2017).

Past reviews of ALEs and health note the disproportionate number of publications from North America (Mackenbach et al., 2014; Van Holle et al., 2012) as well as the potential lack of generalizability of the results of these studies to other countries. A cursory scan of relevant systematic reviews and meta-analysis on the built environment, ALEs and walkability from the last five years reveals that although there are a greater number of studies coming from a wider range of countries (including low- and middle- income countries), the imbalance towards North American studies remains. Approximately half of the studies included in the most recent systematic reviews were conducted in North America (Table 2.1).

Table 2.1 Systematic reviews and meta-analysis of the built environment or ALEs and health with multiple countries from the last 5 years.

Publication	Outcome	Total studies reviewed	Number of Countries	% North America
Malambo 2016	Cardiovascular disease risk	18	6	44.4
Barnett 2017	Physical activity and walking adults	100	22	46.0
Dendup 2018	T2D risk/prevalence	60	14	50.0
Van Cauwenberg 2018	Leisure-time physical activity in older adults	72	19	40.3
den Braver 2018	T2D risk and prevalence	29	11	58.6
Karmeniemi 2018	physical activity	51	10	54.9
Chandrabose 2019	cardiometabolic risk factors	36	7	69.4
Souza Barbosa 2019	Overweight and obesity	10	3	90.0

There are two likely reasons for the focus on North America. The first is that the conceptualization of ALEs originated largely as a reaction to the suburban sprawl of North American cities that developed around automobile use (Handy et al., 2002). Other places like Europe do not share this history. A second contributing factor that could drive the imbalance of such studies towards certain regions and countries could be the widespread use of the proprietary measure Walk Score®. Walk Score has only produced data for the United States, Canada, Australia, and New Zealand (Hall & Ram, 2018). This points to a need for developing open-source methods and measures. In any case, why ALEs might operate differently in some places compared with others, for whom they work or do not work, and what role policy has in shaping urban form at the local, regional, and national levels are questions that cannot be answered without international comparative research. For example, recent evidence from five German cohorts showed little evidence for an association between ALEs and T2D risk (Kartschmit et al., 2020). This finding stands in contrast to the strong associations between favourable built environments and lower T2D risk observed for Canada, the US and Sweden (Auchincloss, Diez Roux, Brown, Erdmann, & Bertoni, 2008; Creatore et al., 2016; Sundquist, Eriksson, Mezuk, & Ohlsson, 2015). There is potential to learn from international jurisdictions by comparing how neighbourhoods operate in dissimilar political, social, and geographic contexts with distinct health care systems.

2.4 TYPE 2 DIABETES

Diabetes mellitus is a chronic metabolic condition characterized by elevated blood glucose levels (hyperglycemia) and is typically detected via routine blood testing. In less common circumstances where the disease goes undetected, symptoms include excessive urination (polyuria), excessive thirst (polydipsia), weight loss, and fatigue. Prolonged uncontrolled blood sugar results in damage to blood vessels which in turn leads to serious complications such as microvascular complications of the retina (retinopathy), kidneys (nephropathy), nerves (neuropathy), and cardiovascular system. There are two major diabetes categories: 1) that which results from autoimmunity to the islet beta-cells of the pancreas, referred to as type 1 diabetes (T1D), and 2) that which stems from the body's resistance to insulin action, often caused or exacerbated by increased weight or low physical activity (T2D). T2D accounts for the majority (90-95%) of total diabetes cases in Canada (Ng, Dasgupta, & Johnson, 2008). Annual global estimates for T2D incidence consistently surpass the worst-case scenario projections of international health organizations (Zimmet, 2017), and Canada is no exception. The country faces one of the highest diabetes prevalence rates (9.41%) among OECD countries (Canadian Institute for Health Information, 2015). Crucially, an estimated 90% of T2D incidence as well as 60% of its associated complications could be delayed or prevented with changes in health-related behaviors (Canadian Institute for Health Information, 2015).

The progression to full disease onset of T2D is generally understood to be a sequence of metabolic events. Underlying these stages are a 'triad' of metabolic defects (Ramlo-Halsted & Edelman, 1999): insulin resistance, dysfunction of the pancreatic beta-cells (responsible for insulin production), and impaired glucose production of the liver. These processes take place years leading up to diagnosis. The natural history of the disease begins with insulin resistance in the muscle, fat, and liver cells. These cells respond poorly to the insulin hormone – a hormone that allows cells to take up glucose (Figure 2.7). As a result, the pancreas produces more insulin to compensate, allowing the body to take up glucose and maintain normal glucose levels. Over time however, the beta-cell function in the pancreas begins to fail, insufficient insulin is produced, and the individual suffers chronically high blood glucose levels which in turn leads to the development of micro- and macro-vascular complications.

The development of T2D can be detected by monitoring fasting blood glucose, testing postprandial glucose levels, and/or administering random glucose tests (Canadian Diabetes Association Clinical Practice Guidelines Expert Committee, 2013). Concurrent with heightened blood glucose are often elevations in cholesterol, blood pressure, triglyceride levels, as well as the presence of abdominal obesity. Disturbances in three or more of these factors are used to satisfy criteria for diagnosis of the *metabolic syndrome* (Alberti et al., 2009), a broadly defined condition that places individuals at higher risk for diabetes and CVD. *Prediabetes* is a precursory diagnosis used to describe those with impaired fasting glucose, impaired glucose tolerance, or glycated hemoglobin levels (glycosylated hemoglobin A1C) that are not high enough to be diagnosed with diabetes (Punthakee, Goldenberg, & Katz, 2018). Although not all individuals with prediabetes will develop the disease, these individuals are at higher risk of developing T2D (Richter, Hemmingsen, Metzendorf, & Takwoingi, 2018) as well as CVD (Huang, Cai, Mai, Li, & Hu, 2016).

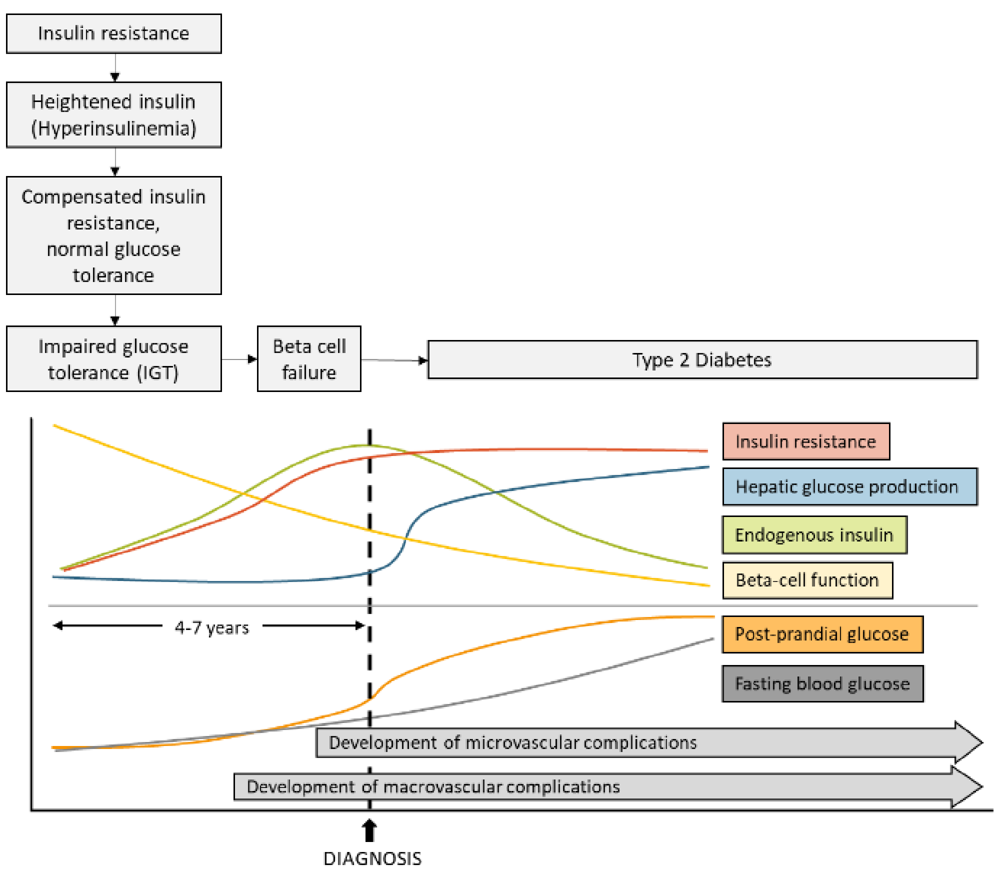

Figure 2.7 Progression and natural history of T2D.
Conceptual representation, adapted from (Ramlo-Halsted & Edelman, 1999).

Physical activity and T2D Risk

Although the etiology of T2D is believed to be complex and multi-causal; an interplay of both genetic and environmental determinants (Lynch & Smith, 2005; Nolan, Damm, & Prentki, 2011), the strongest predictors are demographic factors and behaviours in adulthood, which are further influenced by multiple environmental factors (Kolb & Martin, 2017). The salience of these predictors is underlined by the fact that population-based algorithms can predict risk for T2D based on sex, age, and other sociodemographic and behavioural variables (Chen et al., 2010; Rosella, Manuel, Burchill, Stukel, & team, 2011). Among behavioural factors, physical inactivity is a major contributor toward the development of T2D and antecedent risk factors such as obesity (Rana, Li, Manson, & Hu, 2007; Weinstein et al., 2004). In turn, systematic reviews and meta-analyses have evaluated an abundance of observational studies, prospective studies, and clinical trials. These studies have established associations between higher physical activity levels and lower risk of T2D, irrespective of physical activity intensity (i.e., low, moderate, vigorous) and domain (i.e., leisure, occupational, transport) (Aune, Norat, Leitzmann, Tonstad, & Vatten, 2015; Jeon, Lokken, Hu, & van Dam, 2007; Smith, Crippa, Woodcock, & Brage, 2016). Of these studies, some of the most compelling and influential evidence comes from the randomized controlled trials (RCTs) that demonstrated the success of lifestyle interventions in reducing T2D incidence by up to 58% – notably, the Diabetes Prevention Program, (US), the Finish Diabetes Prevention Study, the Da Qing IGT and Diabetes Study, and the Indian Diabetes Prevention Programme (Knowler et al., 2002; Pan et al., 1997; Ramachandran et al., 2006; Tuomilehto et al., 2001). These RCTs have served as models for many programs being implemented in a variety of real-world settings and populations (Aziz, Absetz, Oldroyd, Pronk, & Oldenburg, 2015).

Physical activity has also been shown to benefit those already diagnosed with T2D, including improved glycemic control, decreased insulin resistance and reductions in other cardiovascular risk factors (Sigal et al., 2018). Physical activity is considered a crucial component to both primary and secondary prevention strategies for CVD (Alves et al., 2016; Durstine et al., 2013). Moderate intensity physical activity, as well as walking, have been associated with lower risk of all-cause and CVD mortality for those with T2D (Sadarangani, Hamer, Mindell, Coombs, & Stamatakis, 2014; Sluik et al., 2012), while randomized trials have shown that simply interrupting prolonged sedentary time with light activities may lead to improvements in glucose regulation (Dempsey et al., 2016; van Dijk et al., 2013). That low-barrier activities such as walking can still impart health benefits is significant, and could be an important target for intervention - especially considering those with T2D are more averse to risk of injury (Huebschmann et al., 2011) and are more likely to develop frailty and mobility-related disabilities (Sinclair & Rodriguez-Manas, 2016).

Neighbourhoods and T2D

While built environments have increasingly been linked with risk of T2D (den Braver et al., 2018), the evidence base connecting neighbourhoods with the health outcomes of adults with T2D is relatively nascent. Both physical and social environments are likely to impact diabetes-related health via multiple pathways (Smalls, Gregory, Zoller, & Egede, 2015). One study linked favourable built environments, food environments as well as higher residential socioeconomic status with improvements in glycemic control for a large cohort of adults with diabetes (Tabaei et al., 2018). Another found that poor housing conditions were longitudinally associated with functional limitations and disability (Schootman et al., 2010). Studies have found neighbourhood associations with other health outcomes as well, including multiple measures of health status (Gary-Webb et al., 2011) and depression (Gariepy, Kaufman, Blair, Kestens, & Schmitz, 2015). While some built environment aspects such as greenspace have shown little association with physical activity in those with T2D (Chong et al., 2019), a handful of studies have demonstrated associations between ALEs and physical activity. Those with T2D who perceive their neighbourhoods as having favourable characteristics for walking are more likely to report regular physical activity (Deshpande, Baker, Lovegreen, & Brownson, 2005), walk more (Taylor, Leslie, Plotnikoff, Owen, & Spence, 2008), and accumulate greater step counts (Hajna, Ross, Joseph, Harper, & Dasgupta, 2016). Another study showed positive associations between perceived active-living friendliness and both self-reported and objectively assessed physical activity (De Greef, Van Dyck, Deforche, & De Bourdeaudhuij, 2011). Using objective neighbourhood measures, Hosler and colleagues (2014) showed that those living in favourable ALEs were more likely to walk for more than 150 minutes per week (Hosler, Gallant, Riley-Jacome, & Rajulu, 2014). Hajna and colleagues (2016) later showed that for T2D patients, living in favourable ALEs was associated with higher physical activity near the home, but not overall physical activity (Hajna, Kestens, et al., 2016). To-date, no studies have studied associations of ALEs, physical activity, and health outcomes in those with T2D, and determined whether they differ from those observed in the general population.

2.5 THEORETICAL FRAMEWORK

Figure 2.8 is a theoretical framework that summarizes this chapter thus far and serves to unify the aims and objectives of this dissertation. The socioecological approach is used to explain how policy and built environments shape our patterns of daily living, which in turn act on our health and outcomes – as measured using hospitalization and mortality. However, the pathway from built environments to health outcomes are continually modified by other demographic factors such as sex, as well as social determinants of health such as income and education. The pathway is further modified by increasing risk and progression of chronic conditions such as T2D over the life course. This pathway is impacted by the policy conditions that are unique to regions and countries, as well as the histories and culture of the people. I conceptualize this pathway as both a continuum where the horizontal axis represents time, as well as a means of mapping interventions that are likely to address population health (left) versus individual health (right).

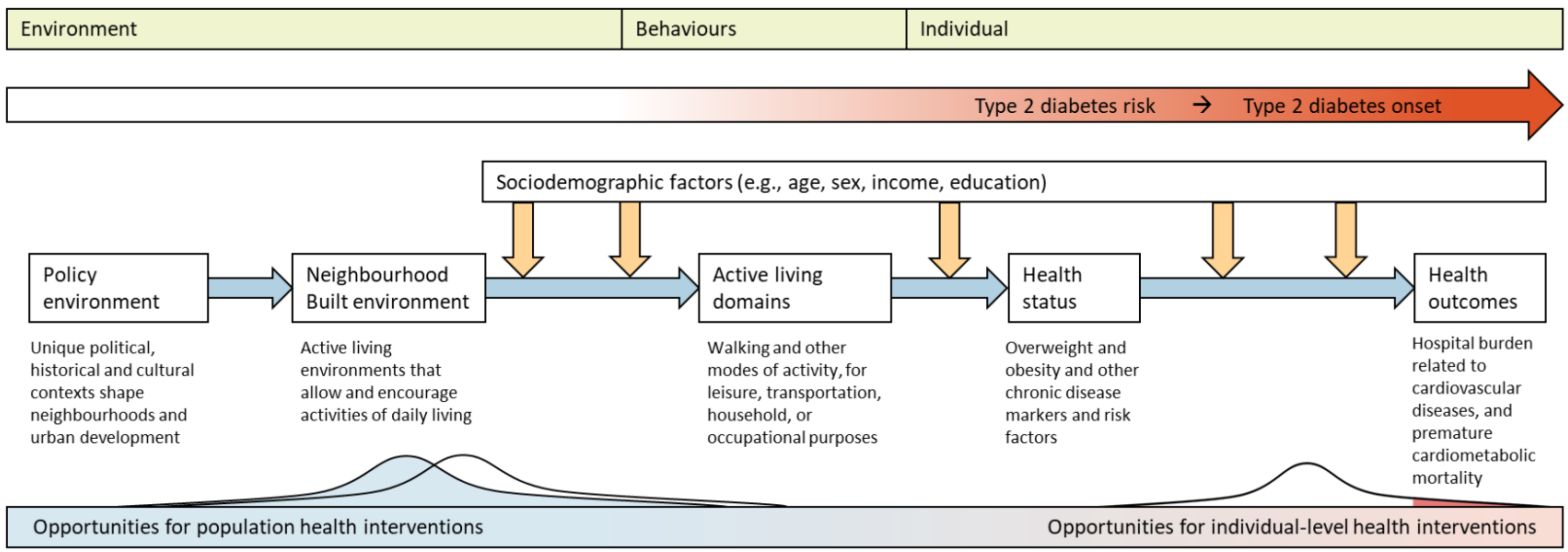

Figure 2.8 Theoretical framework for this dissertation.

The framework is based on the social ecological model and incorporates the population health approach, social and life-course epidemiology, specifically accounting for increasing risk of T2D with time. The framework is an adaptation of Swinburn and colleagues' Framework to Categorise Obesity Determinants and Solutions (Swinburn et al., 2011) and incorporates ideas from Rose's Sick Individuals and Sick Populations (Rose, 1985) as well as Sallis and colleagues' Ecological Model of Active Living (Sallis et al., 2006) - the last of which I am applying to average behaviours across populations.

2.6 LINKING NEIGHBOURHOODS, BEHAVIOURS, AND POPULATION HEALTH

Chapter 2 has thus far served as a review of the literature, positioning this dissertation within the sub-discipline of health geography and offered a theoretical framework linking built environments with behaviour and health outcomes. I now turn to the use of linked population data as an innovative approach to advancing this area of research.

Past research on built environments and population health faced two major data challenges. The first is the difficulty of obtaining detailed, high-quality information on individual-level health and behaviours for large population-based samples. This is often achieved by establishing prospective cohort studies that are both costly and time-consuming to conduct. An alternative is to conduct ecological studies using area-level built environment, behavioural, and health measures, but this approach is vulnerable to the ecological fallacy, where the characteristics assigned to the area are not necessarily that of the individuals in the area. The second issue is obtaining data that can be feasibly linked with spatial information. At present, many studies are hampered by a lack of individual-level geocoded data that, in some settings, are available but remain unlinked to other datasets. Here, I will introduce the use of secondary data and record linkage for studies of environment and health.

The use of secondary datasets and the adoption of record linkage approaches in health geography is a promising means of overcoming these two challenges. Linked survey and administrative data often includes information that equates to millions of person-years that prospective studies would never be able to accumulate (Sorensen, Sabroe, & Olsen, 1996). Administrative data is data that has been collected for administrative or billing purposes, usually related to government service provision. Some of the main advantages of using administrative data for health research include large sample sizes, wide population coverage, minimal attrition, less reliance on self-report, low cost, and flexibility in the study period chosen (Gavrielov-Yusim & Friger, 2014; Jutte, Roos, & Brownell, 2011; Mazzali & Duca, 2015; Riley, 2009). Many administrative databases are also historical censuses with near complete coverage (Calderwood & Lessof, 2009), and for this reason, can be used to define sampling frames for surveys.

Health surveys are the systematic collection of information from individuals about a variety of factors that influence, measure, or are affected by health (Aday & Cornelius, 2006). Routine national health surveys have been instrumental for providing nationally representative estimates of health status, behaviours, and health care utilization, and have allowed us to identify disparities among different subpopulations as well as detect trends over time. Their use in health research also enabled the development of new paradigms for health and health care, such as the behavioural model of health services use (Andersen, 2008). A key aspect shared by the health surveys used for this dissertation is that, among detailed information on self-reported health and behaviours, all three surveys contained variables for residential location that could be geocoded.

Record linkage is an efficient means of creating "information-rich" research environments from previously disparate data sources (Roos, Menec, & Currie, 2004), and is formally defined as "the bringing together of information from two records that are believed to relate to the same entity" (Herzog, Scheuren, & Winkler, 2007). It emerged in the 1960s as a response to the large volumes of data produced with increased social welfare programs, technological advancements in computing, and governments' need for information about the population with regard to service provision and resource use (Fellegi, 1997). The practice of "create[ing] new data from existing sources" (Jutte et al., 2011) that are able to answer population health-related questions without the resources and time necessary for large cohort studies (Black & Roos, 2005) has prompted multi-file consolidation of vital statistics, mortality, morbidity, disease registries, health surveys, clinical and non-health databases (Fair, 1995; Green et al., 2015; Jaro, 1995; Jutte et al., 2011). Linked data enables many different studies that would otherwise be difficult or not possible to conduct, such as longitudinal studies of pre-existing cohorts, clinical trial participants, transgenerational health outcomes as well as regional variations in disease incidence (Fair, 1995).

Methodological and technological advances in our ability to manage, analyse and understand large volumes of data have further stimulated the growth of secondary data repositories around the world. Yet, the strategies for record linkage developed in the late 1960s still remain central to those employed today. *Deterministic linkage* is when an exact match is made on a unique identifier (also called a *match key)* between a *master file* and a *file of interest* that has additional variables not present on the master file (Herzog et al., 2007). This approach is usually taken when unique identifiers are available for all individuals of a population, such as social security numbers. In the absence of a unique identifier, record linkage must rely on *probabilistic linkage,* which links records based on partial matches on multiple key fields common to both files, such as name, date of birth, or postal code. This approach was first recognized by Howard Newcombe as a means of extracting valuable family information from vital records (Newcombe, Kennedy, Axford, & James, 1959). The concept was later formalized into a statistical framework developed at Statistics Canada (Fellegi & Sunter, 1969) which underlies many probabilistic linkage approaches. The Fellegi-Sunter Model considers the set of all possible record pairs between the master file and file of interest that have key fields in common. Each record pair is assigned a probability that the pair is a match (i.e., comes from the same individual) based on the key linkage fields. Since a match on sex is much less meaningful than a match on date of birth, different fields are given different weights in calculating a record pair's match probability. These weights are based on two probabilities associated with each field: the *m probability* is a sensitivity measure that captures the data error rate of a given field (e.g., typographical errors in family name), and the *u probability* is a specificity measure that represents the probability that the field erroneously matches by chance (Fellegi & Sunter, 1969; Herzog et al., 2007; Jaro, 1995; Sayers, Ben-Shlomo, Blom, & Steele, 2016). Next, the weight for a given field is calculated as the logarithm to the base of two of the ratio *m/u* and can thereafter be incorporated into a composite weight for all or combinations of different fields. Last, thresholds are defined to optimally classify the record pair as being a match, a marginal match (which requires clerical review), or not a match, and there is debate as to how these thresholds should be determined (Herzog et al., 2007). Implementation of record linkage routines are often iterative, with successive re-examination of earlier results to inform subsequent linkage rounds until no further matches can be made (Black & Roos, 2005; Jaro, 1995). In practice, most record linkage algorithms use a combination of deterministic and probabilistic strategies. However, the success and quality of record linkage approaches, whether by deterministic or probabilistic methods, rely in part on the ability to identify matching records from the same individual. This is usually achieved by using unique key identifiers such as health insurance numbers, social insurance numbers, or other characteristics such as date of birth or postal codes.

Embedding geospatial measures into routine data collection practices could enable richer analyses of health outcomes that account for both socioeconomic composition and environmental context over the life-course. Although there is a wealth of insight to be gained from linked data on social, demographic and biomedical aspects of population health (Holman et al., 2008; Orr, Smith, Burchill, Katz, & Fransoo, 2016), the inclusion of geocoded information in linkage repositories is essential for our ability to study environments and health with precision and flexibility.

Each manuscript in this dissertation exemplifies the strengths of including geocoded environmental variables alongside health data. Chapters 3-7 are examples of record-linked data studies. The primary data sources for this dissertation include three population-based cohorts (two national health surveys, one longitudinal cohort study) from three different countries, two hospital administrative databases from two different countries, and three national databases containing comparably derived built environment measures (Table 2.2).

Table 2.2 Summary of all surveys, administrative databases, and derived ALE measures used in this dissertation.

	Canada	Wales	Australia
Study	Canadian Community Health Survey (CCHS)	Welsh Health Survey (WHS)	Australian Diabetes, Obesity & Lifestyle Study (AusDiab)*
Agency	Statistics Canada	SAIL Databank	Baker Institute
Type	Annual cross-sectional survey	Annual cross-sectional survey	Longitudinal cohort
Years available	2000-2011	2013-2014	(2000; 2005; 2012)
Years used	2007	2013-2014	2000
Target sample	65,000/year	10,000/year	(4,000-11,000)*
Hospitalization	Discharge Abstract Database (DAD)	Patient Episode Database for Wales (PEDW)	N/A
Years available	1999-2012	2000-2017	
Years used	2007-2011	2013-2017	
Active Living Environments	Canadian Active Living Environment Database (Can-ALE)	Wales Active Living Environment Database (Wal-ALE)	Australia Active Living Environment Database (Aus-ALE)
Geographic unit	Dissemination Area (DA) 400-700 persons	Output Areas (OA) 100-625 persons	Statistical Area Level 1 (SA1) 200-800 persons
Data sources	Canadian Census 2016 OSM street network/foot path file OSM Points of Interest	ONS Usual Residents dataset 2011 OSM street network/foot path file OSM Points of Interest	Australian Census 2016 OSM street network/foot path file OSM Points of Interest

OSM, OpenStreetMap; ONS, Office for National Statistics.
* Since AusDiab is a longitudinal study, there is no annual target sample but instead a baseline sample that had been re-contacted twice. The range represents the attrition that occurred between AusDiab and AusDiab3.

2.7 Summary

Chapter 2 situated this dissertation within the discipline of health geography as a fundamental question of how place shapes behaviours and health. Describing the strengths of population health and life-course theory, I then discussed behavioural approaches to physical activity and demonstrated the usefulness of ecological models for understanding multiple levels of influence on behaviours related to different domains of active living. Thereafter, I provided a cursory overview of our state of knowledge on the relationship between ALEs, physical activity, and health, and presented a summary of the overarching gaps in knowledge of ALEs with respect to health outcomes (morbidity and mortality); the relevance of these environments to those who already have T2D or are at high risk of developing T2D; and the international generalizability of the health benefits associated with living in favourable ALEs. I then summarized this review of the literature in a theoretical framework linking ALEs with physical activity and health outcomes. Last, I provided a brief overview of how record linkage and secondary data can be used to construct large and detailed cohorts that contain demographic, behavioural, health, and environmental information.

Chapter 3

ACTIVE LIVING ENVIRONMENTS, PHYSICAL ACTIVITY, AND PREMATURE CARDIOMETABOLIC MORTALITY: A NATION-WIDE COHORT STUDY

3.1 PREAMBLE

Previous work has tested associations of ALEs, physical activity, and markers for cardiometabolic health and disease incidence, but only a handful have assessed mortality as the outcome of interest. Those that have used ecological approaches or were limited to studying specific subgroups (Griffin et al., 2013). The overarching hypothesis of this work is that ALEs enable more active living that result in positive survival outcomes related to cardiometabolic disease later in life. This chapter is consistent with the main purpose of this dissertation of assessing whether and to what extent to which favourable ALEs are associated population-wide gains in physical activity-related health and contributes to the first objective of this thesis. In this paper, we found that there are potential gains in cardiometabolic survival for older women, but not older men or middle-aged women and men.

This chapter is published as an original research article to *BMJ Open.*

3.2 ABSTRACT

OBJECTIVE To evaluate sex- and age-specific associations of ALEs with premature cardiometabolic mortality.

DESIGN Population-based retrospective cohort study.

SETTING Residential neighbourhoods (1,000-meter circular buffers from the centroids of dissemination areas) across Canada for which the Canadian Active Living Environment Measure (Can-ALE) was derived, based on intersection density, points of interest, and dwelling density.

PARTICIPANTS 249,420 survey respondents from an individual-level record linkage between the Canadian Community Health Survey (2000-2010) and the Canadian Mortality Database until

2011, comprised of older women (65-85 years), older men (65-81 years), middle age women (45-64 years), and middle age men (45-64 years).

PRIMARY OUTCOME MEASURES Premature cardiometabolic mortality and average daily energy expenditure attributable to walking. Multivariable proportional hazards regression models were adjusted for age, educational attainment, dissemination-area level median income, smoking status, obesity, the presence of chronic conditions, season of survey response, and survey cycle.

RESULTS Survey respondents contributed a grand total of 1,451,913 person-years. Greater walking was observed in more favourable ALEs. Walking was associated with lower cardiometabolic death in all groups except for middle age men. Favourable ALEs conferred a 22% reduction in death from cardiometabolic causes (HR 0.78, 95% CI 0.63 to 0.97) for older women.

CONCLUSIONS On average, people walk more in favourable ALEs, regardless of sex and age. With the exception of middle age men, walking is associated with lower premature cardiometabolic death. Older women living in neighbourhoods that favour active living live longer.

3.3 INTRODUCTION

There is growing interest in the role that environments might play in supporting active living and reducing the health burden associated with sedentary lifestyles. Physical inactivity contributes to an estimated one quarter of premature deaths in Canada (Manuel et al., 2016). Even higher proportions of cardiometabolic deaths could be avoided if those who were physically inactive became physically active (Katzmarzyk, Gledhill, & Shephard, 2000). Neighbourhoods that support active living could play a part in reducing sedentary lifestyles, but have not been conclusively linked to reductions in cardiometabolic mortality.

Active living environments (ALEs), also widely known as ‘walkable environments’, are places that are easily navigable with well-connected walking paths, have a number and variety of destinations, and are more densely populated (Cervero & Kockelman, 1997). These neighbourhoods are understood to encourage active living – the kind of neighbourhood-based activity that tends to be ‘built-in’ to one’s daily life. Studies have established links between ALEs and obesity (Mackenbach et al., 2014) as well as cardiometabolic risk factors such as hypertension (Chiu et al., 2016) and T2D (Creatore et al., 2016; Sundquist et al., 2015). Higher walking levels are associated with lower mortality in older adults(Patel et al., 2018), and these benefits are likely driven by reductions in cardiometabolic mortality.

The active living environment's impact on cardiometabolic disease is likely subject to life-course changes in physical activity and cardiometabolic risk from mid-life to old age (Hardy, Lawlor, & Kuh, 2015). The mechanism and extent to which these environments encourage active living and reduce premature cardiometabolic mortality might also differ between the sexes due to biological variations in cardiometabolic risk (Barrett-Connor, 2013), differences in premature mortality - given overall life expectancy for women is higher than for men, as well as gendered social factors that influence health behaviours.

Few studies have assessed relationships between neighbourhood characteristics and cardiometabolic mortality (Griffin et al., 2013; Hankey et al., 2012; Wu, Prina, et al., 2016). Those that have tend to be ecological studies, and have reported inconclusive or conflicting associations between the built environment and mortality (Fecht et al., 2016; Gaglioti et al., 2018; Hamidi et al., 2018). In this study, we determined whether favourable ALEs are associated with lower risk of premature cardiometabolic mortality through the physical activity pathway in groups that are stratified by sex and age.

3.4 METHODS

STUDY POPULATION

We used an individual-level record linkage between the Canadian Community Health Survey (CCHS) cycles 2000 to 2011 and the Canadian Mortality Database (CMDB) years 2000 to 2011. The linked dataset contains 614 755 respondents with follow-up time of up to 11.32 years from survey response to December 31, 2011 or death. The CCHS is an annual, national cross-sectional survey of approximately 65 000 people aged 12 and older sampled from the community-dwelling Canadian population. Response rates for the CCHS exceeded 70% for these cycles (Statistics Canada, 2017b). The CCHS is linked to CMDB (Sanmartin et al., 2016), the registry for all deaths recorded in Canada which contains date of death and primary cause of death, coded by the International Classification of Disease, ICD (Canadian Institute for Health Information, 2012a).

Analyses were stratified by sex and age (at baseline) into older women age 65-85 years (85 years being the average life expectancy for Canadian women (World Health Organization, 2018)), older men age 65-81 years (81 years being the average life expectancy for Canadian men (World Health Organization, 2018)), middle age women 45-64, and middle age men 45-64 years. Low cardiometabolic death rates were seen for younger adults and were not examined. In order to set a minimum period of exposure to neighbourhoods in Canada, we excluded recent immigrants (in the past five years), as well as those with a follow-up time of less than one year between survey response and censoring or death.

Active Living Environments

The Canadian Active Living Environments Database (Herrmann et al., 2019) (Can-ALE) is comprised of geographical measures for Canadian neighbourhoods derived from open data. Briefly, the measures are constructed using 1,000-meter circular (Euclidean) buffers from the centroids of dissemination areas (DAs), the smallest geographic area for which complete census data are released. DAs correspond to roughly 400 to 700 persons. Three components are included in the measure: intersection density, points of interest, and dwelling density. Intersection density (the number ≥3-way intersections) was derived using OpenStreetMap 2016 road and footpath features. The number of points of interest were also retrieved from OpenStreetMap 2016. Dwelling density was obtained from the 2016 Canadian census. Raw scores for the three components were then clustered using k-medians and grouped into five categories representing environments that are very active living-unfriendly (class 1) to those that are very active living-friendly (class 5). We also derived a two-component 2006 score (which lacks points of interest from 2006) that was closer to baseline survey response and confirmed that little change occurred between 2006 and 2016 scores for the active living environment. We interpolated residential locations based on reported postal code in the CCHS. Statistics Canada's Postal Code Conversion File Plus (PCCF+) is a program that assigns spatial coordinates based on population-weighted random allocation. We overlaid these coordinates with 2016 DAs in a Geographic Information System (GIS, ArcGIS v.10, ESRI 2010), and assigned areas their corresponding Can-ALE classification.

Walking Measures

We approximated average daily energy expenditure related to leisure-time walking and to leisure-time physical activity for each respondent, which we refer to as "walking" and "physical activity," respectively. Daily energy expenditure for leisure time physical activity is available as a derived variable in the CCHS and has been described previously (Statistics Canada, 2011a). Average daily energy expenditure for walking was derived using the same method. Briefly, the calculation is based on respondents' self-reported activities in the last three months from baseline survey response. Frequency and time spent walking were multiplied by an assigned metabolic equivalents (MET) value of three for walking. We then divided this number by 365 days to yield daily energy expenditure in kcal/kg/day. We hypothesized that favourable ALEs specifically enable walking as a neighbourhood-based physical activity (Turcotte, 2012).

Outcomes

The cause of interest was death due to metabolic diseases (ICD 10 codes E11-E14, E65-68, E78) or cardiovascular conditions (I10-15, I21-25, I50, I61-69, I70-74) which we term cardiometabolic mortality. Premature death has been defined as death before reaching 75 years (Buajitti et al., 2018), and since the maximum age in the middle age groups at baseline was 64 years, the maximum age reached for middle age men and women was 72 years at censoring. To assess deaths that were premature in nature for older age groups, we analyzed deaths that occurred before average life expectancy for women and for men in Canada by censoring at 85 years and 81 years, respectively (World Health Organization, 2018). We modeled these four groups separately to allow us to observe differences in physical activity levels, cardiometabolic risk trajectories, and potential response to the built environment.

Covariates

Covariates with known associations with mortality were selected *a priori*. These included age, educational attainment, DA-level median income, smoking status, obesity, and the presence of two or more chronic conditions. We also adjusted for survey cycle and season of survey response for models that included average daily energy expenditure related to walking or physical activity. Body mass index (BMI) was adjusted for systematically overestimated height and underestimated weight using previously established correction factors (Connor Gorber, Shields, Tremblay, & McDowell, 2008), which we then used to classify "obesity" as 30 kg/m^2 and above. The presence of two or more chronic conditions was ascertained based on CCHS responses to items in the chronic diseases module that were consistent across survey cycles.

STATISTICAL ANALYSIS

First, we examined whether respondents who lived in ALEs reported higher walking or overall physical activity levels using descriptive statistics (Supplementary Figure A.1). Trends across the five ALE classes were evaluated by entering the categorical ALE variable as an ordinal variable in a generalized linear model with a log link, adjusted for individual-level factors. Second, we assessed whether walking is associated with premature cardiometabolic death for women and men stratified across middle and older age groups using Cox proportional hazards models. Due to the skewed non-negative nature of energy expenditure, we entered daily energy expenditure for walking into the model as a three-level factor variable, consisting of: no walking (reference), less than 1.44 kcal/kg/day and more than or equal to 1.44 kcal/kg/day. This cut-off is equivalent to the recommended 150 minutes or more per week of moderate to vigorous exercise (World Health Organization, 2010), which we applied to walking alone, and to overall physical activity (Supplementary Figure A.2 for sample calculations). Finally, we assessed whether associations between favourable ALEs and lower premature cardiometabolic mortality could be detected using cox proportional hazard models.

All models were adjusted for age, education, area-level income, survey cycle, smoking status, obesity, and the presence of two or more chronic conditions. Cox models assessing associations between walking and premature cardiometabolic mortality were also adjusted for season of survey response. Due to low sample sizes and events in ALE class 5, active living environment classes 1 through 3 were aggregated as less favourable, while classes 4 and 5 were aggregated as more favourable for survival analyses. The proportional hazards assumption was assessed for ALEs using visual inspection of Schoenfeld residuals as well as assessing for similarity between Cox predicted curves and observed Kaplan-Meier curves. Age was entered as a continuous linear variable after testing quadratic and cubic terms, evaluating Martingale residuals, as well as examining interactions with time for potential time-varying behaviour - none of which impacted the final estimates for the active living environment in any group. Competing risks models were also used to assess the impact of non-cardiometabolic premature death on estimates for favourable ALEs. Note that in accordance with confidentiality protocols, counts are reported using a rounding base of five, and therefore may not be additive to rounded totals.

PATIENT AND PUBLIC INVOLVEMENT

Participants and members of the public were not involved in the design, analysis or interpretation of this study. However, the research question is of broad policy relevance and public health interest. The results will be disseminated to the general public, policymakers, and stakeholders through websites, seminars, and conferences.

3.5 RESULTS

Of the 614,755 linked CCHS respondents (Figure 3.1), 311,090 who were under 45 years old or recently immigrated to Canada were removed from the analysis. Of the 303,685 remaining, 268 210 respondents (87.9%) had at least one year of follow-up and were considered eligible for inclusion in the study. Of those eligible, 249,420 respondents (93.0%) had complete information (Supplementary Table A.1).

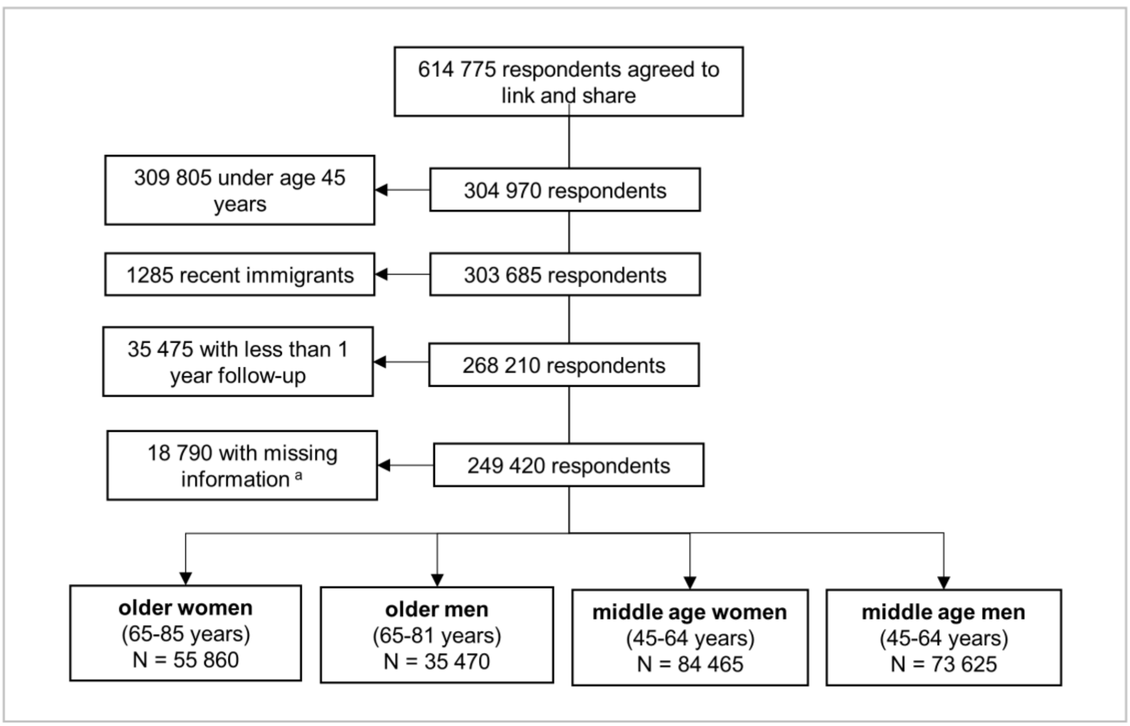

Figure 3.1 Flowchart of participant inclusion for Chapter 3.

[a] Missing data is summarized in the appendix.

Gradation of Walking with ALEs

Mean daily energy expenditure for walking was highly graded by the active living environment in all groups (P for trend <0.01 for all groups, Figure 3.2, panel A), driven in part by the high proportions of inactive respondents (i.e., those who report never walking) living in the least favourable Can-ALE classes. In contrast, overall physical activity was not graded by the favourability of the ALE (Supplementary Figure A.3), except for an inverse graded pattern in middle-aged women (P<0.001). Older women and older men exhibited the largest gains in average daily energy expenditure for walking between the least favourable and most favourable neighbourhoods at 56% (0.63 to 0.98 kcal/kg/day) for older women and 64% (0.72 to 1.18 kcal/kg/day) for older men. The proportion of overall physical activity attributable to walking was high for older women in particular (Figure 3.2, panel B).

Association of walking with premature cardiometabolic mortality

Higher and lower levels of walking compared with no walking were associated with lower risk of premature cardiometabolic death for all groups except middle age men (comparing the highest level of walking to no walking - older women: HR 0.68, 95% CI 0.57 to 0.80; older men: HR 0.65, 95% CI 0.55 to 0.77; middle age women: HR 0.57, 95% CI 0.42 to 0.78; middle age men: HR 1.02, 95% CI 0.83 to 1.24), and was most apparent in middle age women (Figure 3.3). Associations between overall physical activity and premature cardiometabolic mortality were found for all groups (Supplementary Figure A.4).

Association of ALEs with premature cardiometabolic mortality

We identified an inverse association between more favourable environments and premature cardiometabolic mortality for older women, after adjusting for individual-level factors (HR 0.78, 95% CI 0.63 to 0.97, Figure 3.3). No conclusive associations were observed for older men (HR 1.13, 95% CI 0.90 to 1.41), middle age women (HR 1.02, 95% CI 0.68 to 1.54) or middle age men (HR 0.97, 95% CI 0.73 to 1.30). The proportional hazards assumption held, based on visual inspection of Schoenfeld residuals and similarities between Cox predicted curves and Kaplan-Meier curves. Competing risks models yielded similar estimates to cox proportional hazards models (Supplementary Table A.3)

Table 3.1 Characteristics of study population for Chapter 3 (N = 249,420).

Characteristic	Older		Middle age	
	Women	Men	Women	Men
N	55,860	35,470	84,465	73,625
Age (years)	73.21 (5.64)	71.32 (4.40)	54.52 (5.60)	54.35 (5.64)
ALE				
1 (least favourable)	26,170 (46.8)	18,805 (53.0)	43,625 (51.6)	39,455 (53.6)
2	15,285 (27.4)	9,015 (25.4)	22,230 (26.3)	18,630 (25.3)
3	10,475 (18.8)	5,505 (15.5)	13,415 (15.9)	10,925 (14.8)
4	2,800 (5.0)	1,520 (4.3)	3,570 (4.2)	2,995 (4.1)
5 (most favourable)	1,130 (2.0)	625 (1.8)	1,625 (1.9)	1,620 (2.2)
Total follow-up time (person-years)	299,061.96	177,480.84	522,885.69	452,484.72
Median follow-up time (years)	4.81	4.47	6.39	6.35
smoking status				
Never	23,970 (42.9)	5,965 (16.8)	25,065 (29.7)	13,480 (18.3)
former	25,120 (45.0)	24,490 (69.0)	38,515 (45.6)	39,355 (53.5)
Current	6,770 (12.1)	5,020 (14.2)	20,885 (24.7)	20,790 (28.2)
Obese	14,890 (26.7)	9,115 (25.7)	25,340 (30.0)	22,535 (30.6)
2+ chronic conditions	33,915 (60.7)	18,500 (52.2)	33,595 (39.8)	22,990 (31.2)
Average median household income (DA-level)	$62,848	$66,816	$68,437	$69,504
>1 SD below median	9,810 (17.6)	4,635 (13.1)	10,220 (12.1)	8,420 (11.4)
Within 1 SD from median	41,755 (74.8)	27,350 (77.1)	63,980 (75.8)	55,700 (75.7)
<1 SD above median	4,295 (7.7)	3,485 (9.8)	10,260 (12.2)	9,505 (12.9)
Educational attainment				
Less than secondary	25,180 (45.1)	14,530 (41.0)	16,655 (19.7)	15,725 (21.4)
Secondary school	11,725 (21.0)	5,930 (16.7)	22,135 (26.2)	16,460 (22.4)
Degree/diploma	18,955 (33.9)	15,010 (42.3)	45,675 (54.1)	41,440 (56.3)
Premature deaths [a]				
Total (%)	5,250 (9.4)	4,050 (11.4)	2,395 (2.8)	3,040 (4.1)
Cardiometabolic (%)	1,465 (2.6)	1,265 (3.6)	385 (0.5)	830 (1.1)

Data are n, n (%), mean (SD). All covariates are from survey response (baseline).
[a] Premature death was defined as death before the age of 85 years in older women, before 81 years in older men, and before 72 in middle age women and men.

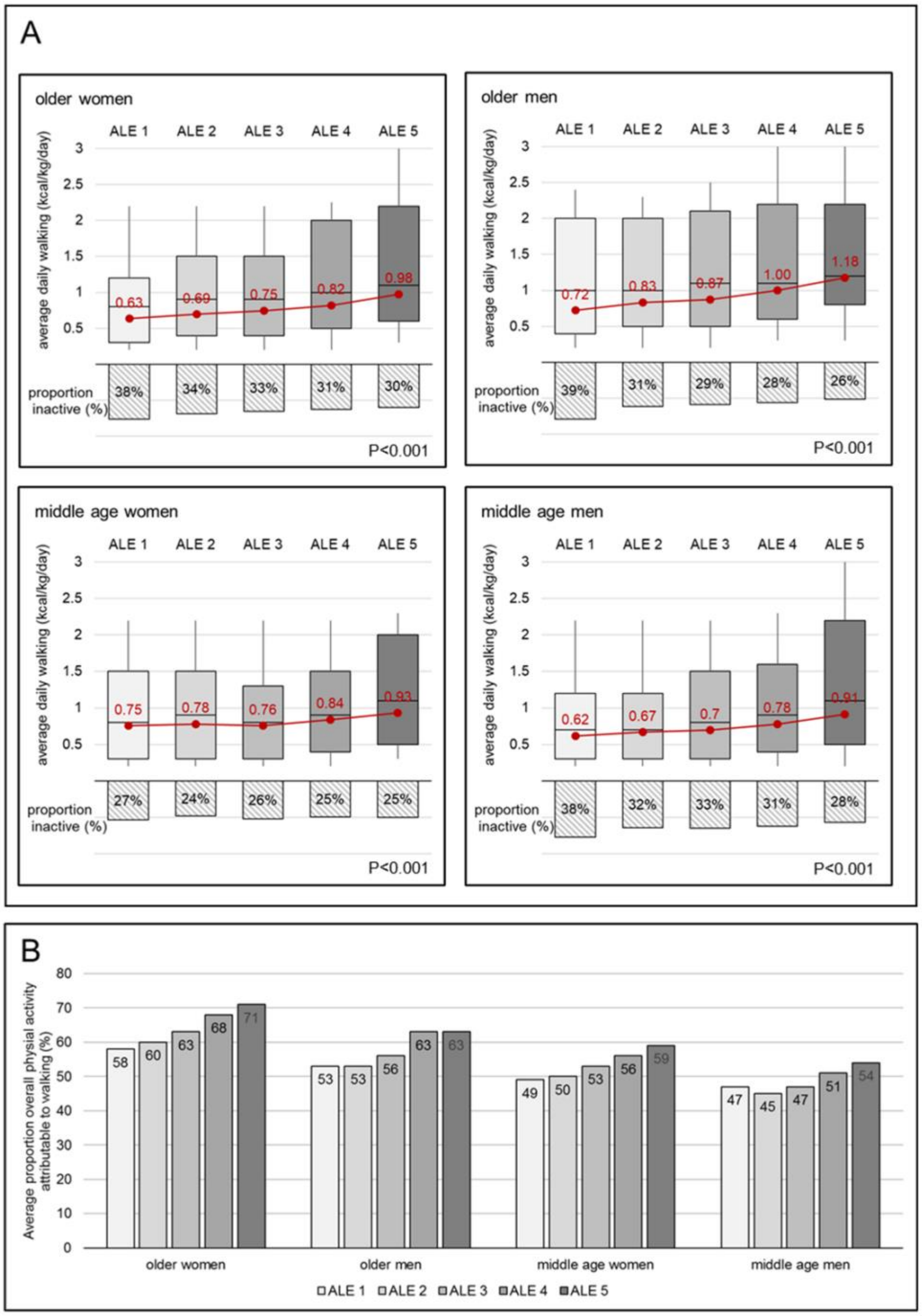

Figure 3.2 Walking levels across ALE class, stratified by sex and age.

Data are mean or (%). Active living environment (ALE) 1 represents the least favourable environment, while ALE 5 represents the most favourable environment. Panel (A) contains box plots, mean energy expenditure related to walking, and proportion that report no walking. Boxes represent the interquartile range (25th to 75th percentile) and the horizontal line represents the median. Note that upper and lower limits of the boxplots have been adjusted to represent the 90th and 10th percentile, respectively, for confidentiality purposes. Red markers and trend line represent means in each ALE class with test for trend (P<0.05). Panel (B) shows the proportion of all physical activity that walking accounts for, by active living environment favourability.

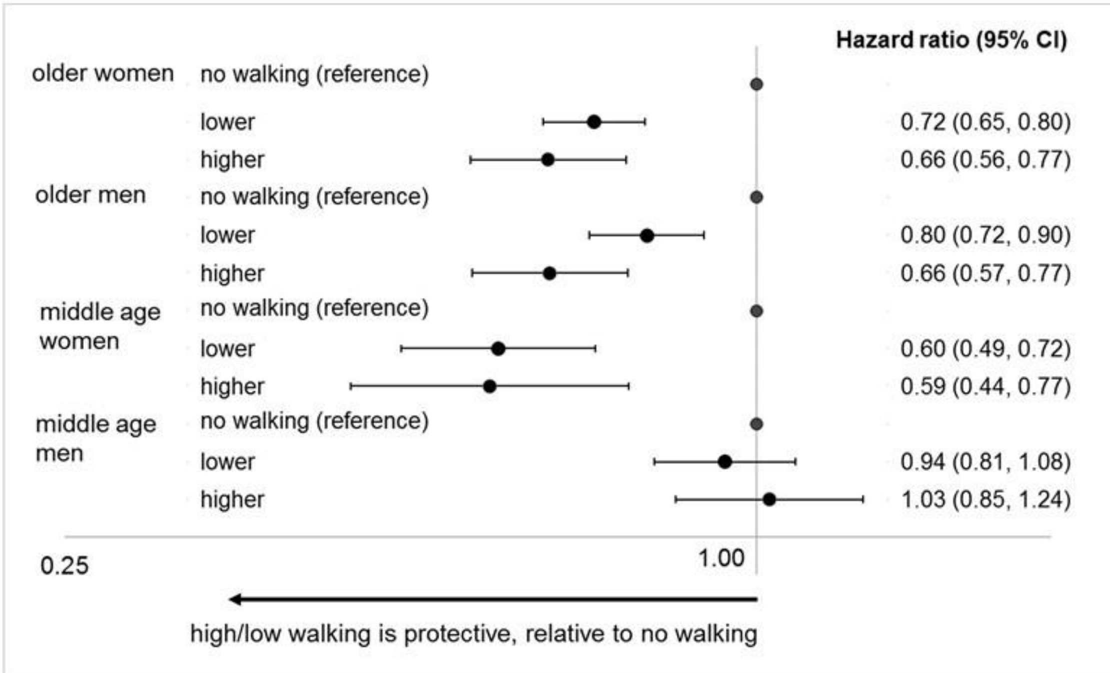

Figure 3.3 Associations between walking and premature cardiometabolic mortality.

Data are hazard ratios (95% CI). Models are adjusted for baseline age, education, income, the presence of two or more chronic conditions, obesity, season of survey response and survey cycle.

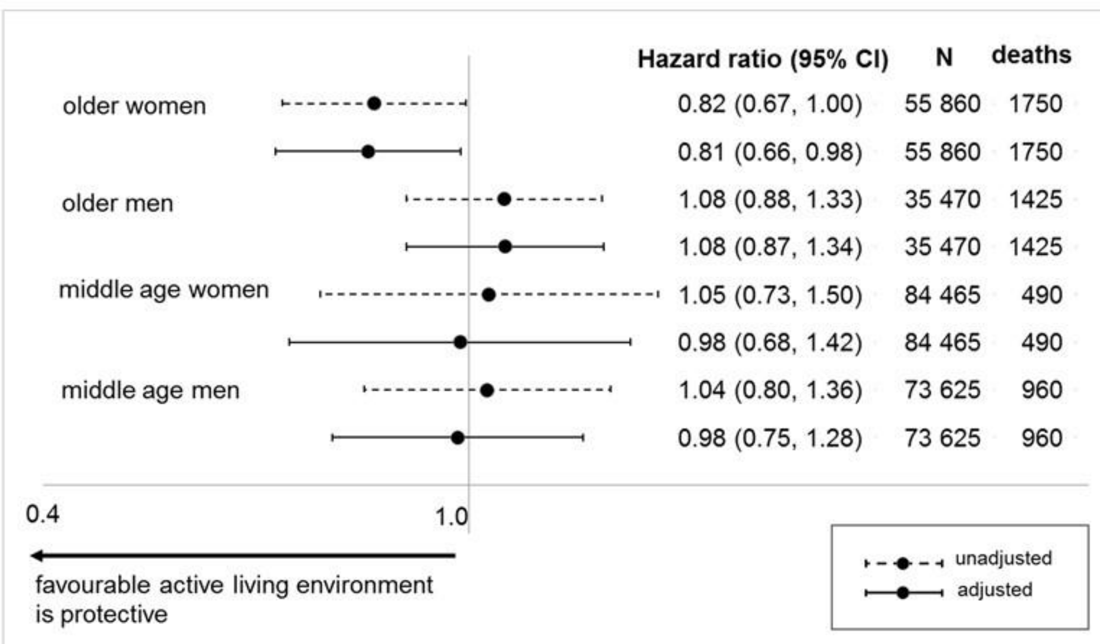

Figure 3.4 Associations between ALE and premature cardiometabolic mortality.

Data are hazard ratios (95% CI). Models are adjusted for baseline age, education, income, the presence of two or more chronic conditions, obesity, season of survey response and survey cycle.

3.6 DISCUSSION

To our knowledge, this is the first individual-level study to examine associations between ALEs and premature cardiometabolic death. We demonstrated that older women living in favourable ALEs were 22% less likely to die prematurely from cardiometabolic diseases than those living in less favourable environments. Older women living in these neighbourhoods walked more, and their walking-related energy expenditure was inversely associated with premature cardiometabolic mortality. The fact that these associations were robust to adjustment for social class (which, for measures such as income, were inversely related to ALE favourability, Supplementary Table A.2) speaks to the importance of neighbourhoods in shaping behaviours and health, over and above the sociodemographic composition of the people living in the neighbourhood. In other groups, the association between the ALE and premature cardiometabolic mortality did not hold. There were, however, positive associations between the ALE and walking, regardless of sex and age. We also observed inverse associations between walking and premature cardiometabolic mortality in all groups except for middle age men (Supplementary Figure A.5).

Consistent with previous studies in Canada (Hajna, Ross, Joseph, et al., 2015; Wasfi, Dasgupta, Eluru, et al., 2016), we found incrementally higher walking levels in more favourable ALEs. The larger increases in walking for older adults living in favourable neighbourhoods relative to middle age adults might point to the growing importance of walking with age(Morris & Hardman, 1997). Older adults often have a smaller, more restricted activity space than younger and middle age adults, and may spend more time where they live(Hirsch, Winters, Clarke, & McKay, 2014). There is also consistent evidence that more women walk for leisure than men, and might also walk more for the purpose of running errands(Pollard & Wagnild, 2017). Although older men report higher daily energy expenditures for walking, older women report the highest and most environmentally graded proportions of physical activity attributable to walking. Some women of previous generations never drove, and while the gap between men and women holding a driver's license has since narrowed, older men are still more likely to drive as a main mode of transportation(Turcotte, 2012). This could explain some of the discrepancies we see between women and men. Nevertheless, the strong relationship between walkable environments and walking for women has been shown using large-scale data (Althoff et al., 2017), and signals the important role that the ALE could play for older women to achieve adequate levels of physical activity.

The associations between leisure walking and survival benefit that we observed in this cohort complement previous work demonstrating the importance of overall leisure-time physical activity to mortality (Moore et al., 2012). The notable absence of association between walking and favourable cardiometabolic outcomes in middle age men could be a result of greater participation in sports and other activities (Pollard & Wagnild, 2017), given the protective association between overall physical activity and premature cardiometabolic mortality we observed for this group. Walking had the highest inverse association (43% risk reduction of premature cardiometabolic death) in middle age women. A recent systematic review of 36 studies found that more women walk for leisure than do men – particularly in younger age groups (Belanger, Townsend, & Foster, 2011). It is possible that the exercise achieved through activities built into daily living endures over the life-course and could place women on an advantageous trajectory when it comes to long-term cardiometabolic outcomes.

Our findings point to a potential avenue for preventing premature cardiometabolic mortality in older women – the importance of which is underlined by the stalls in improving cardiovascular outcomes and mortality for women compared with the improvements observed for men (Pilote et al., 2007). These neighbourhoods might support activities of daily living that will later translate into survival benefits for older women (Chipperfield, 2008).The inverse association between the ALE and premature cardiometabolic death corroborates findings of a previous study which demonstrated a similar relationship between urban compactness and coronary heart disease death in a biomedical cohort of postmenopausal women (Griffin et al., 2013). Our study is also consistent with previous research that links favourable environments to modest reductions in area-level rates of premature cardiovascular disease mortality (Gaglioti et al., 2018), ischemic heart disease (Hankey et al., 2012), and overall mortality (Hamidi et al., 2018; Wu, Prina, et al., 2016). Past research has been limited to ecological studies, area-level socioeconomic variables, and small sample sizes. Our national sample, paired with GIS-derived measures for ALEs, offers the advantage of comprehensive individual-level information to assess the built environment's potential for influencing downstream health outcomes. We were also able to specifically interrogate the pathway between the built environment, behaviour (walking), and subsequent mortality outcomes.

Our study bears several limitations. The CCHS is a repeated cross-sectional survey and we were unable to track residential moves over the study period. To partially mitigate this limitation, we excluded recent immigrants and imposed a one-year exposure lag time before ascertaining premature cardiometabolic death. Our measure of ALEs was assessed at one time point. Built environments, especially street networks in North America, are enduring features over the timeframe of decades (Barrington-Leigh & Millard-Ball, 2015) and so we believe our reliance on a single exposure measurement time point is justified. While we were also unable to adjust for residential self-selection (Boone-Heinonen, Gordon-Larsen, Guilkey, Jacobs, & Popkin, 2011), such adjustment has only resulted in minor impacts in some studies examining the associations between the built environment with walking (Handy, Cao, & Mokhtarian, 2006) and obesity (Sallis et al., 2009). Our study was limited to self-reported physical activity, which is less precise than objective measures (Prince et al., 2008) and is vulnerable to recall bias, especially over longer time frames (Haskell, 2012a). However, such bias is likely to be non-differential with respect to the ALE – an assignment unknown to study participants at survey response. Moreover, the large sample size afforded by multiple waves of a national survey allowed us to overcome the limitations of self-report measures that would likely have generated estimates biased towards the null, and helped uncover nation-wide physical activity variations that could otherwise be overlooked. Linked environmental, survey and administrative data do not allow us to discern whether reported walking and physical activity takes place in one's neighbourhood or not. Previous work using Global Positioning System (GPS) devices has confirmed that higher levels of physical activity of adults living in more walkable environments is indeed, performed near the home (Hajna, Kestens, et al., 2016). As a last point, the reasons why we observe associations in older women and not in other groups could not be easily addressed in our study. We were unable to determine, for instance, whether car use might explain cardiometabolic mortality differences between older women and men. Our large study with linked individual data does however serve as a benchmark point for future work to contextualize the association (or lack of association) between the ALE and premature cardiometabolic mortality.

There is growing recognition that the built environment (Tam, 2017) and urban planning policy (Giles-Corti et al., 2016) are inherently related to health policy. The ALE is, presumably, a population-level exposure, and this study suggests that these environments are likely to encourage population-wide increases in walking, and reductions in premature cardiometabolic death. The question as to how we curtail cardiometabolic disease in middle age people still stands. Like many places around the world, the Canadian population is aging, and many are considering aging in place. Our findings suggest that at present, neighbourhood interventions to support active living are likely to have the greatest gains for older women and can be a viable part of any jurisdiction's approach to preventing premature cardiometabolic death.

3.7 REFERENCES

Althoff, T., Sosic, R., Hicks, J. L., King, A. C., Delp, S. L., & Leskovec, J. (2017). Large-scale physical activity data reveal worldwide activity inequality. *Nature, 547*(7663), 336-339. doi:10.1038/nature23018

Barrett-Connor, E. (2013). Gender differences and disparities in all-cause and coronary heart disease mortality: epidemiological aspects. *Best Practice & Research Clinical Endocrinology & Metabolism, 27*(4), 481-500. doi:10.1016/j.beem.2013.05.013

Barrington-Leigh, C., & Millard-Ball, A. (2015). A century of sprawl in the United States. *Proceedings of the National Academy of Sciences of the United States of America, 112*(27), 8244-8249. doi:10.1073/pnas.1504033112

Belanger, M., Townsend, N., & Foster, C. (2011). Age-related differences in physical activity profiles of English adults. *Preventive Medicine, 52*(3-4), 247-249. doi:10.1016/j.ypmed.2011.02.008

Boone-Heinonen, J., Gordon-Larsen, P., Guilkey, D. K., Jacobs, D. R., Jr., & Popkin, B. M. (2011). Environment and Physical Activity Dynamics: The Role of Residential Self-selection. *Psychology of Sport and Exercise, 12*(1), 54-60. doi:10.1016/j.psychsport.2009.09.003

Buajitti, E., Watson, T., Kornas, K., Bornbaum, C., Henry, D., & Rosella, L. C. (2018). Ontario Atlas of Adult Mortality, 1992-2015: Trends in Local Health Integration Networks.

Canadian Institute for Health Information. (2012). *Canadian Coding Standards for CD-10-CA and CCI for 2012.* Ottawa: CIHI

Cervero, R., & Kockelman, K. (1997). Travel demand and the 3Ds: density, diversity, and design. *Transportation Research Part D-Transport and Environment, 2*(3), 199-219. doi:10.1016/S1361-9209(97)00009-6

Chipperfield, J. G. (2008). Everyday physical activity as a predictor of late-life mortality. *Gerontologist, 48*(3), 349-357. doi:10.1093/geront/48.3.349

Chiu, M., Rezai, M. R., Maclagan, L. C., Austin, P. C., Shah, B. R., Redelmeier, D. A., & Tu, J. V. (2016). Moving to a Highly Walkable Neighborhood and Incidence of Hypertension: A Propensity-Score Matched Cohort Study. *Environmental Health Perspectives, 124*(6), 754-760. doi:10.1289/ehp.1510425

Connor Gorber, S., Shields, M., Tremblay, M. S., & McDowell, I. (2008). The feasibility of establishing correction factors to adjust self-reported estimates of obesity. *Health Reports, 19*(3), 71-82.

Creatore, M. I., Glazier, R. H., Moineddin, R., Fazli, G. S., Johns, A., Gozdyra, P., Matheson, F. I., Kaufman-Shriqui, V., Rosella, L. C., Manuel, D. G., & Booth, G. L. (2016). Association of Neighborhood Walkability With Change in Overweight, Obesity, and Diabetes. *JAMA, 315*(20), 2211-2220. doi:10.1001/jama.2016.5898

Fecht, D., Fortunato, L., Morley, D., Hansell, A. L., & Gulliver, J. (2016). Associations between urban metrics and mortality rates in England. *Environmental Health, 15*(1), S34. doi:10.1186/s12940-016-0106-3

Gaglioti, A. H., Xu, J., Rollins, L., Baltrus, P., O'Connell, L. K., Cooper, D. L., Hopkins, J., Botchwey, N. D., & Akintobi, T. H. (2018). Neighborhood Environmental Health and Premature Death From Cardiovascular Disease. *Preventing Chronic Disease, 15*, E17. doi:10.5888/pcd15.170220

Giles-Corti, B., Vernez-Moudon, A., Reis, R., Turrell, G., Dannenberg, A. L., Badland, H., Foster, S., Lowe, M., Sallis, J. F., Stevenson, M., & Owen, N. (2016). City planning and population health: a global challenge. *The Lancet, 388*(10062), 2912-2924. doi:10.1016/S0140-6736(16)30066-6

Griffin, B. A., Eibner, C., Bird, C. E., Jewell, A., Margolis, K., Shih, R., Ellen Slaughter, M., Whitsel, E. A., Allison, M., & Escarce, J. J. (2013). The relationship between urban sprawl and coronary heart disease in women. *Health Place, 20*, 51-61. doi:10.1016/j.healthplace.2012.11.003

Hajna, S., Kestens, Y., Daskalopoulou, S. S., Joseph, L., Thierry, B., Sherman, M., Trudeau, L., Rabasa-Lhoret, R., Meissner, L., Bacon, S. L., Gauvin, L., Ross, N. A., Dasgupta, K., Diabetes, G. P. S., & Walkablilty Study, G. (2016). Neighbourhood walkability and home neighbourhood-based physical activity: an observational study of adults with type 2 diabetes. *BMC Public Health, 16*, 957. doi:10.1186/s12889-016-3603-y

Hajna, S., Ross, N. A., Joseph, L., Harper, S., & Dasgupta, K. (2015). Neighbourhood walkability, daily steps and utilitarian walking in Canadian adults. *Bmj Open, 5*(11), e008964. doi:10.1136/bmjopen-2015-008964

Hamidi, S., Ewing, R., Tatalovich, Z., Grace, J. B., & Berrigan, D. (2018). Associations between Urban Sprawl and Life Expectancy in the United States. *International Journal of Environmental Research and Public Health, 15*(5). doi:10.3390/ijerph15050861

Handy, S., Cao, X., & Mokhtarian, P. L. (2006). Self-selection in the relationship between the built environment and walking: Empirical evidence from Northern California. *Journal of the American Planning Association, 72*(1), 55-74. doi:10.1080/01944360608976724

Hankey, S., Marshall, J. D., & Brauer, M. (2012). Health impacts of the built environment: within-urban variability in physical inactivity, air pollution, and ischemic heart disease mortality. *Environmental Health Perspectives, 120*(2), 247-253. doi:10.1289/ehp.1103806

Hardy, R., Lawlor, D. A., & Kuh, D. (2015). A life course approach to cardiovascular aging. *Future Cardiology, 11*(1), 101-113. doi:10.2217/fca.14.67

Haskell, W. L. (2012). Physical Activity by Self-Report: A Brief History and Future Issues. *Journal of Physical Activity & Health, 9*, S5-S10. doi:10.1123/jpah.9.s1.s5

Herrmann, T., Gleckner, W., Wasfi, R. A., Thierry, B., Kestens, Y., & Ross, N. A. (2019). A pan-Canadian measure of active living environments using open data. *Health Reports, 30*(5), 16-25.

Hirsch, J. A., Winters, M., Clarke, P., & McKay, H. (2014). Generating GPS activity spaces that shed light upon the mobility habits of older adults: a descriptive analysis. *International Journal of Health Geographics, 13*, 51. doi:10.1186/1476-072X-13-51

Katzmarzyk, P. T., Gledhill, N., & Shephard, R. J. (2000). The economic burden of physical inactivity in Canada. *Canadian Medical Association Journal, 163*(11), 1435-1440.

Mackenbach, J. D., Rutter, H., Compernolle, S., Glonti, K., Oppert, J. M., Charreire, H., De Bourdeaudhuij, I., Brug, J., Nijpels, G., & Lakerveld, J. (2014). Obesogenic environments: a systematic review of the association between the physical environment and adult weight status, the SPOTLIGHT project. *BMC Public Health, 14*, 233. doi:10.1186/1471-2458-14-233

Manuel, D. G., Perez, R., Sanmartin, C., Taljaard, M., Hennessy, D., Wilson, K., Tanuseputro, P., Manson, H., Bennett, C., & Tuna, M. (2016). Measuring burden of unhealthy behaviours using a multivariable predictive approach: life expectancy lost in Canada attributable to smoking, alcohol, physical inactivity, and diet. *PLoS Medicine, 13*(8), e1002082. doi:10.1371/journal.pmed.1002082

Moore, S. C., Patel, A. V., Matthews, C. E., Berrington de Gonzalez, A., Park, Y., Katki, H. A., Linet, M. S., Weiderpass, E., Visvanathan, K., Helzlsouer, K. J., Thun, M., Gapstur, S. M., Hartge, P., & Lee, I. M. (2012). Leisure time physical activity of moderate to vigorous intensity and mortality: a large pooled cohort analysis. *PLoS Medicine, 9*(11), e1001335. doi:10.1371/journal.pmed.1001335

Morris, J. N., & Hardman, A. E. (1997). Walking to health. *Sports Medicine, 23*(5), 306-332.

Patel, A. V., Hildebrand, J. S., Leach, C. R., Campbell, P. T., Doyle, C., Shuval, K., Wang, Y., & Gapstur, S. M. (2018). Walking in Relation to Mortality in a Large Prospective Cohort of Older U.S. Adults. *American Journal of Preventive Medicine, 54*(1), 10-19. doi:10.1016/j.amepre.2017.08.019

Pilote, L., Dasgupta, K., Guru, V., Humphries, K. H., McGrath, J., Norris, C., Rabi, D., Tremblay, J., Alamian, A., Barnett, T., Cox, J., Ghali, W. A., Grace, S., Hamet, P., Ho, T., Kirkland, S., Lambert, M., Libersan, D., O'Loughlin, J., Paradis, G., Petrovich, M., & Tagalakis, V. (2007). A comprehensive view of sex-specific issues related to cardiovascular disease. *Canadian Medical Association Journal, 176*(6), S1-44. doi:10.1503/cmaj.051455

Pollard, T. M., & Wagnild, J. M. (2017). Gender differences in walking (for leisure, transport and in total) across adult life: a systematic review. *BMC Public Health, 17*(1), 341. doi:10.1186/s12889-017-4253-4

Prince, S. A., Adamo, K. B., Hamel, M. E., Hardt, J., Connor Gorber, S., & Tremblay, M. (2008). A comparison of direct versus self-report measures for assessing physical activity in adults: a systematic review. *International Journal of Behavioral Nutrition and Physical Activity, 5*, 56. doi:10.1186/1479-5868-5-56

Sallis, J. F., Saelens, B. E., Frank, L. D., Conway, T. L., Slymen, D. J., Cain, K. L., Chapman, J. E., & Kerr, J. (2009). Neighborhood built environment and income: examining multiple health outcomes. *Social Science and Medicine, 68*(7), 1285-1293. doi:10.1016/j.socscimed.2009.01.017

Sanmartin, C., Decady, Y., Trudeau, R., Dasylva, A., Tjepkema, M., Fines, P., Burnett, R., Ross, N., & Manuel, D. G. (2016). Linking the Canadian Community Health Survey and the Canadian Mortality Database: An enhanced data source for the study of mortality. *Health Reports, 27*(12), 10-18.

Statistics Canada. (2011). *Canadian Community Health Survey (CCHS) Annual Component, 2009-2010 Common Content: Derived Variable (DV) Specifications*. Retrieved from Ottawa:

Statistics Canada. (2017). Evaluation of the Health Statistics Program 2015. Retrieved from https://statcan.gc.ca/eng/about/er/hspfr

Sundquist, K., Eriksson, U., Mezuk, B., & Ohlsson, H. (2015). Neighborhood walkability, deprivation and incidence of type 2 diabetes: a population-based study on 512,061 Swedish adults. *Health Place, 31*, 24-30. doi:10.1016/j.healthplace.2014.10.011

Tam, T. (2017). *The Chief Public Health Officer's Report on the State of Public Health in Canada 2017–Designing Healthy Living*. Retrieved from https://www.canada.ca/en/public-health/services/publications/chief-public-health-officer-reports-state-public-health-canada/2017-designing-healthy-living.html

Turcotte, M. (2012). Profile of seniors' transportation habits. *Canadian Social Trends, 93*(2012001), 1-16.

Wasfi, R. A., Dasgupta, K., Eluru, N., & Ross, N. A. (2016). Exposure to walkable neighbourhoods in urban areas increases utilitarian walking: Longitudinal study of Canadians. *Journal of Transport & Health, 3*(4), 440-447. doi:10.1016/j.jth.2015.08.001

World Health Organization. (2010). *Global recommendations on physical activity for health*: World Health Organization.

World Health Organization. (2018). *World health statistics 2018: monitoring health for the SDGs sustainable development goals*. Retrieved from Geneva: https://apps.who.int/iris/bitstream/handle/10665/272596/9789241565585-eng.pdf?ua=1

Wu, Y. T., Prina, A. M., Jones, A., Barnes, L. E., Matthews, F. E., Brayne, C., & Mrc, C. (2016). Land use mix and five-year mortality in later life: Results from the Cognitive Function and Ageing Study. *Health Place, 38,* 54-60. doi:10.1016/j.healthplace.2015.12.002

Chapter 4

EFFECT MEASURE MODIFICATION OF TYPE 2 DIABETES STATUS ON THE RELATIONSHIP BETWEEN ACTIVE LIVING ENVIRONMENTS AND PREMATURE CARDIOMETABOLIC MORTALITY

4.1 PREAMBLE

In Chapter 3, we examined the relationship between ALE, walking, and cardiometabolic mortality in stratified groups, and observed a protective relationship for ALE for older women. In Chapter 4, we interrogate this association further. As detailed in Chapter 2, one of the overarching hypotheses of this area of research is that ALEs may encourage walking and in turn, may lead to lower incidence of T2D (Creatore et al., 2016; Sundquist et al., 2015). However, others propose that favourable built environments may also lower walking barriers for those who already have the disease (Hajna, Ross, et al., 2016). That ALEs may be of particular importance to older women is of interest because previous studies indicate that although progress has been made in reducing all-cause and cardiovascular mortality rates in men with diabetes, mortality in women with diabetes has not improved (Gregg, Gu, Cheng, Narayan, & Cowie, 2007) and is worse when diagnosed in later stages of the disease (Roche & Wang, 2013).

Chapter 4 investigates whether the protective relationship among older women might vary by T2D status and risk. This chapter is consistent with the main purpose of this dissertation of assessing whether and to what extent to which favourable ALEs are associated with population-wide gains in physical activity-related health. The study contributes to the first objective of this thesis as well as the third objective - assessing whether associations between ALE and health vary in those with or at high risk of T2D.

A version of this chapter is intended for submission as a short communication to *The American Journal of Public Health.*

4.2 Abstract

OBJECTIVE To determine whether the association between active living environments (ALEs) and premature cardiometabolic death varies by T2D status in older women.

RESEARCH DESIGN AND METHODS Women 65-85 years from a population-based Canadian cohort were linked to the national death registry. We examined differences in associations between ALE and mortality using survival analysis with interaction terms and stratified analyses over T2D groups (present, at risk, none).

RESULTS Effect modification for T2D was present on both the additive (relative excess risk due to interaction (RERI) 1.45, 95% CI 0.69 to 2.24) and multiplicative scales (ratio of hazard ratios (HRs) 1.92, 1.10 to 3.38), but was inconclusive for high T2D risk (RERI 0.60, 95% CI -0.04 to 1.23; ratio of HRs 1.75, 0.79 to 3.90). Women living in less favourable ALEs who were at risk for or had T2D were at higher risk for cardiometabolic mortality compared with those without T2D living in favourable ALEs (adjusted HR, aHR 1.42, 95% CI 1.03 to 1.94 for high risk; aHR 2.97, 2.26 to 3.91 for T2D).

CONCLUSION Neighbourhoods conducive to active living could especially delay cardiometabolic death in older women with T2D.

4.3 Introduction

Type 2 diabetes (T2D) is associated with excess weight, lack of physical activity (Sigal et al., 2018; Wharton, Pedersen, Lau, Sharma, & Committee, 2018), and heightened risk of cardiometabolic death (Almdal, Scharling, Jensen, & Vestergaard, 2004). Built environments conducive for active living (also knowns as ‘walkable’ neighbourhoods) may be an important enabling factor for those with T2D, as well as a preventive factor for mitigating T2D onset (Creatore et al., 2016; Sundquist et al., 2015). Such neighbourhoods may be particularly important for older individuals, for whom reductions in mobility often mean more daily life activities are conducted near home (Xue, Fried, Glass, Laffan, & Chaves, 2008). Neighbourhood environments are also important to women’s health (Stafford, Cummins, Macintyre, Ellaway, & Marmot, 2005) and could influence gender differences seen for physical activity (Colley et al., 2011) and walking (Pollard & Wagnild, 2017). Consistent with a previous study of urban sprawl (Griffin et al., 2013), we recently demonstrated a protective association between favourable ALEs and premature cardiometabolic mortality in older women (Mah et al., 2020). We now investigate whether this relationship differs in women with, without, or at risk for T2D.

4.4 Methods

Study Population

For this retrospective cohort study conducted in 2020, we extracted a subsample of older women aged 65-85 years from a record linkage of the Canadian Community Health Survey (2000-2011) and the Canadian Mortality Database (to 2011). We excluded those who immigrated within 5 years of survey response to reduce the risk of inadequate period of exposure to Canadian neighbourhoods. We also excluded those with less than 1-year follow-up time.

Assessment of T2D

We used a validated algorithm to identify persons with T2D (Ng et al., 2008), which considers insulin use, oral anti-hyperglycemic medications, pregnancy, and age at diagnosis. In addition to using the algorithm, we identified individuals who had T2D-related hospital records bearing codes E11-14 (ICD-10) or 250 (ICD-9) occurring before survey response using linkage to the Discharge Abstract Database. To identify those at higher risk of developing T2D, we used the Diabetes Population Risk Tool (Rosella et al., 2011), which considers sex-specific information on BMI, age, ethnicity, hypertension, immigrant status, smoking, education status and heart disease. The upper 10th percentile with the highest risk scores were considered 'high risk' for T2D.

Active Living Environments (ALEs)

The Canadian Active Living Environments Database (Can-ALE) is a five-class measure of how conducive a neighbourhood is to active living (Herrmann et al., 2019). Briefly, neighbourhoods were constructed using 1,000-meter Euclidean buffers from the centroids of dissemination areas. Open data on intersection density, points of interest, and dwelling density were used to construct the measure. Residential locations were interpolated based on postal code and assigned a corresponding Can-ALE classification using GIS (ArcGIS v.10, ESRI 2010). Can-ALE classes 1-3 were considered less favourable, while 4-5 were considered favourable.

Outcome

The CMDB contains date and primary cause of death, coded using the ICD-10. The primary outcome was death due to cardiometabolic diseases, which we defined as that related to diabetes (E11-E14, which excludes type 1 diabetes), overweight and obesity-related conditions (E65-68), cholesterol-related conditions (E78), and cardiovascular disease (I10-15, I21-25, I50, I61-69, I70-74). Premature death was defined as occurring before 85 years of age, the average life expectancy of Canadian women.

Statistical Analysis

We used Cox regression to evaluate the relationship between ALEs and cardiometabolic mortality, and included T2D status (i.e. no T2D, high risk for T2D, has T2D) and a product term between ALEs and T2D status to assess effect modification (Knol & VanderWeele, 2012). Women without T2D in favourable ALEs were the reference group. We also estimated associations of ALEs and premature cardiometabolic mortality using separate models for those without, those at high risk, and those with T2D. All models were adjusted for age, education, area-level income, survey cycle, smoking status, obesity, and the presence of two or more chronic conditions other than diabetes. Analyses were conducted using Stata software version 15.1 (StataCorp, College Station, TX).

4.5 Results

55,860 older women aged 65-85 years met inclusion criteria (Figure 4.1). These included 5,450 women at higher risk of T2D, and 7,880 with T2D (7575 through algorithm, 305 additional women who reported no diabetes but had prior diagnoses). The average follow-up time was 5.35 years. Premature cardiometabolic mortality rates did not differ by ALE in women without T2D (3.82 compared with 3.81 deaths per 1,000 person-years) but were lower in favourable neighbourhoods for active living both among women at high risk for T2D (3.03 versus 5.58) and among those with established T2D (6.02 versus 11.38, Table 4.1).

Effect modification for T2D was present on both the additive (relative excess risk due to interaction, RERI 1.45, 95% CI 0.69 to 2.24) and multiplicative scales (ratio of hazard ratios (HRs) 1.92, 1.10 to 3.38), but was inconclusive for high T2D risk (RERI 0.60, 95% CI -0.04 to 1.23; ratio of HRs 1.75, 0.79 to 3.90). Women living in less favourable ALEs who were at risk for or had T2D were at higher risk for cardiometabolic mortality compared with those without T2D living in favourable ALEs (adjusted HR, aHR 1.42, 95% CI 1.03 to 1.94 for high risk; aHR 2.97, 2.26 to 3.91 for T2D). In contrast, risk of cardiometabolic mortality was not conclusively different among women without T2D who lived in more versus less favourable ALEs. Less favourable ALEs were associated with higher risk of premature cardiometabolic death for women with T2D (aHR 1.92, 1.16 to 3.18). Associations were, however, inconclusive in women who were at higher risk of T2D (aHR 1.88, 0.87 to 4.05), and not present in those without T2D (aHR 1.05, 0.81 to 1.37)

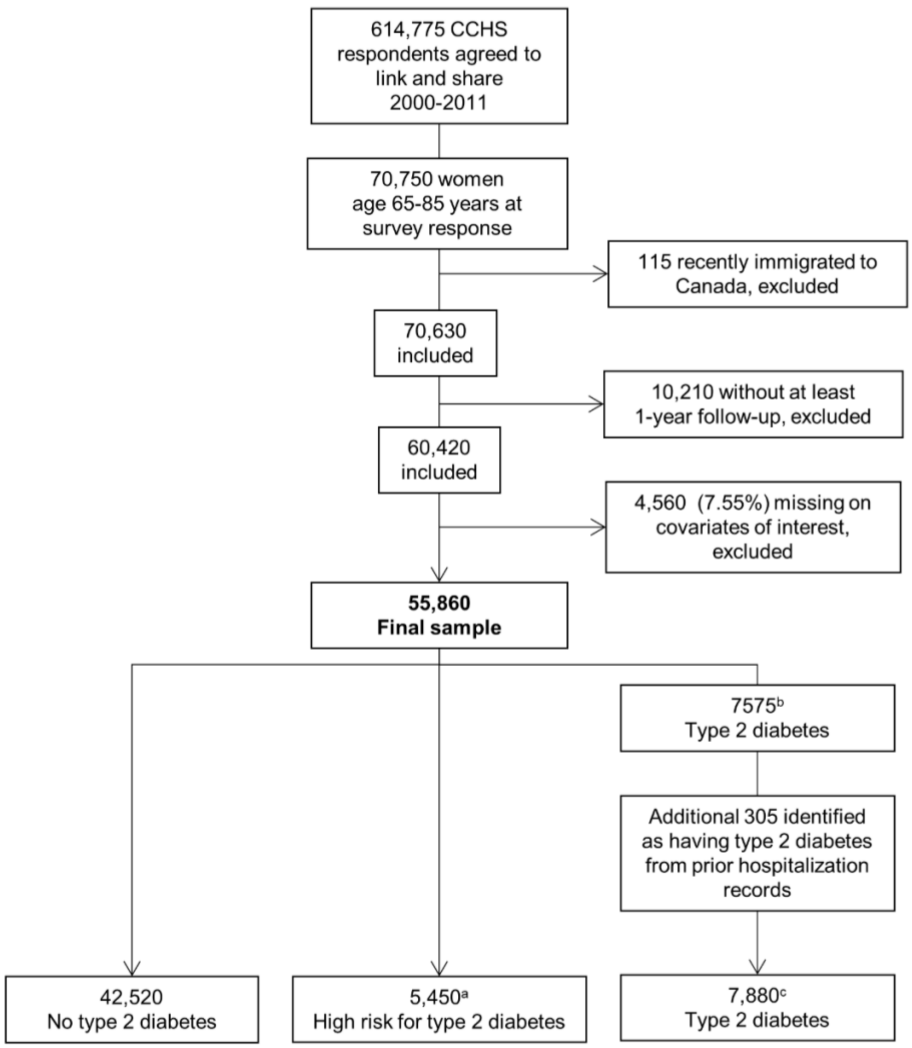

Figure 4.1 Flowchart summary of sample selection for Chapter 4.
N = 55,860.
[a] T2D risk ascertained using algorithm (Rosella et al., 2011).
[b] T2D status ascertained using algorithm (Ng et al., 2008).
[c] T2D status ascertained using algorithm (Ng et al., 2008) and administrative hospital data.

Table 4.1 Effect measure modification of the association of ALEs and premature cardiometabolic death by diabetes status for older women

	More favourable ALE			**Less favourable ALE**			HRs (95% CI) for unfavourable ALE within strata of diabetes status
	N	Rate/1,000 PY (95% CI)	HR (95% CI) [a]	N	Rate/1,000 PY (95% CI)	HR (95% CI) [a]	
No diabetes	2,985	3.82 (2.97, 4.91)	1.00	39,535	3.81 (3.56, 4.08)	1.05 (0.80, 1.36)	1.05 (0.81, 1.37) [b]
High risk	430	3.03 (1.44, 6.35)	0.77 (0.35, 1.70)	5,025	5.58 (4.76, 6.55)	1.42 (1.03, 1.94) *	1.88 (0.87, 4.05) [c]
T2D	515	6.02 (3.69, 9.84)	1.48 (0.85, 2.57)	7,365	11.38 (10.34, 12.53)	2.97 (2.26, 3.91) ***	1.92 (1.16, 3.18) [d] **

EMM on additive scale, RERI (95% CI): *high-risk vs no diabetes*, 0.60 (-0.04, 1.23), P = 0.065; *T2D vs no diabetes*, 1.45 (0.65, 2.24), P < 0.001.

EMM on multiplicative scale, ratio of HRs (95% CI): *high-risk vs no diabetes*, 1.75 (0.79, 3.90), P = 0.171; *T2D vs no diabetes*, 1.92 (1.10, 3.38), P = 0.023.

Hazard ratios (HR) adjusted for age, sex, educational attainment, area-level income, survey cycle, smoking status, obesity, presence of two other chronic conditions.
*P≤0.05, **P≤0.01, ***P≤0.001
[a] Estimates from model of ALE, T2D status and cardiometabolic mortality with a product term between ALE and T2D status (N = 55,860)
[b] Estimates from model of ALE cardiometabolic mortality in older women without T2D (N = 42,520)
[c] Estimates from model of ALE cardiometabolic mortality in older women at higher risk of T2D (N = 5,450)
[d] Estimates from model of ALE cardiometabolic mortality in older women with T2D (N = 7,880)

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4.6 CONCLUSIONS

This is the first study to examine the association between ALEs and premature cardiometabolic mortality for those with T2D and at high risk of T2D. Associations with living in less favourable ALEs were conclusively associated with higher risk of premature cardiometabolic mortality in women with T2D, heightened to a lesser degree (in both magnitude and precision) for women at higher risk of T2D, and were not present in women without T2D. Built environment factors are among existing barriers to regular exercise for those with and at risk of T2D (Korkiakangas, Alahuhta, & Laitinen, 2009). Canadian evidence has shown higher step counts (Hajna, Ross, et al., 2016) as well as neighbourhood-based physical activity (Hajna, Kestens, et al., 2016) in T2D patients living in favourable ALEs. These results imply that neighbourhoods conducive to active living might, in turn, improve cardiometabolic survival so dramatically in women with T2D as to make their trajectories resemble those without T2D. The strengths of this study include a large population-based sample, objectively assessed exposure and outcome measures, robust and validated approaches for identifying T2D and high-risk T2D individuals, and the inclusion of multiple individual-level covariates. The major limitation of this study is the cross-sectional nature of the exposure measures, which prohibited us from accounting for major neighbourhood developmental changes and residential moves. T2D diminishes the protective effect of sex with regard to cardiovascular disease, and exacerbates cardiovascular risk and mortality more for women compared with men (Kautzky-Willer, Harreiter, & Pacini, 2016). Our findings suggest that policies that promote developing neighbourhoods conducive for active living may be a key consideration for improving the longitudinal cardiometabolic health outcomes of older women with T2D and potentially those at higher risk for T2D.

4.7 REFERENCES

Almdal, T., Scharling, H., Jensen, J. S., & Vestergaard, H. (2004). The independent effect of type 2 diabetes mellitus on ischemic heart disease, stroke, and death: a population-based study of 13,000 men and women with 20 years of follow-up. *Archives of Internal Medicine, 164*(13), 1422-1426. doi:10.1001/archinte.164.13.1422

Colley, R. C., Garriguet, D., Janssen, I., Craig, C. L., Clarke, J., & Tremblay, M. S. (2011). Physical activity of Canadian adults: accelerometer results from the 2007 to 2009 Canadian Health Measures Survey. *Health Rep, 22*(1), 7-14.

Creatore, M. I., Glazier, R. H., Moineddin, R., Fazli, G. S., Johns, A., Gozdyra, P., Matheson, F. I., Kaufman-Shriqui, V., Rosella, L. C., Manuel, D. G., & Booth, G. L. (2016). Association of Neighborhood Walkability With Change in Overweight, Obesity, and Diabetes. *JAMA, 315*(20), 2211-2220. doi:10.1001/jama.2016.5898

Gregg, E. W., Gu, Q., Cheng, Y. J., Narayan, K. M., & Cowie, C. C. (2007). Mortality trends in men and women with diabetes, 1971 to 2000. *Annals of Internal Medicine, 147*(3), 149-155. doi:10.7326/0003-4819-147-3-200708070-00167

Griffin, B. A., Eibner, C., Bird, C. E., Jewell, A., Margolis, K., Shih, R., Ellen Slaughter, M., Whitsel, E. A., Allison, M., & Escarce, J. J. (2013). The relationship between urban sprawl and coronary heart disease in women. *Health Place, 20*, 51-61. doi:10.1016/j.healthplace.2012.11.003

Hajna, S., Kestens, Y., Daskalopoulou, S. S., Joseph, L., Thierry, B., Sherman, M., Trudeau, L., Rabasa-Lhoret, R., Meissner, L., Bacon, S. L., Gauvin, L., Ross, N. A., Dasgupta, K., Diabetes, G. P. S., & Walkablilty Study, G. (2016). Neighbourhood walkability and home neighbourhood-based physical activity: an observational study of adults with type 2 diabetes. *BMC Public Health, 16*, 957. doi:10.1186/s12889-016-3603-y

Hajna, S., Ross, N. A., Joseph, L., Harper, S., & Dasgupta, K. (2016). Neighbourhood Walkability and Daily Steps in Adults with Type 2 Diabetes. *PloS One, 11*(3), e0151544. doi:10.1371/journal.pone.0151544

Herrmann, T., Gleckner, W., Wasfi, R. A., Thierry, B., Kestens, Y., & Ross, N. A. (2019). A pan-Canadian measure of active living environments using open data. *Health Reports, 30*(5), 16-25.

Kautzky-Willer, A., Harreiter, J., & Pacini, G. (2016). Sex and Gender Differences in Risk, Pathophysiology and Complications of Type 2 Diabetes Mellitus. *Endocrine Reviews, 37*(3), 278-316. doi:10.1210/er.2015-1137

Knol, M. J., & VanderWeele, T. J. (2012). Recommendations for presenting analyses of effect modification and interaction. *International Journal of Epidemiology, 41*(2), 514-520. doi:10.1093/ije/dyr218

Korkiakangas, E. E., Alahuhta, M. A., & Laitinen, J. H. (2009). Barriers to regular exercise among adults at high risk or diagnosed with type 2 diabetes: a systematic review. *Health Promotion International, 24*(4), 416-427. doi:10.1093/heapro/dap031

Mah, S. M., Sanmartin, C., Riva, M., Dasgupta, K., & Ross, N. A. (2020). Active living environments, physical activity and premature cardiometabolic mortality in Canada: a nationwide cohort study. *Bmj Open, 10*(11), e035942. doi:10.1136/bmjopen-2019-035942

Ng, E., Dasgupta, K., & Johnson, J. A. (2008). An algorithm to differentiate diabetic respondents in the Canadian Community Health Survey. *Health Reports, 19*(1), 71-79.

Pollard, T. M., & Wagnild, J. M. (2017). Gender differences in walking (for leisure, transport and in total) across adult life: a systematic review. *BMC Public Health, 17*(1), 341. doi:10.1186/s12889-017-4253-4

Roche, M. M., & Wang, P. P. (2013). Sex differences in all-cause and cardiovascular mortality, hospitalization for individuals with and without diabetes, and patients with diabetes diagnosed early and late. *Diabetes Care, 36*(9), 2582-2590. doi:10.2337/dc12-1272

Rosella, L. C., Manuel, D. G., Burchill, C., Stukel, T. A., & team, P.-D. (2011). A population-based risk algorithm for the development of diabetes: development and validation of the Diabetes Population Risk Tool (DPoRT). *Journal of Epidemiology and Community Health, 65*(7), 613-620. doi:10.1136/jech.2009.102244

Sigal, R. J., Armstrong, M. J., Bacon, S. L., Boulé, N. G., Dasgupta, K., Kenny, G. P., Riddell, M. C., & Committee, D. C. C. P. G. E. (2018). Physical Activity and Diabetes. *Canadian Journal of Diabetes, 42,* S54-S63. doi:10.1016/j.jcjd.2017.10.008

Stafford, M., Cummins, S., Macintyre, S., Ellaway, A., & Marmot, M. (2005). Gender differences in the associations between health and neighbourhood environment. *Soc Sci Med, 60*(8), 1681-1692. doi:10.1016/j.socscimed.2004.08.028

Sundquist, K., Eriksson, U., Mezuk, B., & Ohlsson, H. (2015). Neighborhood walkability, deprivation and incidence of type 2 diabetes: a population-based study on 512,061 Swedish adults. *Health Place, 31*, 24-30. doi:10.1016/j.healthplace.2014.10.011

Wharton, S., Pedersen, S. D., Lau, D. C., Sharma, A. M., & Committee, D. C. C. P. G. E. (2018). Weight Management in Diabetes. *Canadian Journal of Diabetes, 42,* S124-S129. doi:10.1016/j.jcjd.2017.10.015

Xue, Q. L., Fried, L. P., Glass, T. A., Laffan, A., & Chaves, P. H. M. (2008). Life-space constriction, development of frailty, and the competing risk of mortality. *American Journal of Epidemiology, 167*(2), 240-248. doi:10.1093/aje/kwm270

Chapter 5

ASSESSING ACTIVE LIVING ENVIRONMENTS AND HOSPITAL BURDEN USING CANADIAN POPULATION BASED LINKED DATA

5.1 PREAMBLE

Chapters 3-4 focused on the relationship between ALEs and premature cardiometabolic mortality. Chapters 5-7 turn to questions of whether living in favourable ALEs is associated with hospitalization. To date there is no longitudinal evidence that reductions in hospital burden – the largest share of Canadian health care costs – are associated with environments that support active living. Metrics such as frequency of admission and length of stay, which are often derived from administrative databases, have traditionally been used to assess health care system performance (Lohr & Steinwachs, 2002). Such metrics can also be used to monitor the health status of the population over time and regions, and serve as useful proxies for health status and morbidity (Canadian Institute for Health Information, 2020).

The goal of this study was to describe hospital utilization patterns for Canadians living in each of the five ALE classes (from the least favourable ALE class 1 to the most favourable ALE class 5) and determine whether those who lived in more favourable ALEs differed from those in less favourable ALEs in terms of likelihood of being hospitalized - both overall and specifically for a major cardiovascular event. The underlying hypothesis was that ALEs would promote physical activity leading to lower risk for cardiovascular disease, a key driver of hospitalization. Among those ever admitted to hospital, admission frequency and cumulative length of stay were also assessed. We identified hospitalizations related to major cardiovascular events using ICD-10 codes for acute myocardial infarction, stroke, and congestive heart failure that have been previously validated (Tu et al., 2015). This chapter is consistent with the main purpose of this dissertation and contributes to the second objective of the thesis. The manuscript is intended for submission to *Lancet Public Health.*

5.2 Abstract

Background: Built environments that encourage active living hold promise as a policy lever for increasing physical activity and reducing health care burden - particularly that related to major cardiovascular (CVD) events.

Methods: We examined the role of active living environments (ALEs) on hospitalization odds, frequency, and cumulative length of stay, overall and specifically for major CVD events. The dataset combined survey data from a national census of acute hospitalizations with the Canadian Active Living Environment (Can-ALE), an area-level indicator incorporating geographic measures. We used logistic regression to model the odds of hospitalization for acute myocardial infarction (AMI), congestive heart failure (CHF), stroke and all-causes, and truncated poisson regression to model frequency and cumulative length of stay. We also examined whether to and to what extent the associations were mediated by walking or overall physical activity.

Findings: Among 228,195 respondents, followed on average for 5.37 years (SD 3.36), those living in more favourable ALEs exhibited incrementally lower odds of hospitalization compared to those in the least favourable neighbourhoods. Odds of hospitalization was 22% lower overall (OR 0.78, 95% CI 0.74 to 0.83) and 24% lower for AMI-related admissions (OR 0.76, 95% CI 0.65 to 0.90) in more favourable ALEs compared with the least favourable ALEs. Mediation analyses suggest that walking mediates a modest proportion of the association between favourable ALEs and lower odds of hospitalization for AMI (3.22%) and CHF (10.66%).

Interpretation: Living in neighbourhoods that are more conducive to active living are associated with lower odds of hospitalization. Associations between ALEs and hospitalization for AMI and CHF are partly mediated by walking.

Funding: Canadian Institutes of Health Research - Institute of Population and Public Health, Fonds de Recherche du Québec Santé Doctoral Training Award, Canadian Institutes of Health Research Canada Research Chairs Program.

5.3 INTRODUCTION

Cardiovascular diseases (CVD) consume a substantial proportion of health care resources worldwide (Tarride et al., 2009). Ischemic heart disease and congestive heart failure (CHF) are among the top five reasons for inpatient hospitalizations in Canada (Canadian Institute of Health Information, 2018). Physical inactivity is strong predictor of acute myocardial infarction (AMI), stroke, and CHF, as well as antecedent factors like obesity, diabetes, hypertension, and dyslipidemia (Huai et al., 2013; Kyu et al., 2016; Nayor & Vasan, 2015; Pandey et al., 2015). Nearly half of Canadians over the age of twelve years are considered physically inactive (Statistics Canada, 2020c) and most of the population does not meet physical activity guidelines (Statistics Canada, 2020a). The health care costs of physical inactivity are estimated to be in the billions (Janssen, 2012; Woolcott et al., 2010). Effective population level approaches are needed to address the deficit in physical activity, and perhaps prevent AMI, stroke, and CHF hospitalizations.

There is some evidence that the extent to which one's neighbourhood is conducive to active living, also referred to as 'walkability', is linked to better cardiometabolic risk profiles (Braun et al., 2016; Hajna et al., 2018) and lower CVD risk (Howell et al., 2019). These neighbourhoods could reduce associated health care burden by enabling population-wide physical activity (Colley et al., 2019a), particularly that related to walking (Hajna, Ross, et al., 2016). Ecological studies have demonstrated inverse associations between the walking-friendliness of places and area-level rates of hospitalization for AMI (Mazumdar et al., 2016), hospital admissions, and subsequent health care costs (Yu et al., 2017). In this study, we assessed relationships between neighbourhood ALEs and individual-level rates of hospitalization for major CVD events in a large population-based sample of Canadian adults over the age of 45 years. We also examined the extent to which the relationship between ALE and hospitalization may be mediated through walking and overall physical activity.

5.4 METHODS

STUDY DESIGN AND POPULATION

We accessed a record linkage between the Canadian Community Health Survey (CCHS, 2000 to 2011) and the Discharge Abstract Database (DAD, fiscal years 2004 to 2012) (Sanmartin et al., 2016). The CCHS is a repeat cross-sectional survey that collects self-reported information related to health status, behaviours and conditions from the Canadian population. An annual sample of approximately 65,000 Canadians aged 12 years and older are drawn from the Canadian population, excluding those living in Indigenous communities, full-time members of the Canadian Forces, institutionalized individuals, and those living in certain remote areas (Statistics Canada, 2011b). We selected those aged 45 years and older for inclusion in the study. The DAD contains all hospital separations in Canada except those for the province of Quebec and is coded using the International Classification of Diseases and related Health Problems (ICD-9-CA, ICD-10-CA).

ENVIRONMENTAL EXPOSURES

We used the Canadian Active Living Environments Database (Can-ALE) to classify respondents' neighbourhoods for active living favourability. Can-ALE is a composite measure of intersection and dwelling density and points of interest (i.e. potential walking destinations such as parks, schools, shops, services and landmarks) (Herrmann et al., 2019). As described previously, neighbourhoods were defined based on 1-kilometer circular (Euclidean) buffers drawn around centroids of dissemination areas (DA) - the smallest geographic unit for which complete census data are released in Canada. Intersection density was taken as the number of ≥three-way intersections within each buffer, derived using OpenStreetMap 2016 road and footpath features (OpenStreetMap Contributors, 2017). The number of points of interest were counted within the buffers and were also retrieved from OpenStreetMap 2016. DA-level dwelling densities were obtained from the 2016 Canadian census. Raw scores for the three components were clustered using k-medians and grouped into five categories representing environments that are very active living-unfriendly (ALE class 1) to those that are very active living-friendly (ALE class 5). Survey respondents were linked with their corresponding DA-level ALE scores using their postal codes reported in the CCHS. Interpolated postal code coordinates (Wilkins & Peters, 2012) were overlaid with 2016 DAs in a Geographic Information System (GIS, ArcGIS v.10, ESRI 2010) and assigned their corresponding Can-ALE classification 1 (least favourable) through 5 (most favourable).

We also accounted for the possibility that living within close geographic proximity to hospital might impact hospitalization rates and be related to ALE. We calculated the distance in kilometers between the centroids of DAs and locations of the nearest inpatient care facilities (tagged "amenity = hospital" in Open Streep Map from October 2017) (OpenStreetMap Contributors, 2017).

Sensitivity analyses revealed that a three-kilometer distance was associated with heightened odds of hospitalization and was therefore used as a control variable in subsequent models.

Walking and physical activity

We obtained average daily energy expenditure (kcal/kg/day) for overall leisure-time physical activity and leisure-time walking, which we will refer to as "overall PA" and "walking." Calculations are based on respondents' self-reported activities (such as walking, running, and cycling) in the last three months from baseline survey response (Statistics Canada, 2011a). Frequency and time spent walking and performing other leisure-time activities were multiplied by an assigned metabolic equivalents (MET) value of 3 and then divided by 365 days to yield average daily energy expenditure for walking.

Outcomes

Respondents with acute inpatient admissions to hospital during the study period were considered as 'ever hospitalized.' The study period was from the survey response date (earliest 1 April 2004) to death or the end of the study period (31 March 2013; Figure 5.1). We excluded those that had hospitalization records related to AMI, CHF, or stroke prior to survey response from 1999-2004. In separate sensitivity analyses, we imposed a one-year washout and excluded hospitalizations within a year after survey response to increase the likelihood that undiagnosed prevalent CVD was excluded at the onset of the follow-up period.

We excluded hospitalizations for which pregnancy, childbirth, or diseases of the puerperium (630, 679, V20-V29, ICD-9; O00-O99, Z30-Z39, ICD-10) were considered the most responsible reason for hospitalization. We examined both overall hospitalization and CVD-specific hospitalization, which included:

- AMI: 410, ICD-9; I21-I22, ICD-10
- CHF: 428, ICD-9; I50, ICD-10
- Stroke: 434, 436, 362.3, ICD-9, I63 excluding I63.6, I64, H34.1, ICD-10 (Tu et al., 2015)

Among those ever hospitalized, we also examined hospitalization frequency and cumulative length of stay. Hospitalization frequency was measured using episodes of care; an individual acute inpatient hospitalization was required to be at least 24 hours after any previous discharge to be considered a separate episode from the previous episode. Cumulative length of stay was calculated as the sum of days spent in hospital.

STATISTICAL ANALYSIS

All analyses were conducted under project number 16-HAD-MCG-4802 at the McGill University site of the Canadian Research Data Centre Network, a secure laboratory which provides access to micro-data holdings of Statistics Canada and has in place a detailed protocol to protect the confidentiality of respondents. Consistent with this protocol, all frequencies have a rounding base to the nearest five respondents, and therefore may not be additive to rounded totals.

Descriptive statistics

To determine whether walking and/or overall PA patterns varied by ALE, we generated split density plots to visually compare the proportion of people in each ALE class performing different levels of walking and overall PA using the *beanplot* package (Kampstra, 2008) in R version 3.4.3 (R Foundation for Statistical Computing). We then compared the proportion of hospitalized individuals and hospitalization event rates, as well as cumulative length of stay across ALE classes. To calculate mean event rates by ALE class, we divided aggregate hospitalization counts by total follow-up time during the study period. For mean cumulative length of stay by ALE class, we divided the total summed length of stay by total follow-up time during the study period.

Models of hospitalization

We employed a "double-hurdle" approach to estimate health care use and resource use intensity. We used logistic regression to estimate the relationship between Can-ALE and hospitalizations for all-causes and for major CVD events (AMI, stroke, CHF). We used truncated Poisson regression to model the relationship between Can-ALE and number of hospitalization events and between Can-ALE and cumulative length of stay among those who were ever hospitalized. We adjusted for variables known to influence hospitalization, including age, sex, educational attainment (less than secondary graduation, secondary school graduation, post-graduate degree or diploma), smoking status (never, former, current), obesity (BMI $\geq$ 30), having two or more chronic conditions (yes/no), survey cycle, and living within three kilometers of a hospital (yes/no). An offset variable was included to account for different follow-up times.

We performed mediation analysis to assess the extent to which relationships between favourable ALEs and hospitalization were mediated by walking or overall PA. We used the approach that has been operationalized in Stata via the user-written *med4way* package (Discacciati, Bellavia, Lee, Mazumdar, & Valeri, 2018; VanderWeele, 2014) to assess mediation between Can-ALE, walking/overall PA, and odds of hospitalization. This method accounts for potential interaction between Can-ALE and walking or overall PA (VanderWeele, 2014). Two logistic regression models examined a) the relationship between the exposure (ALE) and the mediator (walking or overall PA), and b) the relationship between the exposure (ALE) and the outcome (hospitalization yes/no). For these analyses, we dichotomized ALEs (ALE classes 1-3 were considered less favourable, classes 4-5 were considered more favourable) as well as walking (yes/no) and overall PA (yes/no). We then estimated the proportion of the association between ALE and odds of hospitalization that is mediated by walking or overall PA, which is calculated as the ratio of the effect due to mediation (known as the pure indirect effect") to the total effect. This method assumes a rare outcome (VanderWeele, 2014). Analyses were conducted using Stata version 16 (StataCorp, College Station, TX, USA).

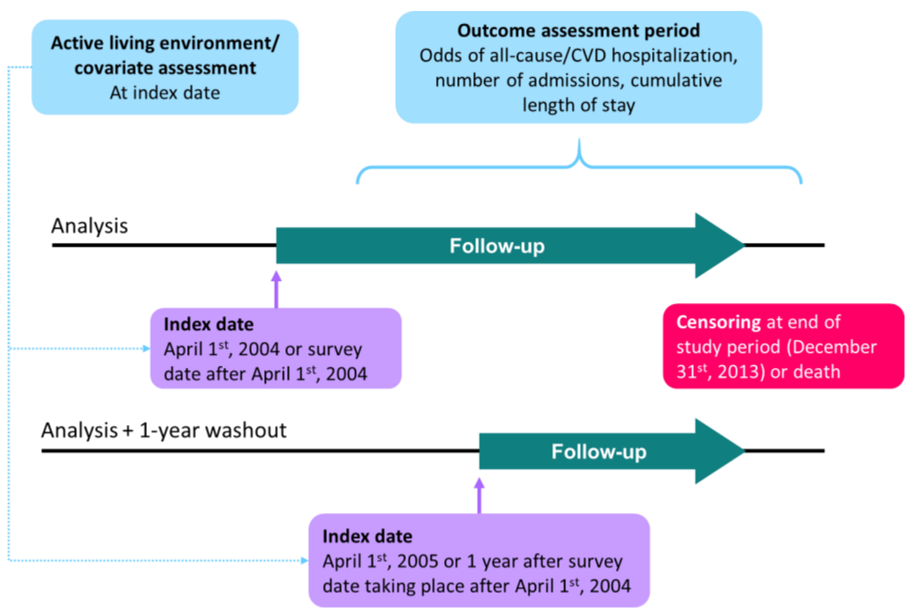

Figure 5.1 Retrospective study design and follow-up periods.
Survey respondents were followed during the study period from April 2004 or survey response to death or the end of the study. We also imposed a one-year washout and excluded hospitalizations within a year after survey response.

5.5 Results

Among 254,700 potentially eligible respondents over the age of 45 years, we excluded 2,765 who died before 1 April 2004); 2,490 respondents who experienced hospitalizations related to AMI, stroke, or CHF before survey response (look back period up to 1999); 1,175 who immigrated to Canada less than five years before survey response; and 20,775 (8.37%) missing key variables of interest (Supplementary Table B.1). In all, 228,195 respondents linked with 194,560 acute hospitalizations were included in our analyses (Figure 5.2). For the sensitivity analysis involving a one-year washout after baseline, we excluded 20,880 hospitalizations occurring within one year of survey response. We also removed 2,790 respondents with less than one year of follow-up time for the sensitivity analysis.

Contributing a total of 6,672,810 person-years of follow-up time (mean of 5.37 years from index date to censoring date), the mean age of the sample was 62.79 years (SD 11.61). A relatively low proportion of the sample lived in the most favourable neighbourhoods for active living (1.5%), while the majority lived in the least favourable ALE (52.23%). Almost half of the sample had a post-secondary degree or diploma (48.86%, Table 5.1). Much of the sample reported ever doing PA (87.07%) and walking (67.4%). Approximately half (53.02%) reported having two chronic conditions, and 29.32% were considered obese at survey response.

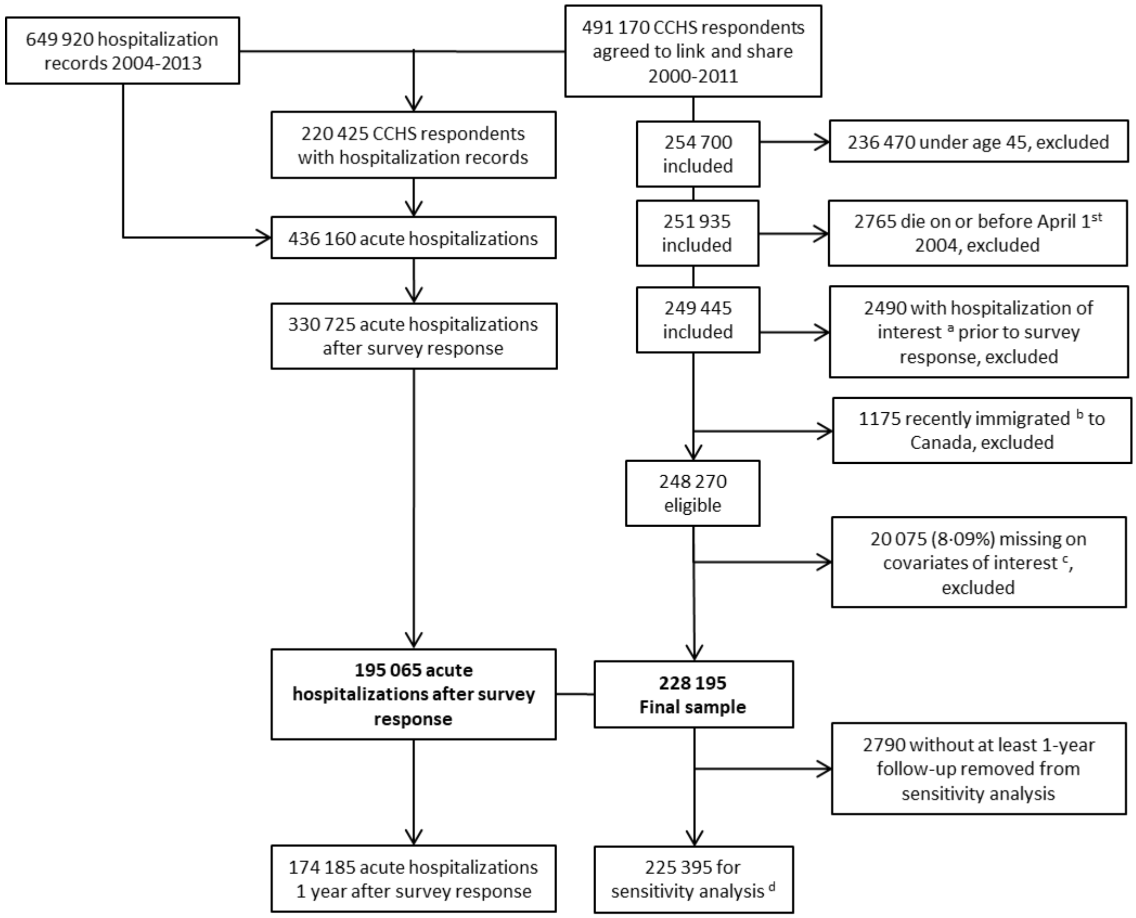

Figure 5.2 Sample selection flowchart.

[a]Hospitalization related to acute myocardial infarction (AMI), congestive heart failure (CHF) or stroke. [b]Immigrated to Canada within 5 years prior to survey response. [c]Missing on education, income, obese, physical activity measures, or neighbourhood measures of the ALE. [d]Hospitalization related to AMI, stroke, or CHF.

Table 5.1 Cohort characteristics for Chapter 5 (N = 228,195).

Active Living Environment (ALE, %)	
1 (lowest)	121,400 (52.23)
2	61,880 (26.67)
3	36,925 (15.92)
4	8,325 (3.59)
5 (highest)	3,475 (1.50)
Mean time under observation (years, SD)	5.37 (3.36)
Median distance from hospital (km, SD)	3.99 (17.41)
Women	129,345 (55.75)
Mean age (SD)	62.79 (11.61)
Average median household income [a]	$ 73,952.30
>1 SD below mean	26,515 (11.43)
Within 1 SD from mean	175,980 (75.85)
>1 SD above mean	29,500 (12.72)
Educational attainment	
Less than secondary	64,795 (27.93)
Secondary graduation only	53,850 (23.21)
Post-secondary degree/diploma	113,355 (48.86)
Smoking status	
Never	67,355 (29.03)
former daily/occasional	118,460 (51.06)
Current	46,185 (19.91)
Walked for leisure in last 3 months	156,370 (67.40)
Performed physical activity in last 3 months	202,000 (87.07)
Obese	68,030 (29.32)
Chronic conditions [b]	108,985 (53.02)

[a] Average median household income is measured at the level of Canadian dissemination areas.
[b] Has two or more chronic conditions.

Split density plots (Figure 5.3) revealed progressively higher mean daily energy expenditure for walking in more favourable ALEs (right-hand areas, black), as well as a lower proportion of the sample that reported performing little or no walking. This is evidenced by incrementally lower areas at the base of each plot with higher ALE class. In contrast, mean daily energy expenditure for overall PA (left-hand areas, grey) did not display similar monotonic increases by ALE favourability.

Overall, 36.7% of the sample were hospitalized during follow-up; 2.6% were hospitalized for AMI, 2.0% for CHF, and 1.5% for stroke. Proportions hospitalized were lower for higher ALEs (e.g., ALE Class 1 vs. 5: all-cause 37.4 vs. 31.2%; AMI 2.7 vs. 2% class 5; CHF 2 vs. 1.3%; Table 5.2). Hospitalization rates and cumulative length of stay days were also lower in more favourable compared to less favourable ALE categories.

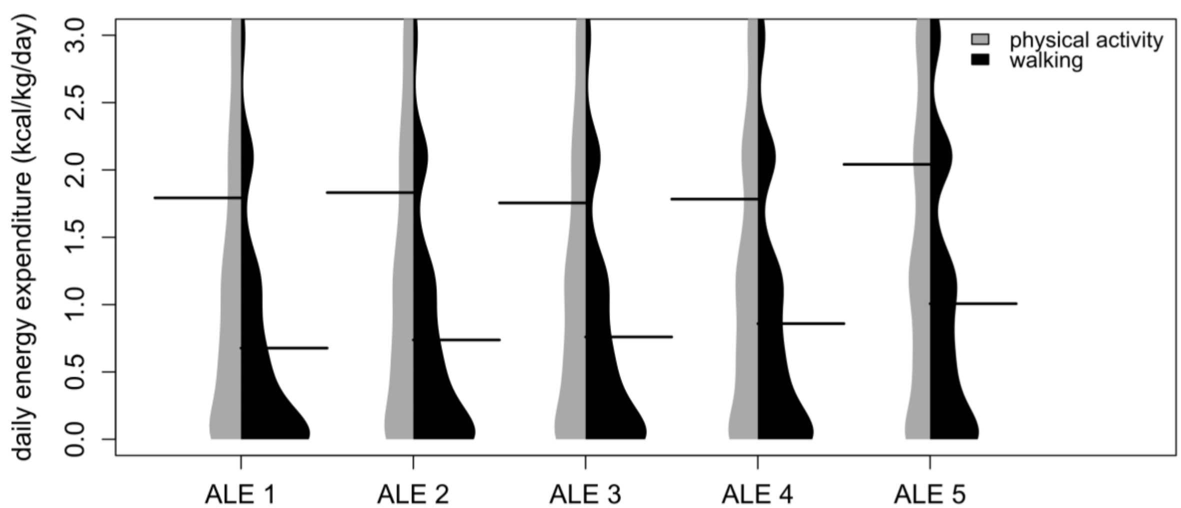

Figure 5.3 Split density plots of walking and physical activity by ALE class.
Split density plots represent the proportion of people in each active living environment (ALE) class reporting different levels of average daily energy expenditures for overall physical activity (gray) and walking (black), from the most unfavourable for active living (ALE 1) to those most favourable for active living (ALE 5). Horizontal lines represent mean average daily energy expenditures for overall physical activity (left pointing) and for walking (right pointing).

After adjusting for individual level factors, living in more favourable ALEs was associated with lower odds of all-cause hospitalization (OR 0.78, 95% CI 0.74 to 0.83, comparing ALE class 4 to ALE class 1) and hospitalization for AMI (OR 0.76, 95% CI 0.65 to 0.91, comparing the second most favourable to least favourable ALEs, Figure 5.4). We also observed a similar but inconclusive trend for CHF (OR 0.74, 95% CI 0.54 to 1.02). Among those hospitalized, living in more favourable ALEs was associated with lower all-cause hospitalization rates (OR 0.87, 95% CI 0.83 to 0.92, comparing ALE class 4 to ALE class 1, (Supplementary Table B.3) and lower all-cause cumulative length of stay for intermediate ALE classes (OR 0.91, 95% CI 0.88 to 0.94, comparing ALE class 3 to ALE class 1, Supplementary Table B.4). However, hospitalization rates and cumulative length of stay for major CVD events did not conclusively vary across ALE classes – although the direction for AMI hospitalization rates were inversely related to higher ALE class. Age, sex, obesity, and the presence of chronic conditions generally predicted elevated CVD-specific and all-cause odds of hospitalization, while education and income were inversely associated with hospitalization (Supplementary Table B.2, Table B.3, Table B.4). Imposing a 1-year washout after survey response and removing those with less than 1 year of follow-up time did not change associations (Supplementary Figure B.1, Figure B.2, Figure B.3).

Approximately 3% of the association of living in a favourable ALE and lower odds of AMI hospitalization was mediated by walking (Table 5.1). For odds of a hospitalization for CHF, 10.66% of the total association of living in a favourable ALE was mediated by walking. There was little evidence of mediation through overall PA for any CVD outcome. Excess relative risks attributable to the pure direct effects of mediation by walking were modest for both AMI (-0.0060, 95% CI -0.0091 to -0.0029) and CHF (-0.0159, 95% CI -0.0203 to -0.0114). Evidence for a mediating role of walking and overall PA for odds of hospitalization for stroke was inconclusive. Since all-cause hospitalization was not a rare outcome, mediation analysis could not be carried out for this variable (VanderWeele, 2014). Imposing a 1-year washout after survey response and removing those with less than 1 year of follow-up time rendered similar results (Supplementary Table B.5).

Table 5.2 Hospitalization trends by Can-ALE class.
(N = 228,195)[1].

	all-cause			AMI			CHF			stroke		
	No. (%)[2]	events/ 1,000 PY	days/ 1,000 PY	No. (%)[2]	events/ 1,000 PY	days/ 1,000 PY	No. (%)[2]	events/ 1,000 PY	days/ 1,000 PY	No. (%)[2]	events/ 1,000 PY	days/ 1,000 PY
ALE												
1	44,685 (37.4)	149.8	1,513.7	3,240 (2.7)	5.2	49.5	2,335 (2.0)	4.9	62.7	1,755 (1.5)	2.7	57.4
2	22,190 (36.5)	139.9	1,443.1	1,525 (2.5)	4.7	45.0	1,215 (2.0)	5.0	60.7	910 (1.5)	2.7	57.9
3	12,885 (35.5)	138.5	1,442.6	880 (2.4)	4.6	44.3	775 (2.1)	5.5	70.5	640 (1.8)	3.3	60.9
4	2,820 (34.4)	131.9	1,494.7	180 (2.2)	4.1	33.2	160 (2.0)	5.3	66.2	130 (1.6)	2.9	66.0
5	1,075 (31.2)	121.8	1,351.4	70 (2.0)	3.8	36.4	45 (1.3)	3.8	48.1	45 (1.3)	2.3	48.8
overall	83,660 (36.7)	144.3	1,480.6	5,890 (2.6)	4.9	46.7	4,535 (2.0)	5.0	63.3	3,480 (1.5)	2.8	58.3

[1] Cause-specific hospitalizations were identified using the primary (most responsible) diagnosis.
[2] Number of people ever-hospitalized.
ALE, active living environment, PY, person-years; AMI, acute myocardial infarction; CHF, congestive heart failure.

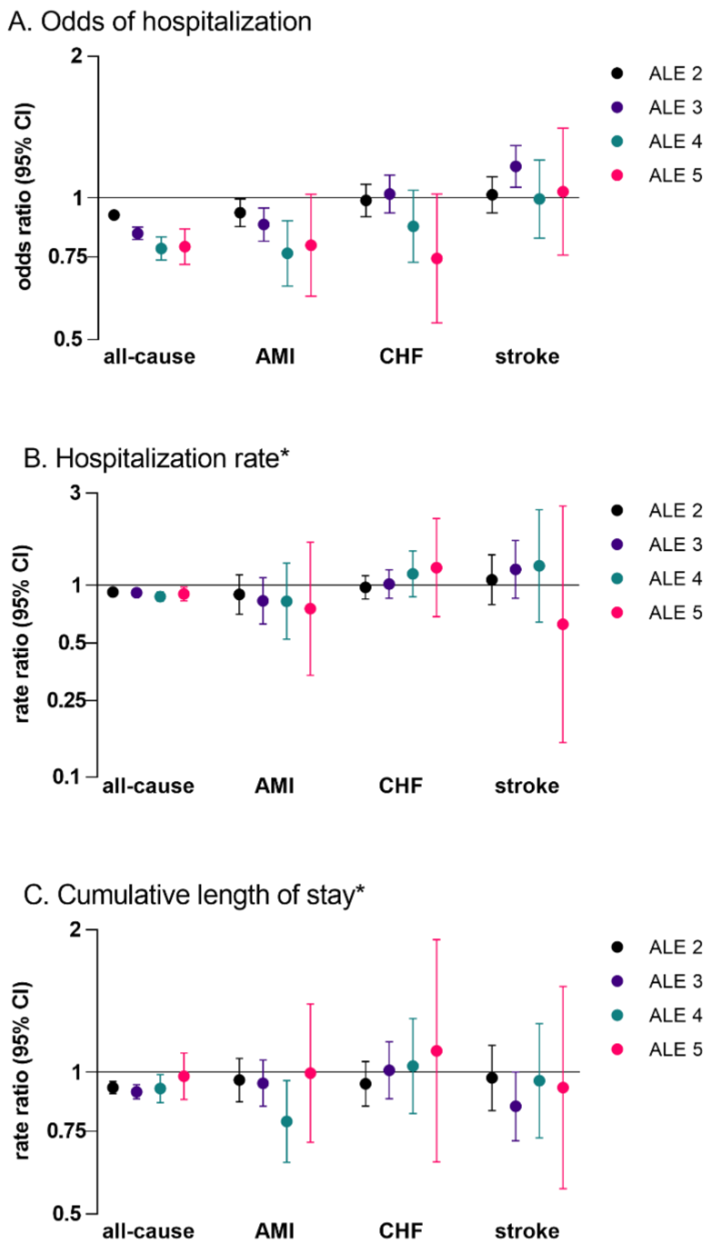

Figure 5.4 Associations between ALEs and hospitalization.

Association between active living environments (ALE) and hospitalization odds (panel A), rate (panel B), and cumulative length of stay (panel C) for all-causes, acute myocardial infarction (AMI), congestive heart failure (CHF) and stroke. Odds of hospitalization was modeled using logistic regression.

*Hospitalization rates and cumulative length of stay were modeled using truncated poisson regression among those ever-hospitalized only (all-cause, N = 83,600; AMI, N = 5,890; CHF, N = 4,535; stroke, N = 3,480). All models were adjusted age, sex, educational attainment, smoking status, obesity, having two or more chronic conditions, survey cycle, living within three kilometers of a hospital, and included an offset variable to account for differences follow-up time across individuals.

Table 5.3 Mediation analysis for the relationship between ALEs, walking or overall physical activity, and major CVD events.

mediator	outcome	Total effect risk ratio (95% CI)	Excess relative risk due to mediation (95% CI)	Effect proportion due to mediation
walking	AMI	0.81 (0.71, 0.92)	-0.0060 (-0.0091, -0.0029)	**0.0322**
overall PA	AMI	0.82 (0.71, 0.93)	-0.0013 (-0.00004, 0.0027)	-0.0073
walking	CHF	0.85 (0.72, 0.98)	-0.0159 (-0.0203, -0.0114)	**0.1066**
overall PA	CHF	0.86 (0.73, 0.99)	0.0035 (0.0001, 0.0070)	-0.0254
walking	stroke	0.95 (0.80, 1.10)	-0.0072 (-0.0112, -0.0032)	0.1315
overall PA	stroke	0.94 (0.79, 1.09)	-0.0013 (-0.00009, 0.0027)	-0.0230

Confidence intervals (95% CI) were calculated using the delta method. Boldface indicates statistical significance ($p \leq 0.05$) for effect proportions due to mediation. Hospitalizations were identified using the primary (most responsible) diagnosis. PA, physical activity, AMI, acute myocardial infarction, CHF, congestive heart failure.

5.6 DISCUSSION

Our results suggest that living in neighbourhoods that are more favourable for active living is associated with lower odds of being hospitalized for overall and specifically for AMI and CHF and may drive lower all-cause hospitalization rates. The distribution of people who reported walking for leisure shifted upwards in favourable ALEs. A small proportion of the inverse association between living in a favourable ALE and hospitalizations for AMI and CHF is mediated through walking. These findings indicate that living in a favourable ALE may reduce hospitalization rate; this is partly but not exclusively related to more walking in these neighbourhoods.

Leveraging this large, linked dataset containing multiple behavioural variables, we were able to assess differences in the distribution of overall PA and walking levels across neighbourhoods by active living-friendliness. Previous studies demonstrate a strong relationship between built environment features and transport walking for Canadian adults (Colley et al., 2019a; Thielman et al., 2015), while the evidence tends to be less clear for similar patterning between ALEs and recreational walking (Farkas et al., 2019), as well as overall PA. In contrast to previous findings, we observed incrementally higher levels of leisure-time walking in more favourable ALEs as well as an upward shift in the proportion of people who reported walking from those who reported no walking. In keeping with previous research, we did not observe monotonic increases by ALE class for overall PA. Our estimates, which ranged from 1.79 to 2.04 kcal/kg/day, were lower in magnitude compared with those reported by Thielman et al. (Thielman et al., 2015), which ranged from 2.52 to 2.23 kcal/kg/day, likely because we excluded younger respondents. Overall, these findings suggest that neighbourhoods conducive to active living may not consistently lead to increased overall PA but could play a role in supporting population-wide leisure-time walking.

Although AMI, CHF, and stroke share many risk factors, the differences in associations with ALE and these three conditions seen in this study implies that built environment interventions may impact certain CVD events more effectively than others. Previous aggregate-level studies showed that a 20-point increase in the proprietary Walk Score® measure was associated with 12.5% fewer hospitalizations per person (Yu et al., 2017), and a 4% reduction in hospitalization odds and frequency of AMI comparing the most to least favourable neighbourhoods (Mazumdar et al., 2016). Our individual-level study shows that living in more favourable ALEs is associated with a reduction in the odds of hospitalization overall and specifically for AMI. The strength and precision of our estimates can be attributed to our large sample size, as well as the specificity of our outcome measures, which contrasts previous approaches that have used broader disease classifications. We specifically examined hospitalizations with ICD codes corresponding to "hard" CVD events that are likely to be driving hospitalization. Moreover, this approach also allowed us to exclude CVDs that have congenital or traumatic aetiologies rather than behavioral causes related to diet or PA.

To our knowledge, there are no other large population-based studies which specifically examine the association between ALEs and CHF or stroke. Prospective studies demonstrate that people who meet minimum recommended PA levels had modest reductions in CHF risk compared with those who far exceed those recommendations (Pandey et al., 2015). In our study, we observed an inconclusive but generally inverse relationship between ALE and odds of CHF hospitalization, which could signal that neighbourhood-induced shifts in the distribution of the sample performing none versus low levels of walking may have some downstream associations with CHF-related hospitalization. However, we found no evidence of protective associations with ALEs for hospitalization frequency or length of stay among those who were hospitalized for CHF at least once. Some posit that the ability of PA to benefit those who already have CHF is likely to depend on exercise type (Haykowsky et al., 2007) and intensity (Arena, Myers, Forman, Lavie, & Guazzi, 2013). This dependence on PA type/intensity, the severity CHF as an end-stage disease, and our null findings related to hospitalization frequency and cumulative length of stay indicate that ALEs are unlikely to reduce hospitalizations for those who already have the CHF.

Associations between ALEs and hospitalization for stroke were inconclusive in this study, yet registry studies in Sweden demonstrate modest reductions in the odds of stroke related to neighbourhood availability of PA facilities that were attenuated or eliminated after adjusting for individual-level factors (Calling, Li, Kawakami, Hamano, & Sundquist, 2016; Hamano, Kawakami, Li, & Sundquist, 2013), while a smaller cross-sectional study from China showed evidence of a protective association between subjective perceptions of the physical activity environment and risk of stroke (Jia et al., 2018). It is well-known that the burden of disease from coronary heart diseases and stroke varies in different countries. The reasons for these differences are not fully understood but may be influenced by variations in underlying risk factors across countries (Kim & Johnston, 2011). These differences may also suggest that, although AMI and stroke share many of the same risk factors, the relative contributions of each risk factor are different between AMI and stroke (Joseph et al., 2017; O'Donnell et al., 2016; Yusuf et al., 2004). Previous studies have also demonstrated that the protective associations between physical activity and risk of stroke are present but tend to be weaker and less consistent than AMI (Li & Siegrist, 2012). While we cannot fully explain absence of an association between favourable ALEs and stroke, it is possible, in the context of the Canadian population, that the physical activity gained from living in a favourable ALE may not be of a sufficient level or intensity to achieve appreciable reductions in stroke incidence.

To our knowledge, this study constitutes the largest sample on which a formal mediation analysis of the relationship between ALEs, walking, and health outcomes has been performed. Previous investigations of the mediating effect of physical activity on the relationship between ALEs, obesity (Van Cauwenberg, Van Holle, De Bourdeaudhuij, Van Dyck, & Deforche, 2016), and cardiovascular health (Chandrabose, Cerin, et al., 2019) have produced a wide range of results. A Canadian study (Hajna et al., 2018) found little evidence to suggest a mediating role for moderate-to-vigorous physical activity or daily step counts in models of ALE and cardiometabolic risk factors, while another (Colley et al., 2019b) detected a significant mediating effect of moderate-to-vigorous physical activity of the association between ALE and obesity, but not for leisure time physical activity or step counts. Our results do indicate that a small but conclusive proportion (3.22%) of the relationship between ALE and odds of hospitalization for AMI and a larger but inconclusive proportion (10.66%) of the relationship between ALE and odds of hospitalization for CHF could specifically be mediated through walking. That a relatively small proportion of the relationship between ALEs and hospitalization for major CVD events is explained by leisure-time walking suggests that the benefit of favourable ALEs could be attained through non leisure activities and activities other than leisure-time walking that are not captured in our dataset.

Our study bears limitations. First, our findings are based on observational retrospective data, which is prone to bias and unmeasured confounding. However, we adjusted for a variety of individual-level sociodemographic and behavioural variables with known associations to CVD. Second, both environmental and behavioural factors were available for a single time-point at baseline, which did not allow us to account for changes in ALE, residential moves, or behavioural modifications over time. To mitigate this limitation, we tested a one-year washout period and found little change in the resulting estimates. We also note that features of the built environment such as street connectivity tend to be enduring features of the urban landscape (Barrington-Leigh & Millard-Ball, 2017) and are unlikely to change over a study period such as ours. Third, the hospitalization dataset available for this study was composed of inpatient acute hospitalizations, and did not capture primary care, outpatient care, or emergency department visits which constitute a substantial proportion of health care burden in Canada (Canadian Institute for Health Information, 2012e). Moreover, these data are unable to address the degree to which ALE may prevent indirect health costs (lost or reduced economic productivity, premature retirement or death) incurred for those living with CVD. However, we note that acute hospitalizations account for the majority of direct health costs associated with CVDs like AMI (Tran, Ohinmaa, Thanh, Welsh, & Kaul, 2018) and are an important indicator of disease morbidity. Finally, we note that this study is not nationally representative, as we did not have hospitalization data from the province of Quebec which represents nearly a quarter of the Canadian population.

Reducing the burden of CVD and associated health care costs is a challenge for aging populations who are also becoming increasingly physically inactive. Our large individual-level observational study suggests that neighbourhoods built for active living might trigger higher levels of walking and could in turn prevent hospitalization related to certain CVD events. Our study also highlights the potential importance of walking for CVD prevention (Zheng et al., 2009). Living in more favourable ALEs was associated with as much as a 24% reduction in the odds of an AMI-related hospitalization and a 22% reduction in the odds of hospitalization for any cause, relative to the least favourable neighbourhoods. While inconclusive, more favourable ALEs may also result in reductions in the odds of hospitalization for CHF. These reductions should be placed in the context of those seen for intensive lifestyle intervention programs (Ma et al., 2017) and pharmacological approaches (Law, Morris, & Wald, 2009), and speaks to the policy potential of ALE as a meaningful instrument for policy and population health.

5.7 REFERENCES

Arena, R., Myers, J., Forman, D. E., Lavie, C. J., & Guazzi, M. (2013). Should high-intensity-aerobic interval training become the clinical standard in heart failure? *Heart Failure Reviews, 18*(1), 95-105. doi:10.1007/s10741-012-9333-z

Barrington-Leigh, C., & Millard-Ball, A. (2017). The world's user-generated road map is more than 80% complete. *PloS One, 12*(8), e0180698. doi:10.1371/journal.pone.0180698

Braun, L. M., Rodriguez, D. A., Evenson, K. R., Hirsch, J. A., Moore, K. A., & Diez Roux, A. V. (2016). Walkability and cardiometabolic risk factors: Cross-sectional and longitudinal associations from the Multi-Ethnic Study of Atherosclerosis. *Health Place, 39*, 9-17. doi:10.1016/j.healthplace.2016.02.006

Calling, S., Li, X., Kawakami, N., Hamano, T., & Sundquist, K. (2016). Impact of neighborhood resources on cardiovascular disease: a nationwide six-year follow-up. *BMC Public Health, 16*, 634. doi:10.1186/s12889-016-3293-5

Canadian Institute for Health Information. (2012). Hospital Cost Drivers Technical Report. In: CIHI Ottawa, Canada.

Canadian Institute for Health Information. (2020). Health Indicators: What’s the difference between metrics, indicators and performance indicators? Retrieved from https://www.cihi.ca/en/health-indicators

Canadian Institute of Health Information. (2018). *Inpatient hospitalization, surgery, newborn, alternate level of care and childbirth statistics, 2017-2018.* Retrieved from https://www.cihi.ca/sites/default/files/document/dad-hmdb-childbirth-quick-stats-2017-2018-snapshot-en-web.pdf

Chandrabose, M., Cerin, E., Mavoa, S., Dunstan, D., Carver, A., Turrell, G., Owen, N., Giles-Corti, B., & Sugiyama, T. (2019). Neighborhood walkability and 12-year changes in cardio-metabolic risk: the mediating role of physical activity. *Int J Behav Nutr Phys Act, 16*(1), 86. doi:10.1186/s12966-019-0849-7

Colley, R. C., Christidis, T., Michaud, I., Tjepkema, M., & Ross, N. A. (2019a). The association between walkable neighbourhoods and physical activity across the lifespan. *Health Reports, 30*(9), 3-13. doi:10.25318/82-003-x201900900001-eng

Colley, R. C., Christidis, T., Michaud, I., Tjepkema, M., & Ross, N. A. (2019b). An examination of the associations between walkable neighbourhoods and obesity and self-rated health in Canadians. *Health Reports, 30*(9), 14-24. doi:10.25318/82-003-x201900900002-eng

Discacciati, A., Bellavia, A., Lee, J. J., Mazumdar, M., & Valeri, L. (2018). Med4way: a Stata command to investigate mediating and interactive mechanisms using the four-way effect decomposition. *Int J Epidemiol*. doi:10.1093/ije/dyy236

Farkas, B., Wagner, D. J., Nettel-Aguirre, A., Friedenreich, C., & McCormack, G. R. (2019). A systematized literature review on the associations between neighbourhood built characteristics and walking among Canadian adults. *Health Promotion and Chronic Disease Prevention in Canada-Research Policy and Practice, 39*(1), 1-14. doi:10.24095/hpcdp.39.1.01

Hajna, S., Dasgupta, K., & Ross, N. A. (2018). Laboratory-Assessed Markers of Cardiometabolic Health and Associations with GIS-Based Measures of Active-Living Environments. *International Journal of Environmental Research and Public Health, 15*(10). doi:10.3390/ijerph15102079

Hajna, S., Ross, N. A., Joseph, L., Harper, S., & Dasgupta, K. (2016). Neighbourhood Walkability and Daily Steps in Adults with Type 2 Diabetes. *PloS One, 11*(3), e0151544. doi:10.1371/journal.pone.0151544

Hamano, T., Kawakami, N., Li, X., & Sundquist, K. (2013). Neighbourhood environment and stroke: a follow-up study in Sweden. *PloS One, 8*(2), e56680. doi:10.1371/journal.pone.0056680

Haykowsky, M. J., Liang, Y., Pechter, D., Jones, L. W., McAlister, F. A., & Clark, A. M. (2007). A meta-analysis of the effect of exercise training on left ventricular remodeling in heart failure patients: the benefit depends on the type of training performed. *Journal of the American College of Cardiology, 49*(24), 2329-2336. doi:10.1016/j.jacc.2007.02.055

Herrmann, T., Gleckner, W., Wasfi, R. A., Thierry, B., Kestens, Y., & Ross, N. A. (2019). A pan-Canadian measure of active living environments using open data. *Health Reports, 30*(5), 16-25.

Howell, N. A., Tu, J. V., Moineddin, R., Chu, A., & Booth, G. L. (2019). Association Between Neighborhood Walkability and Predicted 10-Year Cardiovascular Disease Risk: The CANHEART (Cardiovascular Health in Ambulatory Care Research Team) Cohort. *Journal of the American Heart Association, 8*(21), e013146. doi:10.1161/JAHA.119.013146

Huai, P., Xun, H., Reilly, K. H., Wang, Y., Ma, W., & Xi, B. (2013). Physical activity and risk of hypertension: a meta-analysis of prospective cohort studies. *Hypertension, 62*(6), 1021-1026. doi:10.1161/HYPERTENSIONAHA.113.01965

Janssen, I. (2012). Health care costs of physical inactivity in Canadian adults. *Applied Physiology Nutrition and Metabolism-Physiologie Appliquee Nutrition Et Metabolisme, 37*(4), 803-806. doi:10.1139/h2012-061

Jia, X., Yu, Y., Xia, W., Masri, S., Sami, M., Hu, Z., Yu, Z., & Wu, J. (2018). Cardiovascular diseases in middle aged and older adults in China: the joint effects and mediation of different types of physical exercise and neighborhood greenness and walkability. *Environ Res, 167*, 175-183. doi:10.1016/j.envres.2018.07.003

Joseph, P., Leong, D., McKee, M., Anand, S. S., Schwalm, J. D., Teo, K., Mente, A., & Yusuf, S. (2017). Reducing the Global Burden of Cardiovascular Disease, Part 1: The Epidemiology and Risk Factors. *Circ Res, 121*(6), 677-694. doi:10.1161/CIRCRESAHA.117.308903

Kampstra, P. (2008). Beanplot: A boxplot alternative for visual comparison of distributions. *Journal of statistical software, 28*(1), 1-9.

Kim, A. S., & Johnston, S. C. (2011). Global variation in the relative burden of stroke and ischemic heart disease. *Circulation, 124*(3), 314-323. doi:10.1161/CIRCULATIONAHA.111.018820

Kyu, H. H., Bachman, V. F., Alexander, L. T., Mumford, J. E., Afshin, A., Estep, K., Veerman, J. L., Delwiche, K., Iannarone, M. L., Moyer, M. L., Cercy, K., Vos, T., Murray, C. J., & Forouzanfar, M. H. (2016). Physical activity and risk of breast cancer, colon cancer, diabetes, ischemic heart disease, and ischemic stroke events: systematic review and dose-response meta-analysis for the Global Burden of Disease Study 2013. *BMJ, 354*, i3857. doi:10.1136/bmj.i3857

Law, M. R., Morris, J. K., & Wald, N. J. (2009). Use of blood pressure lowering drugs in the prevention of cardiovascular disease: meta-analysis of 147 randomised trials in the context of expectations from prospective epidemiological studies. *BMJ, 338*, b1665. doi:10.1136/bmj.b1665

Li, J., & Siegrist, J. (2012). Physical activity and risk of cardiovascular disease--a meta-analysis of prospective cohort studies. *Int J Environ Res Public Health, 9*(2), 391-407. doi:10.3390/ijerph9020391

Lohr, K. N., & Steinwachs, D. M. (2002). Health services research: an evolving definition of the field. *Health Services Research, 37*(1), 7-9. doi:10.1111/1475-6773.01020

Ma, C., Avenell, A., Bolland, M., Hudson, J., Stewart, F., Robertson, C., Sharma, P., Fraser, C., & MacLennan, G. (2017). Effects of weight loss interventions for adults who are obese on mortality, cardiovascular disease, and cancer: systematic review and meta-analysis. *BMJ, 359*, j4849. doi:10.1136/bmj.j4849

Mazumdar, S., Learnihan, V., Cochrane, T., Phung, H., O'Connor, B., & Davey, R. (2016). Is Walk Score associated with hospital admissions from chronic diseases? Evidence from a cross-sectional study in a high socioeconomic status Australian city-state. *Bmj Open, 6*(12), e012548. doi:10.1136/bmjopen-2016-012548

Nayor, M., & Vasan, R. S. (2015). Preventing heart failure: the role of physical activity. *Current Opinion in Cardiology, 30*(5), 543-550. doi:10.1097/HCO.0000000000000206

O'Donnell, M. J., Chin, S. L., Rangarajan, S., Xavier, D., Liu, L., Zhang, H., Rao-Melacini, P., Zhang, X., Pais, P., Agapay, S., Lopez-Jaramillo, P., Damasceno, A., Langhorne, P., McQueen, M. J., Rosengren, A., Dehghan, M., Hankey, G. J., Dans, A. L., Elsayed, A., Avezum, A., Mondo, C., Diener, H. C., Ryglewicz, D., Czlonkowska, A., Pogosova, N., Weimar, C., Iqbal, R., Diaz, R., Yusoff, K., Yusufali, A., Oguz, A., Wang, X., Penaherrera, E., Lanas, F., Ogah, O. S., Ogunniyi, A., Iversen, H. K., Malaga, G., Rumboldt, Z., Oveisgharan, S., Al Hussain, F., Magazi, D., Nilanont, Y., Ferguson, J., Pare, G., Yusuf, S., & investigators, I. (2016). Global and regional effects of potentially modifiable risk factors associated with acute stroke in 32 countries (INTERSTROKE): a case-control study. *Lancet, 388*(10046), 761-775. doi:10.1016/S0140-6736(16)30506-2

OpenStreetMap Contributors. (2017). OpenStreetMap Base Data. Retrieved from https://www.OpenStreetMap.org

Pandey, A., Garg, S., Khunger, M., Darden, D., Ayers, C., Kumbhani, D. J., Mayo, H. G., de Lemos, J. A., & Berry, J. D. (2015). Dose-Response Relationship Between Physical Activity and Risk of Heart Failure: A Meta-Analysis. *Circulation, 132*(19), 1786-1794. doi:10.1161/CIRCULATIONAHA.115.015853

Sanmartin, C., Decady, Y., Trudeau, R., Dasylva, A., Tjepkema, M., Fines, P., Burnett, R., Ross, N., & Manuel, D. G. (2016). Linking the Canadian Community Health Survey and the Canadian Mortality Database: An enhanced data source for the study of mortality. *Health Reports, 27*(12), 10-18.

Statistics Canada. (2011a). Canadian Community Health Survey—Annual Component. User Guide 2010 and 2009/2010 Microdata Files. Retrieved from http://www23.statcan.gc.ca/imdb-bmdi/document/3226_D7_T9_V8-eng.pdf

Statistics Canada. (2011b). *Canadian Community Health Survey (CCHS) Annual Component, 2009-2010 Common Content: Derived Variable (DV) Specifications*. Retrieved from Ottawa:

Statistics Canada. (2020a). Table 13-10-0337-01 (formerly CANSIM 117-0019) – Distribution of the household population meeting/not meeting the Canadian physical activity guidelines. (Publication no. 10.25318/1310033701-eng). Retrieved April 23, 2020

Statistics Canada. (2020b). Table 13-10-0451-01 - Health indicators, annual estimates, 2003 - 2014 (Publication no. 10.25318/1310045101-eng). Retrieved April 23, 2020

Tarride, J. E., Lim, M., DesMeules, M., Luo, W., Burke, N., O'Reilly, D., Bowen, J., & Goeree, R. (2009). A review of the cost of cardiovascular disease. *Canadian Journal of Cardiology, 25*(6), e195-202. doi:10.1016/s0828-282x(09)70098-4

Thielman, J., Rosella, L., Copes, R., Lebenbaum, M., & Manson, H. (2015). Neighborhood walkability: Differential associations with self-reported transport walking and leisure-time physical activity in Canadian towns and cities of all sizes. *Preventive Medicine, 77*, 174-180. doi:10.1016/j.ypmed.2015.05.011

Tran, D. T., Ohinmaa, A., Thanh, N. X., Welsh, R. C., & Kaul, P. (2018). The Healthcare Cost Burden of Acute Myocardial Infarction in Alberta, Canada. *PharmacoEconomics - Open, 2*(4), 433-442. doi:10.1007/s41669-017-0061-0

Tu, J. V., Chu, A. N., Donovan, L. R., Ko, D. T., Booth, G. L., Tu, K. R., Maclagan, L. C., Guo, H. L., Austin, P. C., Hogg, W., Kapral, M. K., Wijeysundera, H. C., Atzema, C. L., Gershon, A. S., Alter, D. A., Lee, D. S., Jackevicius, C. A., Bhatia, R. S., Udell, J. A., Rezai, M. R., & Stukel, T. A. (2015). The Cardiovascular Health in Ambulatory Care Research Team (CANHEART) Using Big Data to Measure and Improve Cardiovascular Health and Healthcare Services. *Circulation: Cardiovascular Quality and Outcomes, 8*(2), 204-+. doi:10.1161/Circoutcomes.114.001416

Van Cauwenberg, J., Van Holle, V., De Bourdeaudhuij, I., Van Dyck, D., & Deforche, B. (2016). Neighborhood walkability and health outcomes among older adults: The mediating role of physical activity. *Health Place, 37*, 16-25. doi:10.1016/j.healthplace.2015.11.003

VanderWeele, T. J. (2014). A unification of mediation and interaction: a 4-way decomposition. *Epidemiology, 25*(5), 749-761. doi:10.1097/EDE.0000000000000121

Wilkins, R., & Peters, P. (2012). *PCCF + Version 5K* User's Guide. Automated geographic coding based on the Statistics Canada Postal Code Conversion Files including Postal Codes through May 2011*. Retrieved from Ottawa, ON, Canada:

Woolcott, J. C., Ashe, M. C., Miller, W. C., Shi, P., Marra, C. A., & Team, P. R. (2010). Does physical activity reduce seniors' need for healthcare?: a study of 24 281 Canadians. *British Journal of Sports Medicine, 44*(12), 902-904. doi:10.1136/bjsm.2008.057216

Yu, Y., Davey, R., Cochrane, T., Learnihan, V., Hanigan, I. C., & Bagheri, N. (2017). Neighborhood walkability and hospital treatment costs: A first assessment. *Preventive Medicine, 99*, 134-139. doi:10.1016/j.ypmed.2017.02.008

Yusuf, S., Hawken, S., Ounpuu, S., Dans, T., Avezum, A., Lanas, F., McQueen, M., Budaj, A., Pais, P., Varigos, J., Lisheng, L., & Investigators, I. S. (2004). Effect of potentially modifiable risk factors associated with myocardial infarction in 52 countries (the INTERHEART study): case-control study. *Lancet, 364*(9438), 937-952. doi:10.1016/S0140-6736(04)17018-9

Zheng, H., Orsini, N., Amin, J., Wolk, A., Nguyen, V. T., & Ehrlich, F. (2009). Quantifying the dose-response of walking in reducing coronary heart disease risk: meta-analysis. *European Journal of Epidemiology, 24*(4), 181-192. doi:10.1007/s10654-009-9328-9

Chapter 6

DOES LIVING NEAR HOSPITAL OBSCURE THE ASSOCIATION BETWEEN FAVOURABLE ACTIVE LIVING ENVIRONMENTS AND LOWER HOSPITALIZATION?

6.1 PREAMBLE

Our findings from Chapter 5 indicate that living in favourable ALEs is associated with reductions in the odds of hospitalization for all-causes and major cardiovascular events. However, favourable ALEs tend to have more places of interest, and we might expect that health care facilities are among these places. This presents a problem: living close to a hospital would theoretically increase access and potentially, hospital utilization by virtue of proximity. The relationship between living close to hospital and higher hospital use has been shown previously (Goodman et al., 1997; Lin et al., 2002; Rudge et al., 2013).

Although hospital distance is accounted for in Chapter 5, I wanted to determine the distances from hospital that made the most impact on associations between ALE and odds of hospitalization for cardiometabolic diseases, and what the extent of this impact would be. This chapter is consistent with the main purpose of this dissertation and contributes to the second objective of thesis of examining population-level associations between ALEs, physical activity, and hospitalization. While the major focus of this dissertation is on the geographies of disease and ill-health, this chapter is also intended to address the spatial patterning of health care provision – another key vein of health geography.

This manuscript is intended for submission as a short communication to *Health & Place.*

6.2 ABSTRACT

Hospitals tend to be among the destinations that make densely populated, well-connected neighbourhoods more conducive to active living. We determine whether living near a hospital distorts the association between living in favourable ALEs and hospitalization for cardiometabolic diseases. We used a record linkage of 442,345 respondents of the Canadian Community Health Survey with their hospitalization records for cardiometabolic disease. We then assessed respondents' neighbourhoods using the Canadian Active Living Environments measure (Can-ALE), a measure based on ≥3-way intersection density, residential density, and points of interest. We then calculated the distance in kilometers between the centroids of respondents' assigned dissemination areas and the nearest user-contributed location for hospitals from OpenStreetMap. We monitored changes in estimates for the association between ALEs and odds cardiometabolic hospitalization using a series of logistic regressions with indicator variables for distances to hospital of 500 meters to 10 kilometers. We found that living between 500 meters and six kilometers of a hospital and was associated with modestly higher odds of cardiometabolic hospitalization (OR 1.10, 95% CI 1.02 to 1.18 for 500 meters; OR 1.05, 95% CI 1.01 to 1.09 for six kilometers). Living in more favourable ALEs was associated with lower odds of hospitalization (OR 0.79, 95% CI 0.68 to 0.91; comparing the most favourable to least favourable ALEs). Effect estimates between more favourable ALEs and lower odds of hospitalization were marginally strengthened when living within 2-6 kilometers to a hospital was accounted for. This study demonstrates the importance of disentangling interrelated geographic factors and underlines the potential for built environments to elicit reductions in health care.

6.3 INTRODUCTION

Canada is among the highest health care spenders in the Organisation for Economic Co-operation and Development (OECD). The country has spent 8.8% of its annual GDP on healthcare in recent years (Canadian Institute for Health Information, 2019), and a growing proportion of costs were related to chronic conditions attributable to physical inactivity (Janssen, 2012; Katzmarzyk et al., 2000). There is public health interest in the neighbourhood's ability to promote healthy lifestyles and active living (Tam, 2017) and in turn, minimize physical inactivity-related illnesses and health care utilization. Neighbourhoods that are favourable for active living (also known as *walkability)* have been associated with higher rates of certain forms of physical activity, lower obesity (Colley et al., 2019b), lower type 2 diabetes incidence (Creatore et al., 2016; Sundquist et al., 2015), and could be a cost-neutral way to achieve population-wide reductions in hospital burden (Mazumdar et al., 2016; Yu et al., 2017).

ALEs are characterized as being highly connected, densely populated, and tend to be places that have a greater number and variety of destinations to walk to, such as parks, schools, shops, services and landmarks. However, hospitals and health care institutions tend to be among these destinations. Living within close proximity to health care is associated with higher utilization in Canada (Lin et al., 2002) and elsewhere (Goodman et al., 1997; Rudge et al., 2013) and could obscure the protective association between ALEs and hospital burden (Figure 6.1). The extent to which living near hospital distorts the protective relationship between favourable neighbourhoods and lower hospital burden is unknown.

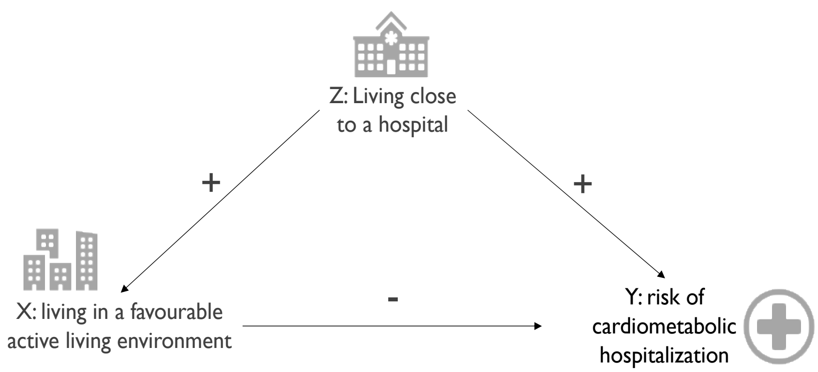

Figure 6.1 Conceptual diagram for ALEs and living close to hospital.
Living nearby a hospital tends to be positively associated with living in a neighbourhood favourable for active living (typically more densely populated, more highly connected, and contains more destinations), and also tends to be positively associated with higher hospital utilization and could mask the inverse association between ALEs and cardiometabolic-related hospitalizations.

In this study, we determined whether living near a hospital impacts the association between living in a favourable ALE and reduced odds of being hospitalized for cardiometabolic disease. First, we conducted a sensitivity test of the association between living within different proximities to a hospital and increased odds of cardiometabolic hospitalization. After identifying the distance associated with the greatest increase odds of hospitalization, we determine whether including this distance as a covariate impacts estimates for the association between the ALE and odds of hospitalization.

6.4 METHODS

STUDY SAMPLE

We accessed a sample of nearly half a million respondents from multiple waves of the Canadian Community Health Survey (CCHS, 2000-2011) who were over the age of 19 years, had not immigrated to Canada within 5 years of survey response, and were not missing data on key variables of interest. These individuals were linked to their records in the Discharge Abstract Database (DAD, 2000-2013), a census of all acute hospitalizations in Canada, as well as their death records in the Canadian Mortality Database (CMDB). We note that the sample excludes respondents from the province of Quebec, which does not currently submit acute care data to the DAD. We defined the study period as beginning on 1 April 2004 or the date of CCHS survey response (if after 1 April 2004) and ending on the date of death in the CMDB or the last day of the fiscal year for the DAD (31 March 2013). DAD years 2000-2003 were used to identify and exclude respondents with pre-existing cardiometabolic disease. Residential locations were determined using respondents' postal codes and Statistics Canada's Postal Code Conversion File Plus (PCCF+), which assigns spatial coordinates based on population-weighted random allocation (Wilkins & Peters, 2012). In a Geographic Information System (ArcGIS 10.5, ESRI), we performed an intersection with the spatial coordinates to assign each respondent their residential location at the level of the 2016 dissemination area, the smallest geographic units (corresponding to 400-700 persons) for which complete census data is released.

CANADIAN ACTIVE LIVING ENVIRONMENT (CAN-ALE) MEASURE

The Canadian Active Living Environments Database (Can-ALE) are a set of measures for Canadian communities derived entirely from open-source data that has been described previously (Herrmann et al., 2019). In short, Can-ALE is composed of street connectivity, dwelling density, and points of interest. First, 1,000-meter circular (Euclidean) buffers were drawn around the centroids of 2016 dissemination areas. Next, we took intersection density as a measure of street connectivity and calculated the number ≥3-way intersections within these buffers using OpenStreetMap road and footpath features that were present in in 2016. Dwelling density was obtained from the 2016 Canadian census, and 2016 points of interest from OpenStreetMap (OSM) were counted in each buffer. Last, raw scores for the three components were k-medians clustered into five categories, representing neighbourhoods that are the most conducive to active living (ALE class 5) and the least conducive to active living (ALE class 1).

Hospital proximity measure

We identified 1337 in-patient care facilities using user-contributed locations from OpenStreetMap that were tagged "amenity = hospital" (OpenStreetMap Contributors, 2017), and manually reviewed these locations to confirm that major acute care hospitals were captured in these data. We saw little evidence of misclassification of outpatient clinics into this dataset. We calculated the distance in kilometers between the centroids of respondents' assigned dissemination areas and the nearest inpatient care facility using ArcGIS's Near Proximity Tool (ArcGIS 10.5, ESRI).

Hospitalization

Hospital admissions in the DAD were included if they occurred after date of survey response in the CCHS to better ensure exposure status of respondents regarding the ALE and their proximity to hospital. Hospitalizations related to cardiometabolic disease were included in the outcome of interest due to their established links with physical activity and ALEs (Chandrabose, Rachele, et al., 2019). We identified hospital admissions related to cardiometabolic diseases using the 10th revision of the International Statistical Classification of Diseases and Related Health Problems (ICD-10) codes. Respondents with admissions that a) occurred after survey response, and b) bore codes for ischaemic heart disease (I20-I25), hypertension (I10-I15), cerebrovascular disease (I61-69), diabetes (E11-14), and/or heart failure (I50) considered the most responsible diagnosis were counted as having had a cardiometabolic admission during the study period.

Statistical analysis

We first examined associations between living different distances (500 meters to 10 kilometers) from hospital and the odds of cardiometabolic hospitalization using a series of logistic regressions with indicator variables for hospital distances. To assess whether and to what extent living near a hospital distorts the protective effect of living in neighbourhoods that are conducive to active living, we assessed change in estimate for associations of the ALE and cardiometabolic hospitalization. A time offset was included to account for different times under observation. All models were adjusted for sex, age, survey cycle, educational attainment (less than secondary, secondary school graduation, post-graduate degree/diploma), smoking status (never, former, current), obesity – comprised of an indicator for age and sex-corrected body mass index of 30 or higher (Connor Gorber et al., 2008), and included a quadratic term for age. Since younger respondents will not have reached full educational attainment, we also conducted a sensitivity analysis and excluded those aged 25 years and younger from the sample. Significance was evaluated at α = 0.05 for all models. Statistical analyses were carried out using Stata version 16.

6.5 RESULTS

Choropleth maps of derived measures of hospital proximity for all of Canada's dissemination areas revealed that neighbourhoods that are geographically close to hospitals overlap considerably with being favourable for active living, as illustrated for two major Canadian cities (Figure 6.2).

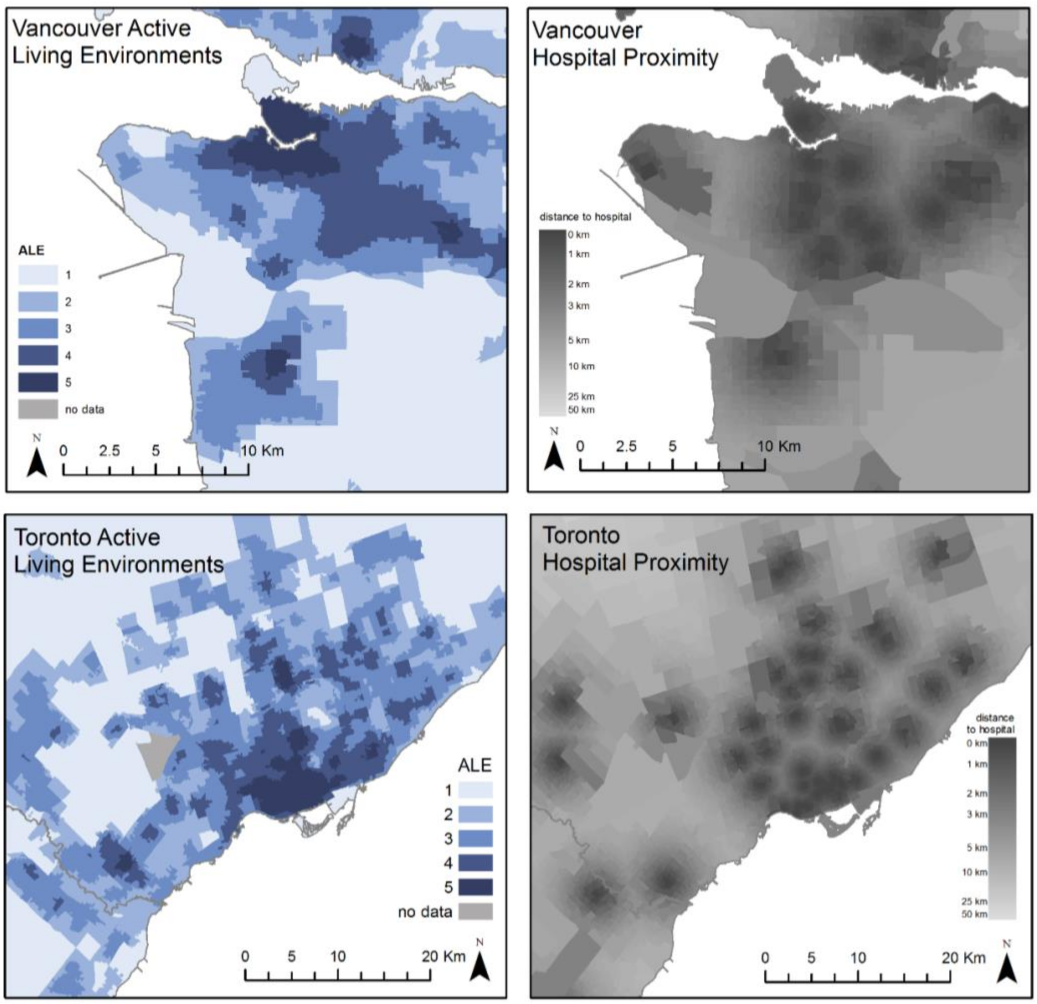

Figure 6.2 Choropleth maps of ALEs and hospital proximity.
Maps of two major cities in Canada (which are covered in our linked dataset) illustrate that neighbourhoods that are more favourable (ALE class 5, most favourable; ALE class 1, least favourable) for active living tend to overlap with those highly proximal to hospital. ALE, active living environment; km, kilometer.

After removing 2,900 respondents who died before the study period, 5,325 respondents who experienced the outcome of interest before baseline, 8,615 respondents who immigrated to Canada within 5 years of baseline, 474,300 respondents remained. Complete case analysis was possible for 93% of the remaining sample, which resulted in a final sample of 442,345 survey respondents (Figure 6.3, Supplementary Table C.1).

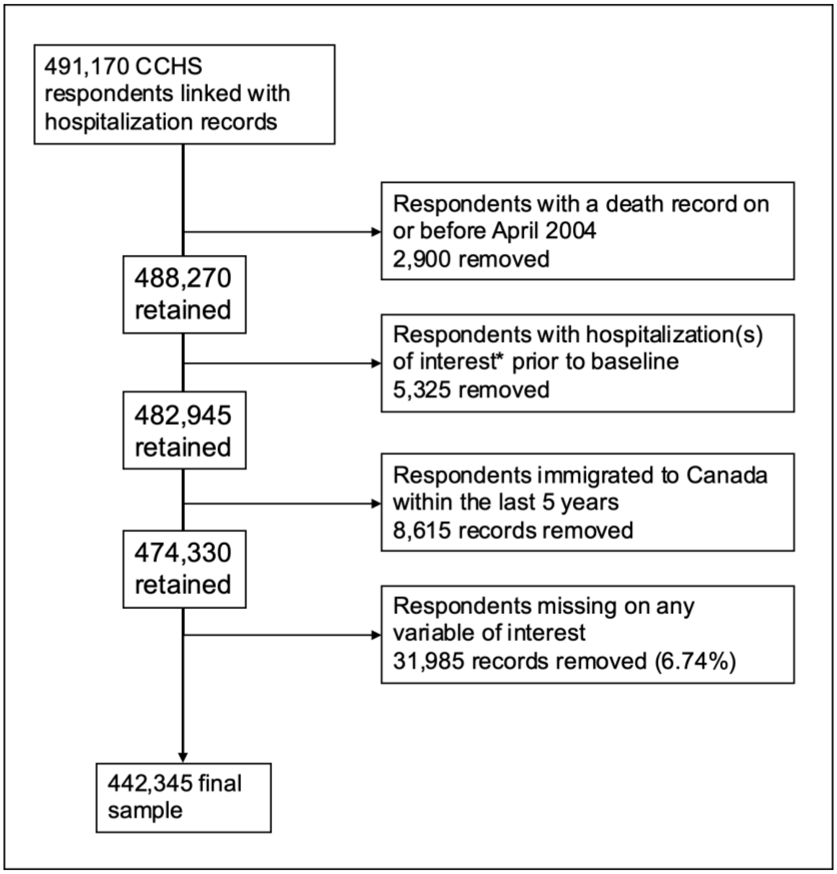

Figure 6.3 Sample selection flowchart.
(N = 442,345). *Respondents who were hospitalized for ischaemic heart disease, hypertension, cerebrovascular disease, diabetes, and/or heart failure prior to survey response were removed from the sample.

A small proportion of respondents lived in the most favourable neighbourhoods for active living (1.59%, Table 6.1), and the median distance to the nearest hospital was 3.94 kilometers. On average, groups living farthest away from hospital were those middle-aged adults 45-64 years old, those without secondary graduation, and those considered obese.

Table 6.1 Cohort characteristics for Chapter 6 (N = 442,345).

	N (%) [a]	Median distance from hospital (km, SD)
Overall	442,345	3.94 (18.55)
ALE		
1 (lowest)	221,115 (49.99)	10.40 (23.61)
2	123,020 (27.81)	2.77 (9.62)
3	74,565 (16.86)	2.35 (3.12)
4	16,605 (3.75)	1.58 (1.19)
5 (highest)	7,040 (1.59)	0.99 (0.74)
Sex		
Women	236,385 (53.44)	3.81 (18.03)
Men	205,965 (46.56)	4.08 (19.12)
Mean age (years, SD) [b]	46.27 (20.25)	
<25	80,405 (18.18)	4.00 (19.58)
25-44	1306,45 (29.53)	3.79 (19.75)
45-64	136,610 (30.88)	4.27 (18.51)
65+	94,685 (21.41)	3.66 (15.75)
Education		
Less than secondary	123,170 (27.84)	4.49 (21.38)
Secondary graduation	110,500 (24.98)	3.82 (17.08)
Post-graduate degree/diploma	208,680 (47.18)	3.76 (17.39)
Smoking status		
Never	161,000 (36.4)	3.94 (16.69)
Former	178,550 (40.36)	4.10 (17.69)
Current	102,800 (23.24)	3.68 (22.34)
Obese		
No	333,160 (75.32)	3.86 (18.24)
Yes	109,185 (24.68)	4.25 (19.43)

[a] Sample size and proportion (%), unless otherwise indicated.
[b] Age at survey response.
km, kilometers; SD, standard deviation

Most of the survey sample lived within 10 kilometers of a hospital (71.89%) and half lived within 4 kilometers (50.52%; Figure 6.4).

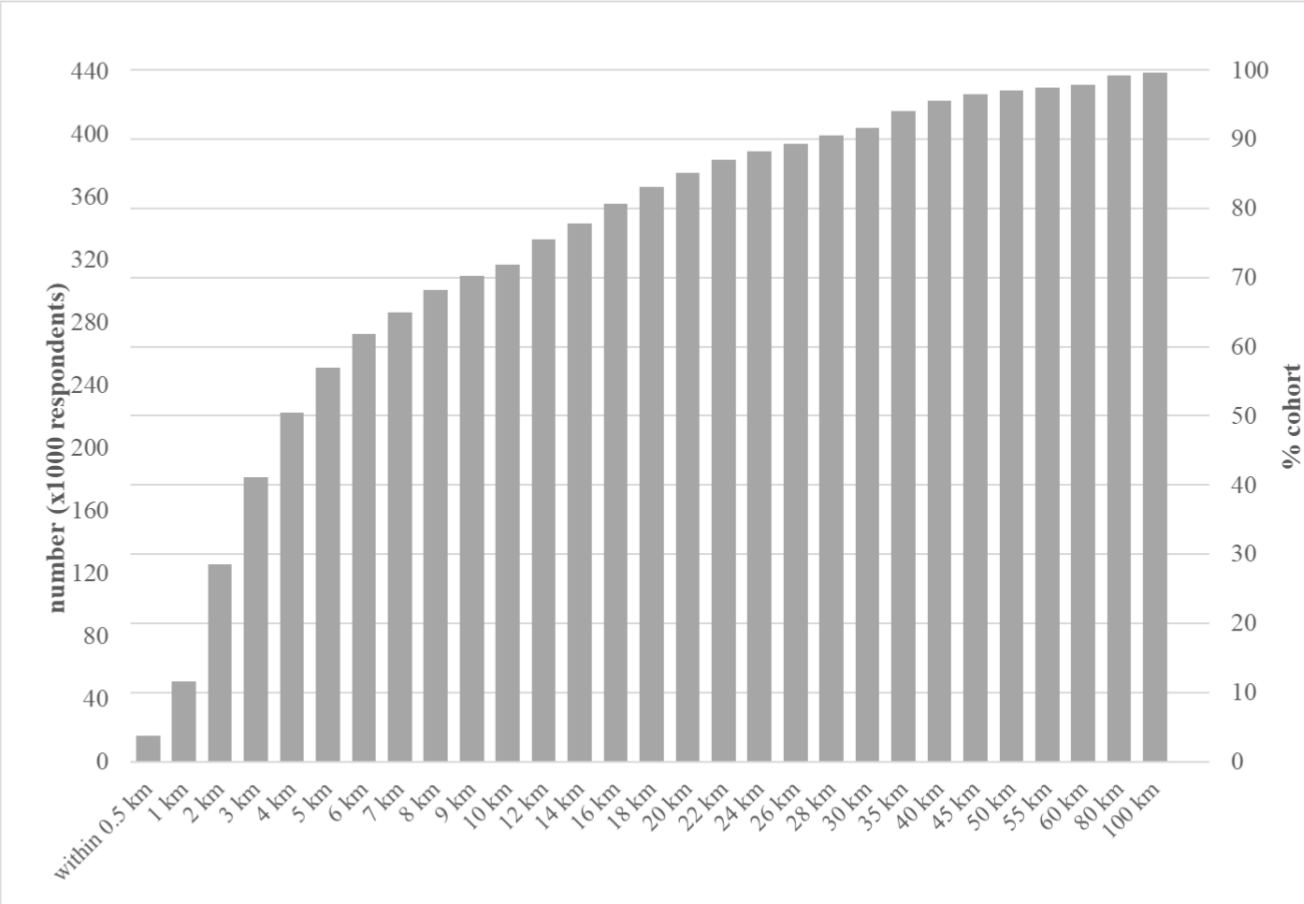

Figure 6.4 Cumulative distribution of survey respondents living within increasing distances to hospital. (N = 442,345).

After testing distances between one and 10 kilometers, we found that living between 500 meters and six kilometers of a hospital and was associated with small but conclusively heightened odds of cardiometabolic hospitalization and was highest living closest to hospital at 500 meters (OR 1.10, 95% CI 1.02 to 1.18; Figure 6.5). Living up to six kilometers away from hospital remained conclusively linked with higher odds of admission (OR 1.05, 95% CI 1.01 to 1.09).

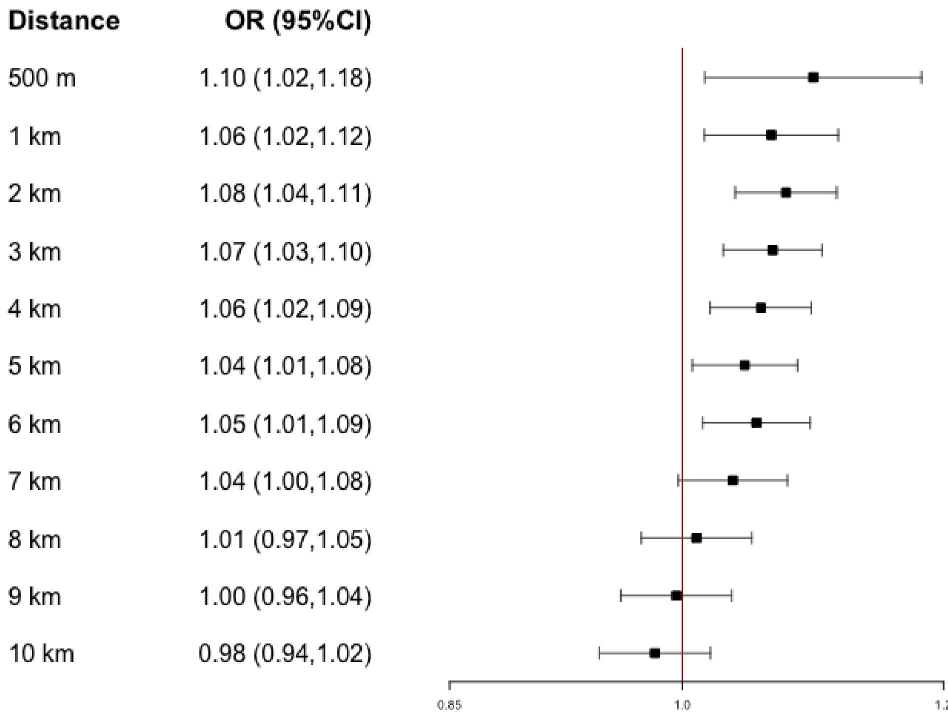

Figure 6.5 Association between distance to hospital and odds of cardiometabolic hospitalization. Series of logistic regressions between indicator variables for increasing distances to hospital and odds of cardiometabolic hospitalization. OR, odds ratio, km, kilometer. Adjusted for ALE, sex, age, survey cycle, educational attainment, smoking status, obesity.

Consecutive inclusion of indicator variables for distances between one and 10 kilometers from hospital revealed that the impact of hospital proximity on the association between the ALE and reduced odds of cardiometabolic hospitalization was modest (Figure 6.6), but most pronounced at distances between 2 km and 6 km and consistently distinguishable across ALE classes at 3 km. Inclusion of indicator variables for living within 2 or 3 km away from hospital increased the protective association of ALE and cardiometabolic hospitalization by 5.06% comparing the most favourable to the least favourable neighbourhoods (odds ratio [OR] 0.79, 95% CI 0.68 to 0.91 before adjusting for hospital proximity; OR 0.75, 95% CI 0.65 to 0.87 after adjusting for hospital proximity). Sensitivity analyses rendered nearly identical estimates when respondents aged 25 years and younger were excluded (Supplementary Figure C.1).

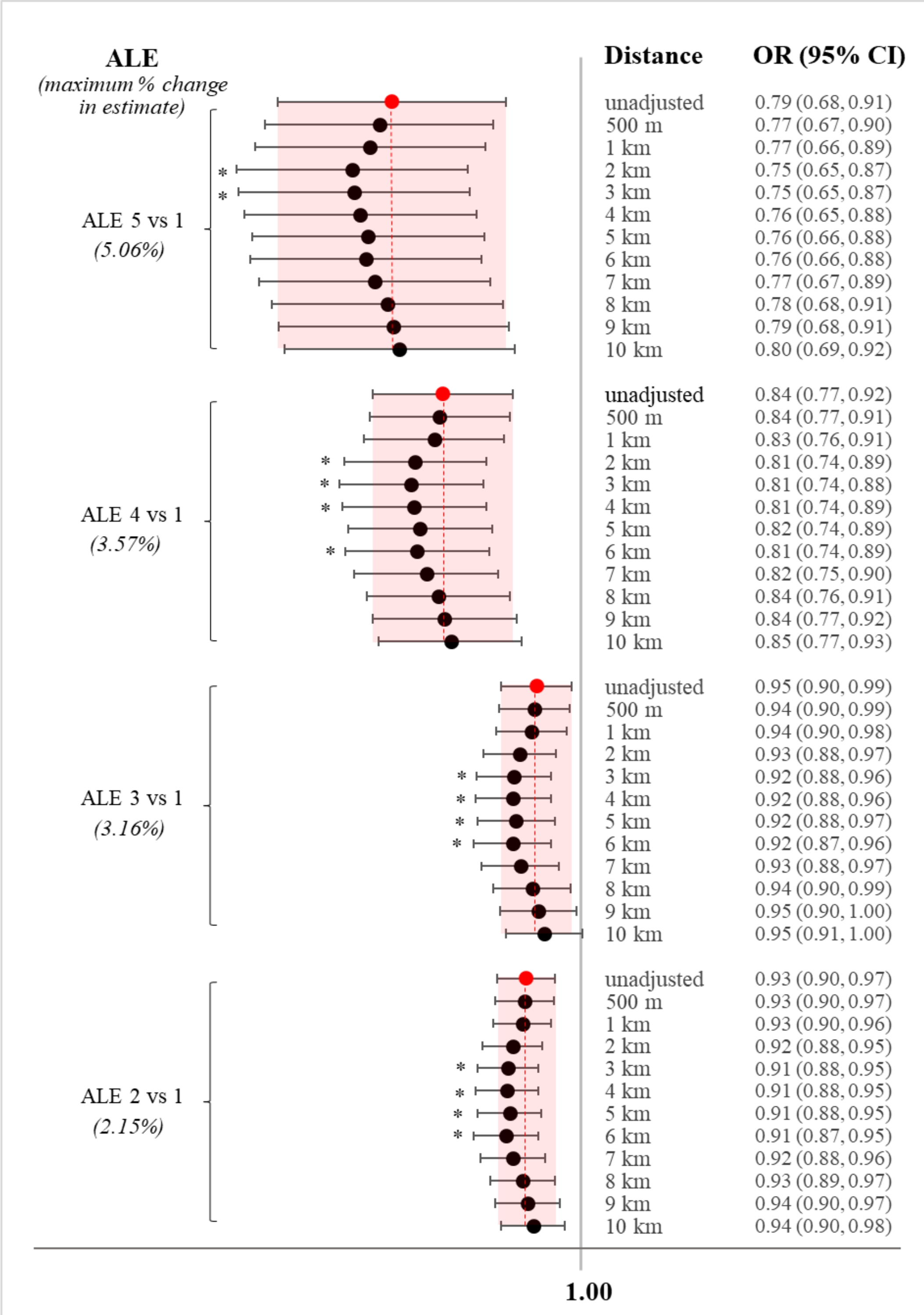

Figure 6.6 Change in estimates for the inclusion of hospital distance in models of ALEs and hospitalization.

Changes in the odds ratios (OR) for successive ALE classes relative to the least favourable ALE (ALE 1, reference) when indicator variables for increasing distances to hospital are included. OR, odds ratio, km, kilometer. Markers in red represent estimates from models unadjusted for distance to hospital, while stars indicate distances with the greatest change in estimate of the protective association between ALE and risk of cardiometabolic hospitalization. Adjusted for sex, age, survey cycle, educational attainment, smoking status, and obesity.

6.6 DISCUSSION

This is the first study to show that living close to a hospital partially masks the association between residing in favourable ALEs and lower odds of hospitalization for cardiometabolic diseases. We first derived measures for hospital proximity and demonstrated that areas with hospitals tend to overlap with highly walkable neighbourhoods. We then determined that living within three kilometers of a hospital was the distance that was associated with the greatest increase in odds of hospitalization. Finally, we showed that, for models adjusted for living within 2-6 kilometers of a hospital, the effect estimates between more favourable ALEs and lower odds of hospitalization were marginally strengthened.

Although living within 500 meters of hospital is associated with the highest increase in odds of cardiometabolic hospitalization, our sensitivity analysis indicated that living within three kilometers of hospital was most consistently associated with the greatest increase in odds of cardiometabolic hospitalization across ALE classes. Although it is challenging to quantitatively compare our findings with previous studies (which tend to test the health impacts of much greater distances away hospital), a few have found heightened utilization at similar distances to the ranges we investigated. A study conducted in British Columbia found that, compared with living less than five kilometers away from hospital, living five to ten kilometers from hospital was associated with 23.7% reduction in the odds of an avoidable hospitalization (Lin et al., 2002), while studies in the US found similar distance effects (Goodman et al., 1997) and have also shown that less than 5 miles (8 kilometers) away from hospital is a strong predictor of frequent ED use (Wu, Grannis, Xu, & Finnell, 2016). A UK study estimated that predicted adult attendances fall by 1.5% with each additional kilometer away from hospital (Rudge et al., 2013).

A previous ecological study of walkability and hospitalization found inversely graded relationships between neighbourhood walkability and both hospital admissions and costs per person, but another study found modest reductions (4%) in hospitalizations related to myocardial infarction comparing only the most walkable neighbourhoods to the least walkable neighbourhoods, and did not find conclusive associations for intermediate neighbourhoods (Mazumdar et al., 2016). Although protective association of ALEs in our study was not fully masked by hospital proximity, the benefit of living in more favourable ALEs would have been underestimated had we not accounted for hospital proximity. This finding implies that hospital distance could be an important for elucidating the full range of association between ALEs and health care use and may allow us to better differentiate relationships between intermediate environmental exposures and hospitalization.

Our objective for this short communication was to determine whether and to what extent the protective effects of living in an ALE are masked by living close-by to a hospital and showed that the impact of hospital proximity is small, but not negligible. One limitation of this study is that our outcome data are acute inpatient hospitalizations, and does not include primary care, outpatient care, or emergency department visits – the last of which is likely the most sensitive health care utilization outcome to geographic distance (Henneman et al., 2011; Lee et al., 2007; Rudge et al., 2013). Nevertheless, the small but conclusive upticks in acute hospitalizations for patients living close to hospital could imply that our study underestimates the impact of hospital distance on associations between ALEs and overall burden of cardiometabolic diseases. While not the focus of this study, we also acknowledge that geographic distance itself is a limited measure that is part of a wider issue of access to health care relating to urban and rural differences, travel time, variations in the availability of primary and specialist care (Chan, Hart, & Goodman, 2006; Sibley & Weiner, 2011), and is also impacted by distinct regional health care and administrative practices between provinces. We were not able to address the broader range of predisposing, enabling, and perceived necessity factors related to health care access (Andersen, 1995) and their relationship to ALEs and health care burden, but we note that accounting enabling factors such as geographic access may be important to advance association studies of the built environment and hospitalization.

This study bears several strengths, the most important of which are the large sample size extracted from linked survey and administrative data, as well as multi-province individual-level coverage of our data. Furthermore, our measures for ALEs, hospital proximity, and hospitalization were objectively derived from open-source data and administrative data and are not prone to self-report biases common to large survey data. Future studies of ALEs and hospital burden may benefit from accounting for geographic factors affecting access to health care.

6.7 REFERENCES

Andersen, R. M. (1995). Revisiting the behavioral model and access to medical care: does it matter? *Journal of Health and Social Behavior, 36*(1), 1-10. doi:10.2307/2137284

Canadian Institute for Health Information. (2019). *National Health Expenditure Trends, 1975 to 2019*. Retrieved from Ottawa: https://www.cihi.ca/en/national-health-expenditure-trends-1975-to-2019

Chan, L., Hart, L. G., & Goodman, D. C. (2006). Geographic access to health care for rural Medicare beneficiaries. *Journal of Rural Health, 22*(2), 140-146. doi:10.1111/j.1748-0361.2006.00022.x

Chandrabose, M., Rachele, J. N., Gunn, L., Kavanagh, A., Owen, N., Turrell, G., Giles-Corti, B., & Sugiyama, T. (2019). Built environment and cardio-metabolic health: systematic review and meta-analysis of longitudinal studies. *Obesity Reviews, 20*(1), 41-54. doi:10.1111/obr.12759

Colley, R. C., Christidis, T., Michaud, I., Tjepkema, M., & Ross, N. A. (2019). An examination of the associations between walkable neighbourhoods and obesity and self-rated health in Canadians. *Health Reports, 30*(9), 14-24. doi:10.25318/82-003-x201900900002-eng

Connor Gorber, S., Shields, M., Tremblay, M. S., & McDowell, I. (2008). The feasibility of establishing correction factors to adjust self-reported estimates of obesity. *Health Reports, 19*(3), 71-82.

Creatore, M. I., Glazier, R. H., Moineddin, R., Fazli, G. S., Johns, A., Gozdyra, P., Matheson, F. I., Kaufman-Shriqui, V., Rosella, L. C., Manuel, D. G., & Booth, G. L. (2016). Association of Neighborhood Walkability With Change in Overweight, Obesity, and Diabetes. *JAMA, 315*(20), 2211-2220. doi:10.1001/jama.2016.5898

Goodman, D. C., Fisher, E., Stukel, T. A., & Chang, C. (1997). The distance to community medical care and the likelihood of hospitalization: is closer always better? *American Journal of Public Health, 87*(7), 1144-1150. doi:10.2105/ajph.87.7.1144

Henneman, P. L., Garb, J. L., Capraro, G. A., Li, H., Smithline, H. A., & Wait, R. B. (2011). Geography and travel distance impact emergency department visits. *Journal of Emergency Medicine, 40*(3), 333-339. doi:10.1016/j.jemermed.2009.08.058

Herrmann, T., Gleckner, W., Wasfi, R. A., Thierry, B., Kestens, Y., & Ross, N. A. (2019). A pan-Canadian measure of active living environments using open data. *Health Reports, 30*(5), 16-25.

Janssen, I. (2012). Health care costs of physical inactivity in Canadian adults. *Applied Physiology Nutrition and Metabolism-Physiologie Appliquee Nutrition Et Metabolisme, 37*(4), 803-806. doi:10.1139/h2012-061

Katzmarzyk, P. T., Gledhill, N., & Shephard, R. J. (2000). The economic burden of physical inactivity in Canada. *Canadian Medical Association Journal, 163*(11), 1435-1440.

Lee, J. E., Sung, J. H., Ward, W. B., Fos, P. J., Lee, W. J., & Kim, J. C. (2007). Utilization of the emergency room: impact of geographic distance. *Geospatial Health, 1*(2), 243-253. doi:10.4081/gh.2007.272

Lin, G., Allan, D. E., & Penning, M. J. (2002). Examining distance effects on hospitalizations using GIS: a study of three health regions in British Columbia, Canada. *Environment and Planning a-Economy and Space, 34*(11), 2037-2053. doi:10.1068/a3528

Mazumdar, S., Learnihan, V., Cochrane, T., Phung, H., O'Connor, B., & Davey, R. (2016). Is Walk Score associated with hospital admissions from chronic diseases? Evidence from a cross-sectional study in a high socioeconomic status Australian city-state. *Bmj Open, 6*(12), e012548. doi:10.1136/bmjopen-2016-012548

OpenStreetMap Contributors. (2017). OpenStreetMap Base Data. Retrieved from https://www.OpenStreetMap.org

Rudge, G. M., Mohammed, M. A., Fillingham, S. C., Girling, A., Sidhu, K., & Stevens, A. J. (2013). The combined influence of distance and neighbourhood deprivation on Emergency Department attendance in a large English population: a retrospective database study. *PloS One*, *8*(7), e67943. doi:10.1371/journal.pone.0067943

Sibley, L. M., & Weiner, J. P. (2011). An evaluation of access to health care services along the rural-urban continuum in Canada. *BMC Health Services Research, 11*, 20. doi:10.1186/1472-6963-11-20

Sundquist, K., Eriksson, U., Mezuk, B., & Ohlsson, H. (2015). Neighborhood walkability, deprivation and incidence of type 2 diabetes: a population-based study on 512,061 Swedish adults. *Health Place, 31*, 24-30. doi:10.1016/j.healthplace.2014.10.011

Tam, T. (2017). *The Chief Public Health Officer's Report on the State of Public Health in Canada 2017–Designing Healthy Living*. Retrieved from https://www.canada.ca/en/public-health/services/publications/chief-public-health-officer-reports-state-public-health-canada/2017-designing-healthy-living.html

Wilkins, R., & Peters, P. (2012). *PCCF + Version 5K* User's Guide. Automated geographic coding based on the Statistics Canada Postal Code Conversion Files including Postal Codes through May 2011.* Retrieved from Ottawa, ON, Canada:

Wu, J., Grannis, S. J., Xu, H., & Finnell, J. T. (2016). A practical method for predicting frequent use of emergency department care using routinely available electronic registration data. *BMC Emergency Medicine, 16*, 12. doi:10.1186/s12873-016-0076-3

Yu, Y., Davey, R., Cochrane, T., Learnihan, V., Hanigan, I. C., & Bagheri, N. (2017). Neighborhood walkability and hospital treatment costs: A first assessment. *Preventive Medicine, 99*, 134-139. doi:10.1016/j.ypmed.2017.02.008

Chapter 7

AN INTERNATIONAL COMPARATIVE STUDY OF ACTIVE LIVING ENVIRONMENTS AND HOSPITALIZATION FOR WALES AND CANADA

7.1 PREAMBLE

Both the volume and richness of Canadian survey and administrative data allowed me to link ALEs with mortality and hospitalization in Chapters 3 through 6. Chapter 7 is the first of two manuscripts that leverage internationally sourced data to assess the generalizability of the relationships between ALEs, behaviours, and health seen for Canadians. Recognizing the lack of comparable built environment measures, as well as the limitations of proprietary measures (Hall & Ram, 2018), I lead the development of comparably derived measures using the Can-ALE methodology and open-source data. These chapters serve, in some sense, as preliminary validation studies for the Wales Active Living Environment (Wal-ALE) measure (Chapter 7) and the Australia Active Living Environment (Aus-ALE) measure (Chapter 8).

Chapter 7 addresses the fourth objective of this dissertation, and does so by leveraging two major data linkage initiatives in Canada (Statistics Canada) and Wales (the Secure Anonymised Information Linkage Databank, SAIL) which contain similar health surveys and hospitalization databases. Little is known about the active-living friendliness of neighbourhoods in Wales UK, and whether similar gains in physical activity and health outcomes are associated with more highly connected areas that contain a greater density of destinations and dwellings. In light of the associations seen in Chapters 5-6, the goal of this study is to determine whether similar associations between favourable ALEs and hospitalization exist for Wales, which is consistent with objective 2 of this dissertation. Last, chronic disease information available from both health surveys was used to identify whether relationships between the built environment and subsequent hospital use varied by T2D status. Therefore, I was also able to address objective 3.

This study is an example of an effort to utilize data from multiple countries for comparative studies. This analysis illustrates the challenges of large-scale international comparative research. While the highly developed linked data infrastructure in both Canada and Wales made this study feasible, variations in measurement, health classification systems, and history made extensive harmonization and validation of the data sources necessary. I also want to note that although I showed in Chapter 5 that overall leisure-time physical activity is not patterned by ALE class in Canada, I used this variable in this study because it was most similar to the items available in the Welsh data sources.

This manuscript is intended for submission to *Social Sciences and Medicine.*

7.2 ABSTRACT

RATIONALE The UK and Canada share many similarities in population-wide levels of physical inactivity, obesity, and type 2 diabetes (T2D). Although positive associations between built environments that encourage active living, physical activity, and chronic diseases are relatively well-characterized in Canada, less is known for the UK.

OJBECTIVE To compare the relationship between active living environments (ALEs) and hospital burden in the general population and those with T2D in Wales UK and Canada.

METHODS A population-based comparison was performed using record linked survey data from the Welsh Health Survey (N = 9,968), and the Canadian Community health Survey (N = 40,335). Hospitalization visits were captured in the Patient Episode Database for Wales and the Discharge Abstract Database for Wales and Canada, respectively. We derived GIS measures of the ALE for Canada and Wales using equivalent protocols and open-source data for street networks, points of interest, and residential density. Descriptive statistics and multivariable regression were used to describe similarities and differences in ALEs, socio-demographic characteristics, health behaviours, and relate ALEs to hospital burden.

RESULTS The two cohorts shared similar proportions of respondents reporting no physical activity, obesity, and T2D. The most favourable ALEs in Canada were much more densely populated and had more points of interest than the most favourable ALEs in Wales. Living in favourable ALEs in Canada was associated with lower odds of obesity at baseline (OR 0.33, 95% CI 0.26 to 0.41), but not in Wales (OR 1.35, 95% CI 1.15 to 1.60). Respondents living in more favourable ALEs in Canada had lower odds of hospitalization for all-causes (OR 0.66, 95% CI

0.54 to 0.81) and inconclusively for cardiometabolic causes (OR 0.79, 95% CI 0.55 to 1.12), while the opposite was true for all-cause (OR 1.37, 95% CI 1.04 to 1.80) and cardiometabolic (OR 1.57, 95% CI 1.04 to 2.36) hospitalizations of respondents living in more favourable ALEs in Wales. No conclusive evidence of differences in hospitalization by ALE class were observed for those with T2D in the Welsh or Canadian cohorts.

CONCLUSION This study is a proof-of-concept for conducting cross-country comparisons of environments and population health using secondary record linked data and equivalently derived neighbourhood measures. We demonstrated that respondents living in more favourable ALEs in Canada had lower odds of hospitalization for all-causes, while the opposite was true for respondents in Wales.

7.3 INTRODUCTION

Rising obesity and chronic disease rates are among the most pervasive over-arching population health patterns emerging worldwide (Abarca-Gómez et al., 2017; NCD Risk Factor Collaboration). Although this rise is driven in part by biological and demographic consequences of ageing populations, widespread physical inactivity is a major contributing factor (Guthold et al., 2018), especially in the context of urbanization (Kohl et al., 2012) and greater reliance on motorized vehicle transport. There is increased interest in the potential for built environments to help mitigate increases in chronic diseases by enabling physical activity. The extent to which neighbourhoods encourage active living are commonly understood and measured as a combination of a neighbourhood's design, diversity in destinations, and residential density. Also referred to as neighbourhood *walkability*, active living environments (ALEs) have been linked to higher step counts (Althoff et al., 2017; Hajna, Ross, Brazeau, et al., 2015), favourable weight (Barbosa et al., 2019) and cardiometabolic profiles (Chandrabose, Rachele, et al., 2019) internationally, could be particularly beneficial for T2D patients (Smith, Wingard, Smith, Kritz-Silverstein, & Barrett-Connor, 2007), who are at higher risk of cardiovascular complications. Area-level studies indicate these neighbourhoods could be linked with lower hospital burden and expenditure (Mazumdar et al., 2016; Yu et al., 2017) but there is no individual-level evidence linking ALEs to health care use to date. Moreover, much of the research on ALEs has been conducted in North America, which begs the question as to whether and to what extent these associations are generalizable to other countries (Mackenbach et al., 2014).

Cross-national comparative studies allow us to broaden the range and variability in ALEs we are able to study, as well as examine how these neighbourhood typologies operate in different regional contexts (Bilal, Auchincloss, & Diez-Roux, 2018). The International Physical Activity and the Environment Network (IPEN) study remains the key international cohort that has been used to establish broadly positive associations between favourable neighbourhood attributes, physical activity (Sallis et al., 2016), and obesity (Sallis et al., 2020). Due to the challenges and costs of obtaining analogous data on environments and downstream disease outcomes in multiple countries as well as comparably derived measures (Badland & Schofield, 2005), few research initiatives have been able to assess ALEs against international health trends. The growing adoption of record linkage approaches to answer population health questions (Jutte et al., 2011) as well as the availability of locational information on many national health surveys is a powerful means of achieving internationally comparable cohorts for studies of environments and health.

Although Wales and Canada have distinct histories, transportation infrastructures, and cultural attitudes to physical activity and food (Croucher, Wallace, & Duffy, 2012), they share interesting parallels in geography and population health. Both the UK and Canada are wealthy nations with universal health care systems, and have populations living primary in urban areas (70% urban-dwelling for Wales, 80% for Canada). Wales (National Assembly for Wales Finance Committee, 2018) and Canada have anticipated the need to invest in and adapt to their ageing populations, both of which will face nearly a quarter of the population over the age of 65 years by 2030 (Baxter & Boyce, 2011; Government of Canada, 2014). Obesity rates are similar at 23% for Welsh age 16 years and older (Public Health Wales Observatory, 2019) and 26.8% for those age 18 years and older in Canada (Statistics Canada, 2019). Diabetes prevalence rates are strikingly similar at 7.3% for both Wales (StatsWales, 2016) and Canada (Statistics Canada, 2018). Most of the working population are car commuters in Wales (81% in 2017) (Department for Transport, 2016) and Canada (74% in 2016) (Yaropud, Gilmore, & LaRochelle-Côté, 2019). Importantly, Wales and Canada have well-developed data linkage infrastructures that can facilitate population-scale socio-environmental health research.

The primary objective of our study was to conduct an international comparative study of ALEs and hospital burden between Wales and Canada. We obtained health surveys from the two countries with comparable sociodemographic and behavioural information that had been linked with administrative hospitalization data. Each survey contained residential information of respondents, which we used to derive identical objective measures for neighbourhood environments in each country. First, we describe the extent to which individual-level variables, hospitalization metrics, and time period could be harmonized between the two countries. Next, we compare the compositional differences and similarities of each study sample, neighbourhood-measures of the built environment for each country, and hospitalization metrics for each sample and specifically, respondents with T2D. Then, we assessed for variations in the predicted odds of reporting no physical activity, obesity, and T2D at baseline between ALEs after accounting for individual level covariates and compared results of Welsh and Canadian survey respondents. Finally, we determined whether the general population and those with T2D living in more favourable ALEs would exhibit lower predicted odds of hospitalization for all-causes and cardiometabolic diseases over the study and compared patterns for Welsh survey respondents with those for Canadian survey respondents.

7.4 METHODS

DATA SOURCES

Two parallel analyses were conducted using population-based health surveys, administrative health data, and comparably derived ALE measures from Wales and Canada (Table 7.1). Each analysis was conducted within Trusted Research Environments (TREs) for linked microdata – the Secure Anonymised Information Linkage (SAIL) Databank for Wales, and the Canadian Research Data Centres Network (CRDCN) for Canada. The Welsh Health Survey (WHS) and Canadian Community health Survey (CCHS) are two national cross-sectional health surveys conducted by the National Centre for Social Research (commissioned by the Welsh Government) and Statistics Canada, respectively. Both surveys aim to provide population-wide estimates of health status as well as health-related behaviours and determinants. As such, both collect similar information on socio-demographic, self-reported health and lifestyle factors. Participants of the WHS from were linked with hospitalization records in the Patient Episode Database for Wales (PEDW), a register of all inpatient and day-case activity in National Health Service (NHS) Wales hospitals. Participants of the CCHS were linked with hospital records in the Discharge Abstract Database (DAD), a census of all acute inpatient hospitalizations to which all provinces submit (except for the province of Quebec). Both hospitalization data sources contain information on date of admission, date of discharge, and diagnostic codes for the 10th revision of the International Statistical Classification of Diseases and Related Health Problems (ICD-10).

Table 7.1 Linked data sources for Wales and Canada.

	WALES	CANADA
Linked data environment	Secure Anonymised Information Linakge (SAIL) Databank	Canadian Research Data Centre Network
Health survey	Welsh Health Survey (WHS)	Canadian Community Health Survey (CCHS)
Years available	2013-2014	2000-2011
Years used	2013-2014	2007
Annual target sample	10,000	65,000
Hospitalization	Patient Episode Database for Wales (PEDW)	Discharge Abstract Database (DAD)
Years available	2000-2017	1999-2012
Years used	2013-2017	2007-2011
Active Living Environments	Wales Active Living Environment Database (Wal-ALE)	Canadian Active Living Environment Database (Can-ALE)

STUDY POPULATION

We selected survey cycles and hospitalization fiscal years from each country to harmonize as closely as possible 1) follow-up time for hospitalization, 2) sample size, and 3) time period of the surveys. Therefore, we identified the most recent cycle of the CCHS that would allow for a follow-up time of 3-4 years in the administrative hospitalization database after survey response as being 2007. We also restricted the target age range of the CCHS (persons over the age of 12) to be respondents aged 16 years and older to match that of the WHS.

T2D was ascertained for Canadian and Welsh populations using a combination of survey response items and hospitalization data. For Wales, those who reported having diabetes and managed their condition using *only* insulin were considered type 1 diabetes patients and were not included in the T2D count. The rest who reported having diabetes were considered T2D patients. For Canada, an algorithm that includes combination of survey items that included self-reported diabetes, age of diagnosis, and medication was used to identify T2D patients (Ng et al., 2008). For both Wales and Canada, we also considered individuals with hospitalization records occurring before survey response for T2D-related admissions (ICD-10, code E11) as having T2D.

We assessed physical inactivity and obesity as intermediate outcomes of interest. We defined "no physical activity" as reporting doing no exercise in the last week for Welsh survey respondents and doing no leisure time physical activity in the last three months for Canadian respondents. Respondents were classified as "obese" if their body mass index exceed 30 kg/m^2 – a derived variable that was available on both the WHS and CCHS. We considered age, sex, educational attainment, and smoking status (never, former, current) as potential confounders of the relationship between the ALE and hospital burden. While age, sex, and smoking status variables were comparably coded for the two datasets, educational systems in Wales and Canada differ substantially from each other – a fact that was apparent in the dissimilar educational variables available in the WHS versus the CCHS. We therefore matched each educational level reported in the WHS or CCHS, based on similarity in qualification and frequencies of people holding those qualifications between each country, and regrouped these variables into three categories for each dataset. For Canada, these categories were defined as those with a post-graduate degree or diploma ("high"), those with high school graduation ("intermediate"), and without high school graduation ("low"). For Wales, "high" educational attainment comprised of those who reported having a degree, professional qualification, foreign qualification, or a vocational qualification of level of 4 or higher based on Regulated Qualifications Framework (RQF), framework for Higher Education Qualifications (FHEQ), National Vocational Qualifications system, or other vocational/work-related qualification. We classified those who reported no qualifications as "low" educational attainment, and all remaining respondents as "intermediate".

Measure for the Active Living Environment

The Canadian Active Living Environments (Can-ALE) Database is a nationally derived set of built environment measures for active living friendliness that has been described previously (Herrmann et al., 2019). Briefly, neighbourhoods were delineated using 1,000-meter circular buffers around the centroids of dissemination areas (DA) in Canada, which is the smallest geographic unit for which census data are released and represents 400-700 persons. Data on the road network and footpaths were downloaded from OpenStreetMap (OpenStreetMap Contributors, 2017) and used to calculate the density of ≥3-way intersections within each buffer. The number of points of interest within each buffer were also calculated using Open Street Map data. We used dwelling densities from the 2016 Canadian census. Raw scores for the three components were clustered into five categories using k-medians, representing environments that are very active living-unfriendly (ALE class 1) to those that are very highly active living-friendly (ALE class 5). Canadian survey respondents were then linked with their corresponding neighbourhoods by overlaying interpolated postal code coordinates (Wilkins & Peters, 2012) with 2016 DAs in a Geographic Information System (ArcGIS 10.5, ESRI).

Using the identical protocol for Can-ALE, the Welsh Active Living Environments (Wal-ALE) Database (Fry, Akbari, Mah, & Ross, 2018) was derived for Output Areas (OAs), which correspond to an average population of 300 people (with approximately 125 households) and is roughly comparable to the Canadian DA. Intersection density and points of interest components were derived using OpenStreetMap data, and dwelling density was calculated using data from the Office for National Statistics Usual Residents data. Source code and documentation for Wal-ALE are freely available at http://richfry.github.io/walkability/.

Outcomes

The primary outcome of interest was acute inpatient hospitalization. Day procedures are not consistently submitted to the Canadian DAD across provinces. The Welsh PEDW does not contain a specific flag for day case records. To remove hospitalizations that were likely to have been day cases, we removed records with same day start and end person-spell dates. Day procedures in the DAD were removed from the analysis using the Facility Type Code variable, which are marked 'A' if the record is a day procedure. The units of analysis that were judged to be most relevant and comparable between the two datasets were person-spells for Wales and episodes of care for Canada – both of which consider contiguous records for inpatient care as a single event. Records in the Welsh PEDW were already organized into distinct person-spells, whereas Canadian DAD records occurring within 24 hours of each other were considered part of the same episode. All-cause hospitalizations included admissions for any cause except for pregnancy or childbirth. We also tracked hospitalizations relating to broad classes of conditions where the following ICD-10 codes were present in any diagnostic position: circulatory diseases (I00-I99), Endocrine, nutritional and metabolic diseases (E00-E88), respiratory diseases (J00-J98) and cancers (C00-D48). Last, we tracked cardiometabolic hospitalizations we considered to be most plausibly related to physical inactivity using the following ICD-10 codes: I10-15 (hypertension), I20-25 (ischaemic heart disease), I61-69 (cerebrovascular disease), I50 (heart failure), E11-E14 (diabetes, excluding type 1 diabetes).

STATISTICAL ANALYSIS

We first generated and compared descriptive statistics of the Welsh and Canadian study samples, Wal-ALE and Can-ALE neighbourhood measures of active living friendliness, sociodemographic characteristics by ALE, and overall hospital utilization for the general population and for those with T2D as indicated by the Welsh and Canadian linked administrative data sources. We report the proportion of people ever-hospitalized after survey response for any cause and for certain causes (circulatory disease; endocrine, nutritional and metabolic diseases; respiratory diseases; cancers; cardiometabolic diseases), crude hospitalization rates per 100 person-years among those hospitalized (calculated by dividing aggregate hospitalization counts by the total time under observation of individuals, multiplied by 100), and average length of stay among those hospitalized – for the general population, and for those with T2D as a subgroup of interest.

We used logistic regression to assess the relationship between living in favourable ALEs and odds of reporting no physical activity, odds of obesity (body mass index exceeding 30 kg/m^2), and odds of having T2D at survey response. The relationship between ALEs and odds of hospitalization for all-causes and cardiometabolic diseases was modeled for the general population and for those with T2D using logistic regression. The predicted baseline probability of zero physical activity, obesity, and having T2D, as well as the predicted probability of hospitalization for all-causes and for cardiometabolic diseases over the study period were estimated for each Wal-ALE and Can-ALE class 1 through 5 using the -margins- command and confidence intervals were calculated using the delta method (StataCorp, College Station, Texas 77845 USA). Models were run separately for Welsh and Canadian samples, and estimates were compared. All were adjusted for sex, age, smoking status, and educational attainment, and included a quadratic term for age. Robust estimators of variance as well as an offset term to account for different follow-up times were used in all models. All analyses were carried out using Stata version 15 (StataCorp, College Station, Texas 77845 USA). Note that in accordance with confidentiality protocols, all frequencies are reported using a rounding base of five, and therefore may not be additive to rounded totals.

7.5 RESULTS

POPULATION CHARACTERISTICS

The two study populations were moderately balanced on baseline characteristics, including sex, BMI, obesity, the proportion of physically inactive respondents, and those with T2D (Table 7.2).

Mean age for the Welsh cohort (52.6 years, SD 18.5) was similar compared with the Canadian cohort (49.2 years, SD 18.8) but had larger proportion of older respondents age 65 years and older (30.9%) compared with the Canadian cohort (23.3%). The proportion of respondents in each educational attainment level were relatively similar, however smoking rates appeared much higher in Canada (23.6% current smokers, 33.5% never-smokers) than Wales (18.9% current smokers, 50.0% never-smokers). Mean BMI and the proportion of respondents who were obese were very similar (27.5, SD 5.6 for Canada compared with 26.8, SD 5.4 for Wales). 10.2% of Canadian respondents reported doing no leisure time physical activity in the last three months, and a similar 11.4% of Welsh respondents reported doing no exercise in the last week.

Table 7.2 Characteristics of study populations for Wales and Canada.

	No. (%)	
	Wales [a] (N = 9,968)	Canada [b] (N = 40,335)
Age, mean (SD)	52.6 (18.5)	49.2 (18.8)
Age category (%)		
Younger 16-44	3,367 (33.8)	17,105 (42.4)
Middle 45-64	3,521 (35.3)	13,815 (34.3)
Older 65+	3,080 (30.9)	9,415 (23.3)
Female	5,232 (52.5)	21,765 (54.0)
Educational attainment		
Low	1,841 (18.5)	8,645 (21.4)
Moderate	3,310 (33.2)	10,205 (25.3)
High	4,817 (48.3)	21,485 (53.3)
Smoking (%)		
Never	4,880 (50.0)	13,520 (33.5)
Former	3,208 (32.2)	17,285 (42.9)
Current	1,880 (18.9)	9,530 (23.6)
BMI (SD)	26.8 (5.4)	27.5 (5.6)
Obese (%)	2,358 (23.7)	10,880 (27.0)
No physical activity (%) [c]	1,132 (11.4)	4,114 (10.2)
T2D (%)	805 (8.1)	2,960 (7.3)

[a] Data source: Welsh Health Survey.
[b] Data source: Canadian Community Health Survey.
[c] For Wales, respondents who had not performed any exercise in the last 7 days before survey response. For Canada, respondents who had not performed any leisure-time physical activity in the last 3 months before survey response.
BMI, Body Mass Index; SD, standard deviation; T2D, type 2 diabetes.

NEIGHBOURHOOD CHARACTERISTICS

K-medians clustering of ALEs rendered relatively similar proportions of ALE-classes for Wales and Canada (Table 7.3), however a higher proportion of Canadian neighbourhoods were classified as being very unfavourable for active living (36.9%) compared with Wales (25.5%). A greater proportion of the respondents in the Canadian sample (48.8%) lived in the least favourable ALEs than the Welsh sample (28.5%), and the lowest proportion of people lived in the most favourable environments for both Wales (3.6%) and Canada (1.9%). A greater proportion of people lived in intermediate Wal-ALE classes 3 (27.1%).

Table 7.3 Active living environments in Wales (Wal-ALE) and Canada (Can-ALE).

	ALE 1 [a]	ALE 2	ALE 3	ALE 4	ALE 5
Wal-ALE (LSOAs, %) [b]	484 (25.5)	517 (27.3)	510 (26.9)	279 (14.7)	106 (5.6)
Can-ALE (DAs, %) [b]	20,722 (36.9)	15,327 (27.3)	13,077 (23.3)	4,541 (8.1)	2,422 (4.3)
WHS (%) [c]	2,838 (28.5)	2,932 (29.4)	2,700 (27.1)	1,138 (11.4)	360 (3.6)
CCHS (%) [c]	19,670 (48.8)	11,045 (27.4)	7,095 (17.6)	1,750 (4.3)	780 (1.9)

[a] Frequencies of ALE classes 1 (very unfavourable) through 5 (very favourable).
[b] The number and proportion of geographic units assigned to ALE classes.
[c] The number and proportion of survey respondents assigned to ALE classes.
ALE, active living environment; Wal-ALE, Welsh Active Living Environments; LSOA, lower super output area; Can-ALE, Canadian Active Living Environments; DA, dissemination area; WHS, Welsh Health Survey; CCHS, Canadian Community Health Survey.

When the three components of the Can-ALE and Wal-ALE were examined separately and compared, we observed an overall increase in the number of points of interest, dwelling density and intersection density with higher ALE class for both data sources (Figure 7.1). The average number of points of interest and dwelling density are consistently higher across Can-ALE classes relative to Wal-ALE classes and are especially high in Can-ALE class 5 relative to Wal-ALE class 5. In contrast, average intersection density by Wal-ALE class appeared roughly equal to or higher than equivalent Can-ALE classes. Increases in intersection density with higher ALE also appeared to diminish after Can-ALE and Wal-ALE class 3.

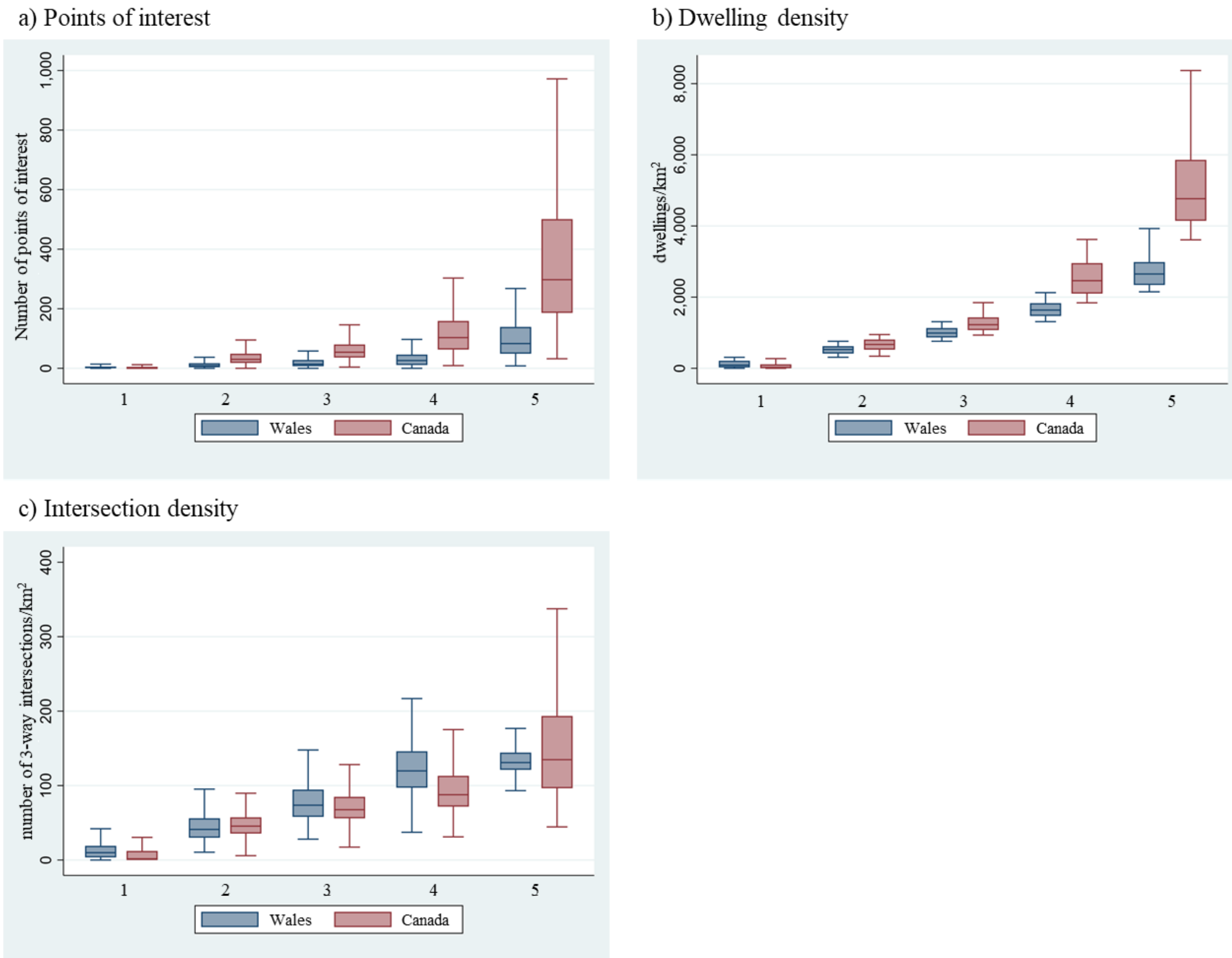

Figure 7.1 Comparison of Wal-ALEs and Can-ALEs.
Boxplots showing the averages and distributions of points of interest (a), dwelling density (b), and intersection density (c) for Welsh lower super output areas compared with Canadian dissemination areas across ALE classes 1 (very unfavourable) through 5 (very favourable).

Demographic composition by ALE class is summarized in Table 7.4. For both Wales and Canada, mean age decreased with increasing ALE favourability. The highest proportion of highly educated Welsh respondents were found among those living in most (53.9%) and least (54%) favourable ALEs, while higher proportions of respondents living in intermediate ALE classes 3 (20.2%) and 4 (20%) had lower levels of educational attainment. In contrast, Canadian respondents living most favourable ALEs had the highest proportion of highly educated people (69.9%) and lowest proportion of people with lower levels of educational attainment (9.6%), while those living in the least favourable environments had the lowest proportion of highly educated people (50.3%) among the Can-ALE classes and highest proportion of people with lower levels of educational attainment (25%). The least favourable Wal-ALE class 1 had the lowest proportion of survey respondents who were current smokers (14.7%), whereas the proportions of survey respondents who were current smokers across Can-ALE classes were more similar. More favourable Can-ALE classes tend to have higher proportions of never-smokers in more favourable ALE classes.

Table 7.4 Demographics by ALE class, Wales and Canada.

	Wales (N = 9,968) [a]					Canada (N = 40,335) [b]				
	ALE 1	ALE 2	ALE 3	ALE 4	ALE 5	ALE 1	ALE 2	ALE 3	ALE 4	ALE 5
N (%)	2,838 (28.5)	2,932 (29.4)	2,700 (27.1)	1,138 (11.4)	360 (3.6)	19,670 (48.8)	11,045 (27.4)	7,095 (17.6)	1,750 (4.3)	780 (1.9)
Age, mean (SD)	55.4 (17.8)	52.1 (18.7)	51.9 (18.5)	50.9 (18.7)	46.3 (18.8)	50.1 (18.3)	48.7 (19.1)	48.1 (19.3)	47.6 (19.0)	47.1 (18.3)
Female %	51.1	53.3	53.3	52.2	51.7	53.8	54.4	54.2	52.8	52.7
Educational attainment %										
Low	15.5	19.4	20.2	20.0	16.7	25.0	18.4	19.1	14.9	9.6
Moderate	30.5	34.3	34.3	35.8	29.4	24.7	26.1	26.1	26.2	20.4
High	54.0	46.3	45.5	44.3	53.9	50.3	55.5	54.9	58.9	69.9
Smoking %										
Never	50.7	48.6	48.4	46.1	50.8	30.6	34.3	38.3	40.3	37.9
Former	34.6	31.6	30.9	32.0	28.3	44.4	43.7	38.6	38.7	39.7
Current	14.7	19.8	20.7	21.9	20.8	25.0	22.0	23.1	21.0	22.4

[a] Data sources: Welsh Health Survey, Welsh Active Living Environment Database (Wal-ALE)
[b] Data sources: Canadian Community Health Survey, Canadian Active Living Environment Database (Can-ALE)
ALE, active living environment; SD, standard deviation.

HOSPITALIZATION CHARACTERISTICS

The proportion of those hospitalized for any cause (except for pregnancy and childbirth) were comparable between Wales (23.4%) and Canada (25.4%, Table 7.5). Despite the shorter average time under observation for the Wales (3.9 years, SD 0.7) compared with the Canada (4.4 years, SD 0.6), odds of cause-specific hospitalizations over the study period appeared to be higher for the Welsh cohort than for the Canadian cohort (12.4% and 8.3% for circulatory illnesses; 8.4% and 4.5% for endocrine, nutritional, and metabolic diseases; 8.0% and 4.9% for respiratory diseases; 11.6% and 6.8% for cardiometabolic diseases, respectively), except for cancers (4.3% and 4.4%, respectively).

Similar in pattern to the proportions of people hospitalized, we observed similar crude all-cause hospitalization rates among those ever-hospitalized for Wales and Canada (11.8 and 11.7 hospitalizations per 100 person-years) and higher cause-specific hospitalization rates for Welsh sample compared with the Canadian sample (in hospitalizations per 100 person-years: 6.1 and 2.9 for circulatory illnesses; 4.0 and 1.5 for endocrine, nutritional, and metabolic diseases; 3.7 and 1.7 for respiratory diseases; 5.7 and 2.4 for cardiometabolic diseases, respectively), while hospitalization rates for cancers were closer among those hospitalized for cancer in Wales and Canada (2.0 and 1.3 hospitalizations per 100 person-years). Length of stay for person-spells in Wales were consistently shorter than length of stay for episodes of care in Canada, regardless of cause of admission.

Those with T2D had consistently higher odds of being hospitalized, more hospitalizations, and slightly longer length of stay, regardless of the cause for admission, in both the Welsh and Canadian cohorts. Proportional differences in hospitalization between the general population and those with T2D were similar across hospitalization risk, rate, and average length of stay between Wales and Canada. For instance, 1.8 times the proportion of people with T2D, compared with the general population, were hospitalized for any cause in the Welsh cohort, while the fold difference comparing those with T2D and the general population for the Canadian cohort was 2.0. Looking specifically at cardiometabolic diseases, 3.3 times the proportion of people with T2D were hospitalized compared with the proportion of the general population in Wales, while 4.1 times the proportion of people with T2D were hospitalized compared with the hospitalized proportion of the general population in Canada. For Canada, the disparity in hospitalization rates between those with

T2D and the general population appeared greater for certain causes than Wales – specifically, for endocrine, nutritional, and metabolic diseases (6.6 fold difference for Canada and 5.6 fold difference for Wales) and cardiometabolic diseases (5.2 fold difference for Canada and 3.9 fold difference for Wales). Average length of stay was similar between general population and those with T2D in both countries.

Table 7.5 Hospitalization trends in Welsh and Canadian samples.

	Wales [a]			Canada [b]		
	General Population (N = 9,968)	T2D (N = 805)	Proportional difference [c]	General Population (N = 40,335)	T2D (N = 2,960)	Proportional difference [c]
Total time under observation, years	38,561	3,012		179,203	12,679	
Average time under observation, years (SD)	3.9 (0.7)	3.7 (0.8)		4.4 (0.6)	4.3 (0.8)	
Hospitalized (%) [d]						
All-cause	2,334 (23.4)	345 (42.9)	1.8	10,235 (25.4)	1,490 (50.3)	2.0
Circulatory diseases	1,237 (12.4)	271 (33.7)	2.7	3,355 (8.3)	705 (23.8)	2.9
ENM diseases [e]	840 (8.4)	300 (37.3)	4.4	1,820 (4.5)	690 (23.3)	5.2
Respiratory diseases	797 (8.0)	134 (16.6)	2.1	1,960 (4.9)	380 (12.9)	2.7
Cancers	428 (4.3)	64 (8.0)	1.9	1,785 (4.4)	260 (8.8)	2.0
Cardiometabolic diseases	1,156 (11.6)	311 (38.6)	3.3	2,730 (6.8)	815 (27.6)	4.1
Hospitalization rate (per 100 PY) [f]						
All-cause	11.8	26.0	2.2	11.7	30.4	2.6
Circulatory diseases	6.1	19.3	3.2	2.9	10	3.4
ENM diseases	4.0	22.1	5.6	1.5	9.9	6.6
Respiratory diseases	3.7	8.5	2.3	1.7	4.7	2.8
Cancers	2.0	4.0	2.0	1.3	2.6	2.0
Cardiometabolic diseases	5.7	22.6	3.9	2.4	12.5	5.2
Average length of stay, days (SD)						
All-cause	7.2 (23.5)	8.1 (16.4)	1.1	9.3 (20.1)	11.4 (22.3)	1.2
Circulatory diseases	9.2 (17.9)	9.7 (19.1)	1.1	12.3 (21.7)	13.7 (22.8)	1.1
ENM diseases	8.6 (17.1)	8.9 (18.5)	1.0	14.4 (24.8)	14.9 (25.0)	1.0
Respiratory diseases	8.4 (15.9)	11.0 (19.6)	1.3	13.3 (23.2)	15.4 (28.7)	1.2
Cancers	7.4 (11.7)	7.5 (11.4)	1.0	10.9 (18.9)	14.2 (24.3)	1.3
Cardiometabolic diseases	8.9 (17.9)	8.9 (18.1)	1.0	13 (21.5)	13.9 (22.2)	1.1

[a] Data source: Welsh Health Survey, Patient Episode Database Wales.
[b] Data source: Canadian Community Health Survey, Discharge Abstract Database.
[c] The proportional fold difference for ever-hospitalization was calculated by dividing the proportion of T2D patients that were hospitalized by the proportion of the general population hospitalized. For hospitalization rate, the average hospitalization frequency for T2D patients was divided by the average hospitalization frequency of the general population. For average length of stay, the average length of stay for T2D patients was divided by the average length of stay of the general population.
[d] Number of hospitalized individuals, (%) is the proportion of people hospitalized.
[f] Aggregate number of hospitalizations per 100 person-years calculated by dividing the total number of hospitalizations by total person time.
PY, person-years; T2D, type2 diabetes; SD, standard deviation, ENM; Endocrine, nutritional and metabolic diseases

ASSOCIATIONS OF ALES, HEALTH, AND HOSPITALIZATION

Adjusted estimates and predicted probabilities for the odds of reporting no physical activity, obesity, and T2D across ALE classes are presented in Table 7.6. More favourable ALEs were associated with higher odds of reporting no physical activity at baseline for both Wales (OR 2.01, 95% CI 1.43 to 2.81, comparing people living in most to least favourable Wal-ALE classes) and Canada (OR 1.27, 95% CI 1.08 to 1.49, comparing respondents living in favourable to least favourable Can-ALE classes). While a difference of 8% in the predicted probability of reporting no physical activity was observed between the most (17%) and least favourable (9%) ALEs for the Welsh cohort, these translated into smaller differences in the predicted probability of reporting no physical activity across ALE classes for the Canadian cohort (ranging between 10-13%).

A strong inverse relationship between living in a favourable ALE and odds of obesity was observed for Canadian respondents (OR 0.33, 95% CI 0.26 to 0.41, comparing people living in most to least favourable Can-ALE classes), which translated into a difference of 29% predicted obesity for respondents living in Can-ALE class 1 compared with 12% living in Can-ALE class 5. In contrast, living in more favourable ALEs was associated with higher odds of obesity at baseline for Wales (OR 1.35, 95% CI 1.15 to 1.60, comparing respondents living in favourable to least favourable Wal-ALE classes), but only translated to a maximum difference of 5% across ALE classes (21% predicted obesity in Wal-ALE class 1 compared with 26% predicted obesity in Wal-ALE class 4).

There were few differences across ALE classes in the odds of T2D at baseline for both Wales and Canada. While there was some evidence of increased odds of having T2D for respondents living in more favourable Wal-ALE classes, these translated to relatively minor differences across Wal-ALE classes in predicted probability of having T2D (7-10%).

Adjusted estimates and predicted probabilities for the odds of all-cause hospitalization and cardiometabolic hospitalization are presented in Table 7.7. Overall, more favourable Wal-ALEs were associated with higher odds of all-cause hospitalization for Welsh respondents (OR 1.37, 95% CI 1.04 to 1.80, comparing people living in most to least favourable Wal-ALE classes), while more favourable Wal-ALEs were associated with lower odds of all-cause hospitalization for Canadian respondents (OR 0.66, 95% CI 0.54 to 0.81, comparing people living in most to least favourable Can-ALE classes). Both Wales and Canada shared a similar range of predicted probabilities of all-cause hospitalization over the study period (22-27% for Wales, 20-27% for Canada) across ALE classes, but opposite in order from each other.

Similarly, more favourable Wal-ALEs were associated with higher odds of cardiometabolic hospitalization for Welsh respondents (OR 1.57, 95% CI 1.04 to 2.36, comparing people living in most to least favourable Wal-ALE classes), while more favourable Wal-ALEs were inconclusively associated with lower odds of cardiometabolic hospitalization for Canadian respondents (OR 0.79, 95% CI 0.55 to 1.12, comparing people living in most to least favourable Can-ALE classes). No conclusive evidence of differences or patterns in hospitalization by ALE class were observed for those with T2D in the Welsh or Canadian cohorts. Predicted probabilities of cardiometabolic hospitalization for Welsh T2D patients in the WHS cohort were considerably higher (34-43%) compared with Canadian T2D patients (24-29%) in the CCHS cohort. T2D patients in both cohorts had higher odds and predicted probability of hospitalization compared with the general population, regardless of which ALE class they lived in. Figure 7.2 summarizes predicted probabilities of reporting no physical activity, obesity, T2D, and hospitalization by ALE class after adjusting for individual level factors presented in Table 7.6 and Table 7.7.

Table 7.6 ALEs and baseline odds of no physical activity (PA), obesity, and T2D

	Wales (N = 9,968) [b]		Canada (N = 40,335) [c]	
	OR (95% CI) [a]	Predicted [d]	OR (95% CI) [a]	Predicted [d]
No PA (yes/no)				
ALE 1 e	1.00	0.09	1.00	0.10
ALE 2	1.25 (1.04, 1.50) *	0.11	0.92 (0.84, 0.99) *	0.10
ALE 3	1.40 (1.16, 1.67) *	0.12	0.97 (0.88, 1.06)	0.10
ALE 4	1.39 (1.10, 1.74) *	0.12	1.27 (1.08, 1.49) *	0.13
ALE 5	2.01 (1.43, 2.81) *	0.17	1.26 (0.99, 1.60)	0.13
Obese (yes/no)				
ALE 1	1.00	0.21	1.00	0.29
ALE 2	1.31 (1.15, 1.48) *	0.25	0.87 (0.82, 0.92) *	0.27
ALE 3	1.29 (1.13, 1.47) *	0.25	0.76 (0.71, 0.81) *	0.24
ALE 4	1.35 (1.15, 1.60) *	0.26	0.55 (0.49, 0.63) *	0.19
ALE 5	1.06 (0.80, 1.40)	0.21	0.33 (0.26, 0.41) *	0.12
T2D (yes/no)				
ALE 1	1.00	0.07	1.00	0.07
ALE 2	1.44 (1.18 ,1.76) *	0.09	0.97 (0.89, 1.07)	0.07
ALE 3	1.40 (1.14 ,1.72) *	0.09	1.02 (0.91, 1.13)	0.07
ALE 4	1.20 (0.91 ,1.58)	0.08	1.13 (0.92, 1.38)	0.08
ALE 5	1.56 (0.99 ,2.44)	0.10	0.86 (0.62, 1.20)	0.06

[a] All models for both Welsh and Canadian cohorts adjusted for age, sex, educational attainment, and smoking status.
[b] Data source: Welsh Health Survey, Patient Episode Database Wales.
[c] Data source: Canadian Community Health Survey, Discharge Abstract Database.
[d] Marginal predicted probability of being sedentary, obese, or having T2D at baseline.
[e] ALE classes 1 (least favourable) to 5 (most favourable). The Welsh Active Living Environment database (Wal-ALE) was used for models with the Welsh cohort, and the Canadian Active Living Environment database (Can-ALE) was used for models with the Canadian cohort.
T2D, type 2 diabetes; OR, Odds ratios; CI, confidence interval; ALE, active living environment.

Table 7.7 Adjusted models of the relationship between ALEs and odds of hospitalization.

	Wales [b]				Canada [c]			
	General Population (N = 9,968)		T2D (N = 805)		General Population (N = 40,335)		T2D (N = 2,960)	
	OR (95% CI) [a]	Predicted [d]	OR (95% CI) [a]	Predicted	OR (95% CI) [a]	Predicted	OR (95% CI) [a]	Predicted
All-cause hospitalization (yes/no)								
ALE 1 [e]	1.00	0.22	1.00	0.40	1.00	0.27	1.00	0.52
ALE 2	1.09 (0.96, 1.25)	0.23	1.15 (0.76, 1.73)	0.43	0.90 (0.85, 0.95) *	0.25	0.93 (0.77, 1.11)	0.50
ALE 3	1.16 (1.01, 1.33) *	0.24	1.29 (0.86, 1.95)	0.45	0.81 (0.75, 0.87) *	0.23	0.85 (0.69, 1.06)	0.48
ALE 4	1.18 (0.99, 1.41)	0.25	1.14 (0.66, 2.00)	0.43	0.78 (0.68, 0.88) *	0.23	0.84 (0.57, 1.23)	0.48
ALE 5	1.37 (1.04, 1.80) *	0.27	1.15 (0.45, 2.92)	0.43	0.66 (0.54, 0.81) *	0.20	0.56 (0.30, 1.07)	0.39
Cardiometabolic hospitalization (yes/no)								
ALE 1	1.00	0.10	1.00	0.34	1.00	0.07	1.00	0.28
ALE 2	1.36 (1.14, 1.63) *	0.13	1.35 (0.89, 2.05)	0.40	1.04 (0.94, 1.15)	0.07	0.87 (0.71, 1.07)	0.26
ALE 3	1.25 (1.04, 1.51) *	0.12	1.35 (0.88, 2.06)	0.40	0.99 (0.88, 1.11)	0.07	0.98 (0.78, 1.25)	0.28
ALE 4	1.40 (1.10, 1.78) *	0.13	1.56 (0.88, 2.76)	0.43	0.94 (0.75, 1.18)	0.06	1.06 (0.68, 1.66)	0.29
ALE 5	1.57 (1.04, 2.36) *	0.14	1.38 (0.53, 3.59)	0.40	0.79 (0.55, 1.12)	0.06	0.77 (0.36, 1.62)	0.24

[a] All models for both Welsh and Canadian cohorts adjusted for age, sex, educational attainment, and smoking status.
[b] Data source: Welsh Health Survey, Patient Episode Database Wales.
[c] Data source: Canadian Community Health Survey, Discharge Abstract Database.
[d] Marginal predicted probability of being hospitalized during the study period.
[e] ALE classes 1 (least favourable) to 5 (most favourable). The Welsh Active Living Environment database (Wal-ALE) was used for models with the Welsh cohort, and the Canadian Active Living Environment database (Can-ALE) was used for models with the Canadian cohort.
T2D, type 2 diabetes; OR, Odds ratios; CI, confidence interval; ALE, active living environment.

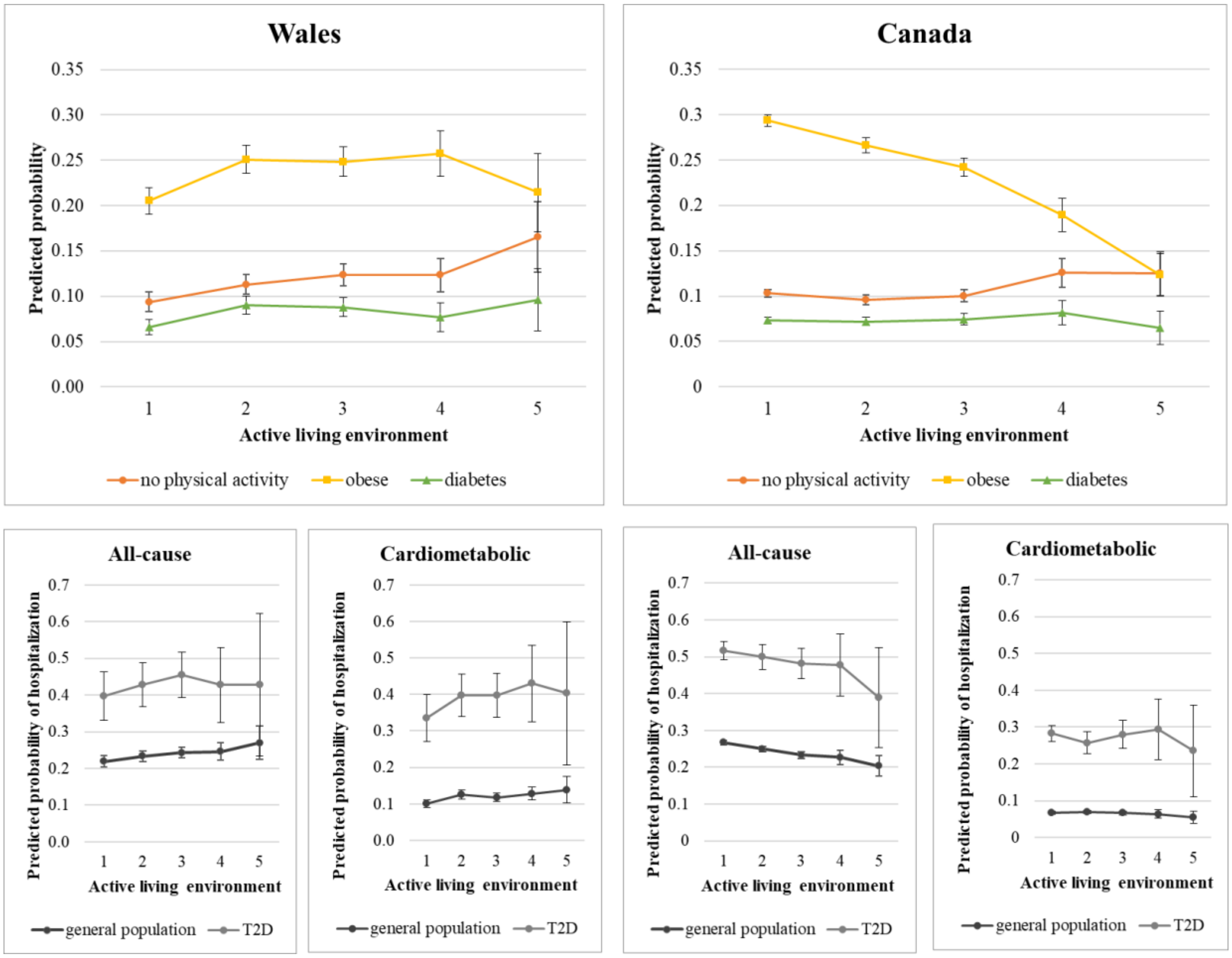

Figure 7.2 Marginal predictions of risk factors and hospitalization by ALE class.
Summary of marginal predictions presented in Tables 7.6 and 7.7 for the odds of sedentary behaviour, obesity, T2D, and hospitalization (all-cause, cardiometabolic) by ALE class 1 (least favourable) to 5 (most favourable). Subgroup analysis was done for hospitalization models for respondents with T2D. Confidence intervals were generated using the delta method.

7.6 Discussion

Main findings

This study serves, in part, as a proof of concept for conducting cross-country comparisons of environments and population health using secondary record linked data and equivalently derived neighbourhood measures. We extracted like samples and variables from two national health surveys for whom a similar length time of routinely collected administrative hospitalization data was available, and produced two parallel cohorts that we found, shared similar proportions of sedentary respondents, obesity, and T2D. We found that the most favourable ALEs in Canada were much more densely populated and had more points of interest than the most favourable ALEs in

Wales. A greater proportion of the Canadian cohort lived in less favourable ALEs, and while this was true of the Welsh cohort as well, there was a greater balance of Welsh respondents living in intermediate ALEs. There were also compositional contrasts for educational attainment and smoking status across ALE classes when comparing Wales with Canada. Next, we found that living in favourable ALEs in Canada was associated with lower odds of obesity at baseline, but not in Wales. Finally, we demonstrated that respondents living in more favourable ALEs in Canada had lower odds of hospitalization for all-causes, while the opposite was true for all-cause and cardiometabolic hospitalizations of respondents living in more favourable ALEs in Wales. We found no evidence to suggest that the relationship between ALEs and hospitalization was different in those with T2D.

RESULTS IN GEOGRAPHICAL AND HISTORICAL CONTEXT

The unique histories of urban development have shaped the urban fabric of Wales and Canada in ways that influence how people interact in and with their neighbourhoods now. Presently, Wales has a population of 3.1 million covering an area roughly the size of the US state of New Jersey at 20,782 square kilometers. Pre-dating motor-vehicle transport, many of the old street networks of towns in the UK endure - many of which had town centres and markets established around pre-existing castles or Roman forts (Boerefijn, 2010) and were chiefly designed for pedestrian foot traffic. Most of the urban and peri-urban areas of Wales to the south grew in the wake of intensified industrialization, mining, and trade in the latter half of the 18th century and were later marked by severe economic depression after the decline of coal. By the late 1900's, urban areas of Wales and the UK in general developed a reputation for being overcrowded, impoverished, and as generally being less desirable places to live than their more picturesque rural counterparts (Cherry & Rogers, 2003). Given this historic underinvestment in these areas and the persistence of smaller rural towns, we were not surprised to observe systematically lower and more consistent population densities and points of interest we found for Welsh neighbourhoods across Wal-ALE classes.

In contrast, the Canadian population is over ten-fold that of Wales at nearly 37.6 million and spans 9.985 million square kilometers. Canada's more recent formation as a country was influenced by the arrival of successive waves of European immigrants that would establish new settlements with the discovery and extraction of natural resources – timber, minerals, fish, furs. Most parts of Canada are also subject to very harsh weather conditions. Aside from port cities, areas that went on to become the largest cities were those with good agricultural land and was more favourably positioned for ease of trade, close to the Canada-US border. Though not as severe a phenomenon as it is for their neighbours to the south, car-oriented low-density urban sprawl is a feature of certain parts of Canada but have resulted in efforts to design suburban areas to be livable as well as Canadian cities that are relatively public transit-oriented. Canada's recent history (compared with Wales), along with the sheer size of the country as well as the heterogeneity across regions and province partly explains the more substantial demarcation in densities and points of interest across Can-ALE classes. There is, however, a physical limit for intersection density, and we see this limitation in the similar upper bounds for street connectivity comparing ALE classes between Wales and Canada.

These unique historical, geographic and social factors have shaped the built environments of Canada and Wales in distinct ways and are also likely to have given rise to some of the observed similarities and differences in sociodemographic patterns across ALEs in the two countries seen in Table 7.4. For example, we found that people living in the least favourable Wal-ALE had the lowest proportion of current smokers (potentially driven by the much older respondents living in these neighbourhoods who are known to have the lowest smoking rates), while the opposite was true for Canada. Although we did not account for race, ethnicity, or immigration status in this study due to the lack of a comparable variables between Canada and Wales, we note that the long history and more homogenous population of Wales stands in contrast to Canada's more recent formation as a country and diverse population. In Canada, living in a walkable neighbourhood is a particularly strong predictor of diabetes for recent immigrants (Booth et al., 2013).

LINKING NEIGHBOURHOODS WITH BEHAVIOURS AND HEALTH STATUS

Importantly, neighbourhood variations in ALE could be influencing obesity in Wales and Canada in different ways. While there was an inverse relationship between walkable environments and obesity rates in Canada– a pattern has been well-characterised for Canada (Colley et al., 2019b; Wasfi, Dasgupta, Orpana, et al., 2016), for Wales - we observed the lowest obesity rates in the most and least favourable neighbourhoods. Weaker relationships between the built environment and obesity outside of North America has been noted previously (Mackenbach et al., 2014). Such a pattern could suggest that neighbourhoods considered 'least favourable' for active living in Wales have health-promoting assets such as green-blue space (Markevych et al., 2017; Mizen et al., 2019) and access to natural environments (Frumkin et al., 2017) that are not captured by a measure based on residential density, street connectivity and the presence of destinations.

Interestingly, residents of the more active-living friendly neighbourhoods for both Canada and Wales were the most likely to report doing no physical activity. While this seems counter-intuitive, it is not inconsistent with evidence from Canada that suggests ALEs are associated with walking - specifically, utilitarian walking (Hajna, Ross, Joseph, et al., 2015) but not overall leisure-time physical activity (Thielman et al., 2015). Leisure-time physical activity is impacted by demographics as well as population center size (Thielman et al., 2015), and encompasses a variety of different activities that may or may not relate to the built environment of one's neighbourhood. No information on walking was available in the WHS years available for this analysis. Moreover, the comparability of physical activity items in the WHS and the CCHS was weaker than other variables used in this analysis, and referred to different terms and different time frames (*exercise* over the last 7 days in the WHS versus *leisure-time physical activity* in the past three months in the CCHS). The lack of comparable physical activity measures for this study underlines the advantages that developing and implementing standardized instruments may bring for future comparative studies on ALEs across countries (Bull, Maslin, & Armstrong, 2009; Craig et al., 2003). Since time of the two survey cycles included in this study, considerable efforts to revise and validate the physical activity measures for both the National Survey for Wales (Rees & Roberts, 2018) and the CCHS (Garriguet, Tremblay, & Colley, 2015) have been made.

International variations in ALEs and hospitalization

Our results for all-cause hospitalizations in Canada echo the results of two previous studies conducted in a single administrative region of Australia, which found that hospitalizations that took place in neighbourhoods with more favourable Walk Scores® (a proprietary measure of the ALE) were associated with lower odds of and fewer hospitalizations for acute myocardial infarction (Mazumdar et al., 2016), as well as lower admissions and hospital costs per person (Yu et al., 2017). Cardiometabolic hospitalizations in Canada appeared marginally lower in more favourable neighbourhoods but were ultimately inconclusive – likely due to the lack of enough power and sample size. In contrast, odds of hospitalization for all-causes and cardiometabolic diseases appeared lowest in the least favourable ALEs of Wales – and finding that could relate to the unmeasured health-promoting characteristics described above, which overlap with both the physical activity and obesity and T2D trends seen in Table 7.6. There are also a variety of other sociodemographic and behavioural differences across ALE classes comparing Wales and Canada that could contribute to the discrepant associations with hospitalization – despite adjusting for many of these factors in our models. Divergent patterns in education and smoking across Wal-ALES versus Can-ALEs could point to key differences in neighbourhood deprivation, its character and history in the two countries. For instance, mounting evidence suggests there are neighbourhood links with population-wide smoking (Pearce, Barnett, & Moon, 2012) that could operate through built environment aspects such as the distribution and density of tobacco outlets (Kirst, Chaiton, & O'Campo, 2019; Shortt et al., 2015) – which can often be concentrated in socioeconomically deprived areas. We were unable conclusively ascertain the relationship between ALE and hospitalization in those with T2D for Canada or Wales, however we were able to observe elevated hospitalization risk in those with T2D compared with the general population in both countries.

Strengths and Limitations

There are several strengths to our study. We leveraged pre-existing health data and open-source environmental data to extract detailed information for two large sample sizes and were able to carry out analyses in parallel for two different countries. We used objectively assessed exposure variables (Can-ALE and Wal-ALE measures) as well as outcomes (routine impatient hospitalization records) that were comparably derived using similar data sources and calculation protocols – a feature that addresses the limitations of previous approaches using subjective measures of health status and neighbourhood characteristics (i.e. measurement error, recall bias). We chose national health surveys that bear similar questionnaire items, and we further harmonized variables to strengthen the extent to which descriptive statistics as well as model-based associations could be compared across the two countries.

Our approach, using linked data for this comparative study also has limitations. Analyses with record-linked data are often conducted in TREs due to the sensitive nature of individual-level microdata. Such was the case for this project. Parallel analyses were carried out on distinct secure servers on which the linked data are housed, which prohibited us from generating pooled estimates for the Canadian and Welsh respondents as a single sample. While this may present a challenge to future international studies, the focus of this paper was comparisons of within-country associations of ALE and hospitalization. Crucially, the UK and Canada have substantially different health care systems with their own administrative data collection, classification, and structuring practices. With respect to this study, Wales operates under a single devolved health care system of the NHS, while Canada's health care system is decentralized, separately administered by 13 provinces and territories. These systemic differences were a likely driver of the inconsistencies in hospitalization metrics between Wales and Canada (Table 7.5). For example, the PEDW contains all inpatient and day case activity undertaken in NHS Wales, while the DAD covers only acute inpatient hospitalizations. We took steps to account for these variations, such as excluding likely day case activity in the PEDW and arrived at similar all-cause hospitalization rates for both countries. Although more work is needed to assess the compatibility of these hospitalization data, it is important to note that these systematic differences are unlikely differentially biased with respect to ALE. Last, there were also important contrasts between the CCHS and the WHS and the variables in each survey that further limit comparability - which include sample size (the Welsh sample size was roughly a quarter of the Canadian sample), the differences average follow-up time (longer for Canadian respondents), and the temporal differences between the survey years available for this analysis. In addition to the absence of a walking measure in the WHS, the nature of and time frames for physical activity measures were dissimilar between the WHS ("exercise", 7-day recall) and the CCHS ("leisure-time physical activity", 3-month recall). These variables are likely to test different concepts of physical activity (Caspersen, Powell, & Christenson, 1985) as well as usual versus current behaviour (Sternfeld & Goldman-Rosas, 2012).

FUTURE DIRECTIONS AND WIDER IMPLICATIONS

This study demonstrates the value record linkage initiatives bring to future international comparative research and underscores the importance of secondary data as well as comparably derived environmental measures across countries. How such similarities in population health are produced despite diverse regional and social contexts remains an overarching question. Among the built environment and sociodemographic variations across each country's ALE classes, it appears that the role of ALEs in shaping behaviours and health is evident for Canada, and perhaps less obvious for Wales. While these analyses imply a need for different policy approaches to urban planning and the built environment in each country, we are also confronted with the limitations of our current understanding of ALEs, the generalizability of observed associations with positive outcomes for health and health behaviours, and our current methods for measuring ALEs.

Comparative administrative data approaches such as ours could allow us to predict, with considerable power and efficiency, the efficacy of urban policies to support active living in places where perhaps, less research has been conducted on the health impacts of neighbourhoods conducive for active living. Our hope is for this study to contribute to our understanding of how ALEs may operate in different settings, begin to inform policy in those settings, as well as add to the growing support for the use of population-scale linked data approaches to international comparative research.

7.7 REFERENCES

Abarca-Gómez, L., Abdeen, Z. A., Hamid, Z. A., Abu-Rmeileh, N. M., Acosta-Cazares, B., Acuin, C., Adams, R. J., Aekplakorn, W., Afsana, K., & Aguilar-Salinas, C. A. (2017). Worldwide trends in body-mass index, underweight, overweight, and obesity from 1975 to 2016: a pooled analysis of 2416 population-based measurement studies in 128. 9 million children, adolescents, and adults. *The Lancet, 390*(10113), 2627-2642. doi:10.1016/S0140-6736(17)32129-3

Althoff, T., Sosic, R., Hicks, J. L., King, A. C., Delp, S. L., & Leskovec, J. (2017). Large-scale physical activity data reveal worldwide activity inequality. *Nature, 547*(7663), 336-339. doi:10.1038/nature23018

Badland, H., & Schofield, G. (2005). Transport, urban design, and physical activity: an evidence-based update. *Transportation Research Part D-Transport and Environment, 10*(3), 177-196. doi:10.1016/j.trd.2004.12.001

Barbosa, J., Guerra, P. H., Santos, C. D., Nunes, A., Turrell, G., & Florindo, A. A. (2019). Walkability, Overweight, and Obesity in Adults: A Systematic Review of Observational Studies. *International Journal of Environmental Research and Public Health, 16*(17), 17. doi:10.3390/ijerph16173135

Baxter, J., & Boyce, S. (2011). The ageing population in Wales. In O. Roberts (Ed.), *Key Issues for the Fourth Assembly*: Research Service National Assembly for Wales.

Bilal, U., Auchincloss, A. H., & Diez-Roux, A. V. (2018). Neighborhood Environments and Diabetes Risk and Control. *Current Diabetes Reports, 18*(9), 62. doi:10.1007/s11892-018-1032-2

Boerefijn, W. N. A. (2010). *The foundation, planning and building of new towns in the 13th and 14th centuries in Europe: an architectural-historical research into urban form and its creation*: Universiteit van Amsterdam [Host].

Booth, G. L., Creatore, M. I., Moineddin, R., Gozdyra, P., Weyman, J. T., Matheson, F. I., & Glazier, R. H. (2013). Unwalkable neighborhoods, poverty, and the risk of diabetes among recent immigrants to Canada compared with long-term residents. *Diabetes Care, 36*(2), 302-308. doi:10.2337/dc12-0777

Bull, F. C., Maslin, T. S., & Armstrong, T. (2009). Global Physical Activity Questionnaire (GPAQ): Nine Country Reliability and Validity Study. *Journal of Physical Activity & Health, 6*(6), 790-804. doi:10.1123/jpah.6.6.790

Caspersen, C. J., Powell, K. E., & Christenson, G. M. (1985). Physical activity, exercise, and physical fitness: definitions and distinctions for health-related research. *Public health reports (Washington, D.C. : 1974), 100*(2), 126-131.

Chandrabose, M., Rachele, J. N., Gunn, L., Kavanagh, A., Owen, N., Turrell, G., Giles-Corti, B., & Sugiyama, T. (2019). Built environment and cardio-metabolic health: systematic review and meta-analysis of longitudinal studies. *Obesity Reviews, 20*(1), 41-54. doi:10.1111/obr.12759

Cherry, G., & Rogers, A. W. (2003). *Rural change and planning: England and Wales in the twentieth century* (Vol. 19): Routledge.

Colley, R. C., Christidis, T., Michaud, I., Tjepkema, M., & Ross, N. A. (2019). An examination of the associations between walkable neighbourhoods and obesity and self-rated health in Canadians. *Health Reports, 30*(9), 14-24. doi:10.25318/82-003-x201900900002-eng

Craig, C. L., Marshall, A. L., Sjöström, M., Bauman, A. E., Booth, M. L., Ainsworth, B. E., Pratt, M., Ekelund, U., Yngve, A., & Sallis, J. F. (2003). International physical activity questionnaire: 12-country reliability and validity. *Medicine and Science in Sports and Exercise, 35*(8), 1381-1395. doi:10.1249/01.MSS.0000078924.61453.FB

Croucher, K., Wallace, A., & Duffy, S. (2012). The influence of land use mix, density and urban design on health: a critical literature review. *York: University of York*.

Department for Transport. (2016). *Transport Statistics Great Britain: 2016*. London: Department for Transport Retrieved from https://www.gov.uk/government/statistics/transport-statistics-great-britain-2016

Frumkin, H., Bratman, G. N., Breslow, S. J., Cochran, B., Kahn, P. H., Jr., Lawler, J. J., Levin, P. S., Tandon, P. S., Varanasi, U., Wolf, K. L., & Wood, S. A. (2017). Nature Contact and Human Health: A Research Agenda. *Environmental Health Perspectives, 125*(7), 075001. doi:10.1289/EHP1663

Fry, R., Akbari, A., Mah, S., & Ross, N. (2018). Measuring Active Living Environments: An international comparison between Canada and Wales. *International Journal of Population Data Science, 3*(2).

Garriguet, D., Tremblay, S., & Colley, R. C. (2015). Comparison of Physical Activity Adult Questionnaire results with accelerometer data. *Health Reports, 26*(7), 11-17.

Government of Canada. (2014). *Action for seniors report*. Retrieved from https://www.canada.ca/en/employment-social-development/programs/seniors-action-report.html

Guthold, R., Stevens, G. A., Riley, L. M., & Bull, F. C. (2018). Worldwide trends in insufficient physical activity from 2001 to 2016: a pooled analysis of 358 population-based surveys with 1.9 million participants. *Lancet Global Health, 6*(10), E1077-E1086. doi:10.1016/S2214-109x(18)30357-7

Hajna, S., Ross, N. A., Brazeau, A. S., Belisle, P., Joseph, L., & Dasgupta, K. (2015). Associations between neighbourhood walkability and daily steps in adults: a systematic review and meta-analysis. *BMC Public Health, 15*, 768. doi:10.1186/s12889-015-2082-x

Hajna, S., Ross, N. A., Joseph, L., Harper, S., & Dasgupta, K. (2015). Neighbourhood walkability, daily steps and utilitarian walking in Canadian adults. *Bmj Open, 5*(11), e008964. doi:10.1136/bmjopen-2015-008964

Hall, C. M., & Ram, Y. (2018). Walk score (R) and its potential contribution to the study of active transport and walkability: A critical and systematic review. *Transportation Research Part D-Transport and Environment, 61*, 310-324. doi:10.1016/j.trd.2017.12.018

Herrmann, T., Gleckner, W., Wasfi, R. A., Thierry, B., Kestens, Y., & Ross, N. A. (2019). A pan-Canadian measure of active living environments using open data. *Health Reports, 30*(5), 16-25.

Jutte, D. P., Roos, L. L., & Brownell, M. D. (2011). Administrative record linkage as a tool for public health research. *Annual Review of Public Health, 32*, 91-108. doi:10.1146/annurev-publhealth-031210-100700

Kirst, M., Chaiton, M., & O'Campo, P. (2019). Tobacco outlet density, neighbourhood stressors and smoking prevalence in Toronto, Canada. *Health & Place, 58*. doi:10.1016/j.healthplace.2019.102171

Kohl, H. W., 3rd, Craig, C. L., Lambert, E. V., Inoue, S., Alkandari, J. R., Leetongin, G., Kahlmeier, S., & Lancet Physical Activity Series Working, G. (2012). The pandemic of physical inactivity: global action for public health. *The Lancet, 380*(9838), 294-305. doi:10.1016/S0140-6736(12)60898-8

Mackenbach, J. D., Rutter, H., Compernolle, S., Glonti, K., Oppert, J. M., Charreire, H., De Bourdeaudhuij, I., Brug, J., Nijpels, G., & Lakerveld, J. (2014). Obesogenic environments: a systematic review of the association between the physical environment and adult weight status, the SPOTLIGHT project. *BMC Public Health, 14*, 233. doi:10.1186/1471-2458-14-233

Markevych, I., Schoierer, J., Hartig, T., Chudnovsky, A., Hystad, P., Dzhambov, A. M., de Vries, S., Triguero-Mas, M., Brauer, M., Nieuwenhuijsen, M. J., Lupp, G., Richardson, E. A., Astell-Burt, T., Dimitrova, D., Feng, X., Sadeh, M., Standl, M., Heinrich, J., & Fuertes, E. (2017). Exploring pathways linking greenspace to health: Theoretical and methodological guidance. *Environ Res, 158*, 301-317. doi:10.1016/j.envres.2017.06.028

Mazumdar, S., Learnihan, V., Cochrane, T., Phung, H., O'Connor, B., & Davey, R. (2016). Is Walk Score associated with hospital admissions from chronic diseases? Evidence from a cross-sectional study in a high socioeconomic status Australian city-state. *Bmj Open, 6*(12), e012548. doi:10.1136/bmjopen-2016-012548

Mizen, A., Song, J., Fry, R., Akbari, A., Berridge, D., Parker, S. C., Johnson, R., Lovell, R., Lyons, R. A., Nieuwenhuijsen, M., Stratton, G., Wheeler, B. W., White, J., White, M., & Rodgers, S. E. (2019). Longitudinal access and exposure to green-blue spaces and individual-level mental health and well-being: protocol for a longitudinal, population-wide record-linked natural experiment. *Bmj Open, 9*(4), e027289. doi:10.1136/bmjopen-2018-027289

National Assembly for Wales Finance Committee. (2018). *The Cost of Caring for an Ageing Population*. Retrieved from https://senedd.wales/laid%20documents/cr-ld11773/cr-ld11773-e.pdf

NCD Risk Factor Collaboration. Worldwide trends in diabetes since 1980: a pooled analysis of 751 population-based studies with 4.4 million participants. *The Lancet, 387*(10027), 1513-1530. doi:10.1016/S0140-6736(16)00618-8

Ng, E., Dasgupta, K., & Johnson, J. A. (2008). An algorithm to differentiate diabetic respondents in the Canadian Community Health Survey. *Health Reports, 19*(1), 71-79.

OpenStreetMap Contributors. (2017). OpenStreetMap Base Data. Retrieved from https://www.OpenStreetMap.org

Pearce, J., Barnett, R., & Moon, G. (2012). Sociospatial inequalities in health-related behaviours: Pathways linking place and smoking. *Progress in Human Geography, 36*(1), 3-24. doi:10.1177/0309132511402710

Public Health Wales Observatory (Producer). (2019, 26 June 2020). Obesity in Wales.

Rees, R., & Roberts, C. (2018). *Discontinuities in Results for Health-Related Lifestyle and General Health between the Welsh Health Survey and National Survey for Wales*. Retrieved from https://gov.wales/sites/default/files/statistics-and-research/2019-02/discontinuities-results-health-related-lifestyle-general-health-between-welsh-health-survey-national-survey-wales-2018.pdf

Sallis, J. F., Cerin, E., Conway, T. L., Adams, M. A., Frank, L. D., Pratt, M., Salvo, D., Schipperijn, J., Smith, G., Cain, K. L., Davey, R., Kerr, J., Lai, P. C., Mitas, J., Reis, R., Sarmiento, O. L., Schofield, G., Troelsen, J., Van Dyck, D., De Bourdeaudhuij, I., & Owen, N. (2016). Physical activity in relation to urban environments in 14 cities worldwide: a cross-sectional study. *The Lancet, 387*(10034), 2207-2217. doi:10.1016/S0140-6736(15)01284-2

Sallis, J. F., Cerin, E., Kerr, J., Adams, M. A., Sugiyama, T., Christiansen, L. B., Schipperijn, J., Davey, R., Salvo, D., Frank, L. D., De Bourdeaudhuij, I., & Owen, N. (2020). Built Environment, Physical Activity, and Obesity: Findings from the International Physical Activity and Environment Network (IPEN) Adult Study. *Annual Review of Public Health, 41*, 119-139. doi:10.1146/annurev-publhealth-040218-043657

Shortt, N. K., Tisch, C., Pearce, J., Mitchell, R., Richardson, E. A., Hill, S., & Collin, J. (2015). A cross-sectional analysis of the relationship between tobacco and alcohol outlet density and neighbourhood deprivation. *BMC Public Health, 15*. doi:10.1186/s12889-015-2321-1

Smith, T. C., Wingard, D. L., Smith, B., Kritz-Silverstein, D., & Barrett-Connor, E. (2007). Walking decreased risk of cardiovascular disease mortality in older adults with diabetes. *Journal of Clinical Epidemiology, 60*(3), 309-317. doi:10.1016/j.jclinepi.2006.06.013

Statistics Canada. (2018). Diabetes, 2017. *Health Fact Sheets*. Retrieved from https://www150.statcan.gc.ca/n1/pub/82-625-x/2018001/article/54982-eng.htm

Statistics Canada. (2019). Overweight and obese adults, 2018. *Health Fact Sheets*. Retrieved from https://www150.statcan.gc.ca/n1/pub/82-625-x/2019001/article/00005-eng.pdf

StatsWales. (2016). Illnesses by gender and year. Retrieved from https://statswales.gov.wales/Catalogue/Health-and-Social-Care/Welsh-Health-Survey/illnesses-by-gender-year

Sternfeld, B., & Goldman-Rosas, L. (2012). A systematic approach to selecting an appropriate measure of self-reported physical activity or sedentary behavior. *Journal of Physical Activity and Health, 9 Suppl 1*, S19-28. doi:10.1123/jpah.9.s1.s19

Thielman, J., Rosella, L., Copes, R., Lebenbaum, M., & Manson, H. (2015). Neighborhood walkability: Differential associations with self-reported transport walking and leisure-time physical activity in Canadian towns and cities of all sizes. *Preventive Medicine, 77*, 174-180. doi:10.1016/j.ypmed.2015.05.011

Wasfi, R. A., Dasgupta, K., Orpana, H., & Ross, N. A. (2016). Neighborhood Walkability and Body Mass Index Trajectories: Longitudinal Study of Canadians. *American Journal of Public Health, 106*(5), 934-940. doi:10.2105/AJPH.2016.303096

Wilkins, R., & Peters, P. (2012). *PCCF + Version 5K* User's Guide. Automated geographic coding based on the Statistics Canada Postal Code Conversion Files including Postal Codes through May 2011*. Retrieved from Ottawa, ON, Canada:

Yaropud, T., Gilmore, J., & LaRochelle-Côté, S. (2019). *Results from the 2016 Census: Long commutes to work by car*: Statistics Canada= Statistique Canada.

Yu, Y., Davey, R., Cochrane, T., Learnihan, V., Hanigan, I. C., & Bagheri, N. (2017). Neighborhood walkability and hospital treatment costs: A first assessment. *Preventive Medicine, 99*, 134-139. doi:10.1016/j.ypmed.2017.02.008

Chapter 8

ACTIVE LIVING ENVIRONMENTS AND WALKING FOR PURPOSE: THE AUSTRALIAN DIABETES, OBESITY AND LIFESTYLE STUDY

8.1 PREAMBLE

Many health surveys ask respondents about their physical activity habits related only to exercise or leisure-time activities. However, this fails to acknowledge that physical activity is often derived from other daily activities (Sallis et al., 2006). Increasingly, health surveys (Colley, Butler, Garriguet, Prince, & Roberts, 2018) and physical activity instruments (Bauman et al., 2009) asked respondents to describe their non-leisure activities. Active transport is highly associated with ALEs, whereas leisure-time activities tend to exhibit weaker or null associations. Aside from active transport, comparably less is known about the potential for ALEs to influence non-leisure walking habits, such as walking for errands or shopping. Moreover, little is known about whether walking for purposes differs in those with or at risk of T2D compared to those without T2D, and whether ALEs have any bearing on those differences. Those at risk of T2D or who have T2D tend to be most resistant to favourable lifestyle behaviours and may respond to their neighbourhoods differently.

The third follow-up survey of the Australian Diabetes, Obesity and Lifestyle Study (2011-2012) contains key variables on weekly walking for transit, errands, and leisure. This study seeks to describe patterns in walking for transit, errands, and leisure for the general population and those who have or are at higher risk of T2D. My goal was to determine whether these neighbourhoods influence purpose-specific walking for healthy populations differently, compared with those who had T2D or were at risk of T2D. This chapter addresses objective 3 and 4 of this dissertation.

This manuscript is intended for submission to *International Journal of Behavioral Nutrition and Physical Activity.*

8.2 Abstract

Background People who live in neighbourhood environments that support active living tend to be more physically active. Physical activity reduces the risk of type 2 diabetes (T2D) and is particularly beneficial to people who are at risk of T2D or have been diagnosed with T2D. The aim of this study was to describe purpose-specific walking in a biomedical cohort across active living environments (ALEs), and to determine whether the relationship between ALEs and walking for purpose might differ in those who have T2D or are at higher risk for T2D.

Methods We examined associations between ALEs and days of purpose-specific walking (transit, errands, leisure, overall) by T2D risk and status. Participants (N = 3,466) of the third follow-up of the Australian Diabetes, Obesity and Lifestyle Study (AusDiab) were linked with the Australian Active Living Environments measure (Aus-ALE), a five-class composite score for ALEs (consisting of residential density, intersection density, and points of interest). Participants who developed T2D were identified as part of the AusDiab study, while T2D risk was ascertained using the AUSDRISK algorithm, which assigns risk based on demographic, lifestyle and anthropometric measures. We used logistic regression was used to examine relationships between ALEs and purpose-specific walking and included product terms between ALE and T2D status to assess for differences in purpose-specific walking by ALE among those without T2D, with T2D, or at high risk of T2D.

Results Leisure walking was the most prevalent type of walking that the cohort engaged in (65.3%), followed by walking for errands (38.7%) and transit walking (11.8%). Living in neighbourhoods that were conducive to active living was associated with more days walked for transit (1.69 more days, OR 27.89, 95% CI 19.06 to 40.82 comparing the least to the most favourable ALEs), errands (2.71 more days, OR 10.06, 95% CI 7.82 to 12.94), leisure (0.21 more days, OR 1.14, 95% CI 0.90 to 1.45) and overall (2.04 more days, OR 3.37, 95% CI 2.62 to 4.33). Having T2D was independently associated with lower transit walking (OR 0.63, 95% CI 0.42 to 0.93), while high risk for T2D was independently associated with lower leisure walking (OR 0.78, 95% CI 0.68 to 0.90). For those living in more favourable neighbourhoods, gains in weekly leisure-time and overall walking appeared to be diminished or were absent for those with T2D or at risk of T2D. Transport walking and errand walking remained higher for those living in favourable ALEs relative to less favourable ALEs, regardless of T2D status.

Conclusion Among the purpose-specific walking outcomes examined in this study, errand walking emerged as both a frequent activity and the most strongly patterned outcome by ALE class. Although the relationship between favourable ALEs and walking for leisure are weaker for those with T2D or are at higher risk for T2D, higher levels of transit walking and errand walking in more favourable ALEs persist, regardless of T2D status, and suggests policies targeting the built environment might consider focusing on transit infrastructure and retail/service destinations. Re-orienting neighbourhoods to serve multiple purposes and functions could be of importance as a target for population-wide increases in physical activity.

8.3 INTRODUCTION

The prevention and management of chronic diseases such as T2D is a national health priority for Australia. According to the Australian Institute of Health and Welfare, a million people (5.3% of the adult population over 18 years) had T2D in 2017-18 (Australian Institute of Health and Welfare, 2020). Over half of the adult population do not meet the country's physical activity guidelines (Australian Institute of Health Welfare, 2020) and two thirds are considered overweight or obese (Australian Institute of Health Welfare, 2019). Individual-level physical activity interventions to prevent (Laatikainen et al., 2007) or manage T2D (Avery, Flynn, van Wersch, Sniehotta, & Trenell, 2012) have seen some success, but may be infeasible to deliver to the vast number of people who have or are at high risk of T2D.

Walking is an important form of physical activity because it is relatively easy for most, low-risk, and can be embedded into daily activities of living. Different domains of walking (e.g., occupational, leisure, transport) have each been linked independently with more favourable mortality outcomes in T2D patients (Hu et al., 2004). Hence, encouraging more walking is now a growing global priority (World Health Organization, 2019). Population health approaches are considering the potential for designing urban environments to support active living and bring about mass changes in physical activity levels (Giles-Corti et al., 2016). Neighbourhoods that are more densely populated, have well-connected street networks, and have a higher number and variety of destinations nearby are consistently shown to be conducive to physical activity associated with different daily activities (McCormack & Shiell, 2011; Saelens & Handy, 2008; Van Holle et al., 2012). While this neighbourhood quality is often referred to as *walkability*, we use the term *Active Living Environment* (ALE) (Hajna et al., 2017) because these neighbourhoods support many activities other than walking. In the general population, ALEs are associated with walking (Owen et al., 2007), lower levels of obesity (Muller-Riemenschneider et al., 2013) and more favourable cardiometabolic risk profiles (Chandrabose, Rachele, et al., 2019). Environmental barriers to walking might especially impact people with T2D (Heiss & Petosa, 2014; Korkiakangas et al., 2009) and those at risk for T2D (Donahue, Mielenz, Sloane, Callahan, & Devellis, 2006). Physical activity rates among those with T2D tend to be lower than those without T2D (Kennerly & Kirk, 2018; Magliano et al., 2008). Whether and to what extent the built environment influences walking related to different types of routine physical activity amongst those in the general population compared to those with or at risk of T2D has not been studied.

In this study, we first described the relationship between ALEs and self-reported purpose-specific walking in the Australian Diabetes, Obesity and Lifestyle Study third wave cohort. We then leveraged the availability of information on T2D risk and status unique to the survey to determine whether the relationship between ALEs and walking for purpose might differ in those who have T2D or are at higher risk for T2D. Identifying the types of activities that are best supported by favourable ALEs, and assessing the extent to which these environments might especially support those with or at risk of T2D could advance our understanding of how built environments could be designed to maximize the physical activity derived from walking for daily activities across the population.

8.4 METHODS

STUDY SETTING AND DATA SOURCES

We conducted a cross-sectional study of ALEs and purpose-specific walking overall and for people with T2D or at risk of T2D. We accessed data from the third wave follow-up participants (N = 4,614) of the Australian Diabetes, Obesity and Lifestyle Study (AusDiab3) conducted from 2011-2012. Design, methods and response rates of AusDiab3 were described previously (Tanamas et al., 2013). The study was approved by the Ethics Committee of the International Diabetes Institute and The Alfred Health Human Ethics Committee no. 39/1 (Project #1851818, *International comparisons of neighbourhood environments, type 2 diabetes, mortality, and hospital burden*) as well as McGill's Research Ethics Board 1 (REB file #21-02-029, *International comparisons of neighbourhood environments, type 2 diabetes, and hospital burden*, Supplementary Figure E.1). Only those for whom we had complete information on all variables of interest were included in the analysis. In addition, we excluded respondents who reported having a disability that could have independently prevented them from being able to walk.

T2D AND T2D RISK

T2D status was ascertained using items on the AusDiab3 survey. Respondents who answered yes to “have you ever been told by a doctor/nurse that you have diabetes?” were included as potential candidates for having T2D. Women who reported being first diagnosed with diabetes during pregnancy were removed. Those who were less than 30 years old when they were told they had diabetes or began insulin under the age of 30 were also removed.

To ascertain whether respondents were at higher risk of developing T2D, we used population risk scores that were derived from the Australian Type 2 Diabetes Risk Assessment Tool (AUSDRISK). AUSDRISK is an algorithm that assigns a score based on age, sex, ethnicity, parental history of diabetes, history of high blood glucose level, use of antihypertensive medications, smoking, physical inactivity and waist circumference (Chen et al., 2010). Physical inactivity was used as a risk factor for AUSDRISK. However, the two variables used to classify individuals as physical inactive were total time engaged in walking and as well as moderate or vigorous activity per week. These were distinct variables from the purpose specific walking outcomes of interest for this study. Nevertheless, we were cautious in our interpretations for this group relative to the general population. We classified those in the top tenth percentile as being at highest risk of developing T2D.

THE AUSTRALIA ACTIVE LIVING ENVIRONMENTS (AUS-ALE) MEASURE

Using a validated methodology that was developed for Canadian neighbourhoods (Herrmann et al., 2019), we derived the Australian Active Living Environment measure (Aus-ALE), a three-part composite k-medians clustered score comprised of: destinations, intersection density, and dwelling density. We used Level 1 Statistical Areas (SA1) as the geographic unit of analysis. To best match the study period, we used SA1s from 2011. We then constructed 1,000-meter buffers around the centroids of each SA1, representing a typical neighbourhood activity area that is reachable by walking and perceived as such (Moudon et al., 2006). Access to destinations was measured as the number of points of interest (i.e. potential walking destinations such as parks, schools, shops, services and landmarks) within each buffer. Street connectivity was measured as the density of ≥3-

way intersections within each buffer. Measures for functional destinations and connectivity were derived using open-source, user-contributed road/footpath network and points of interest (POIs) data from OpenStreetMap (OpenStreetMap Contributors, 2018). SA1 level dwelling density was available from the 2016 Australian Census. Source code and documentation for Aus-ALE are freely available at http://richfry.github.io/walkability/Walkability_Aus.html.

PURPOSE-SPECIFIC WALKING OUTCOMES

The *Health Knowledge, Attitudes & Practices Questionnaire* contained information on walking for different purposes. Respondents were asked, "In the last week, on how many days did you walk in your local neighbourhood" to accomplish different objectives: 1) "To get to or from a public transport stop (e.g., bus, tram, train)"; 2) "To get to or from a retail or other services (e.g., post office, shops, café, supermarket, sport club)"; 3) "For leisure or exercise only? (e.g., along a walking track, in or around a park, around your neighbourhood streets)" and; 4) "In total" (i.e. for any of the above reasons). For simplicity, we refer to these purposes as *transit*, *errand*, *leisure*, and *overall*. We note that transit walking is often interchangeably with *active transport* or *utilitarian walking*, and may include walking to destinations such as work, school, or shops and services. For this study, *transit walking* denotes only walking to and from public transit stops, while *errand walking* denotes only walking to and from retail and service destinations. The survey did not capture walking to work or school. Furthermore, information on walking frequency (times per week) and duration (minutes per session) were not available for purpose-specific walking variables and were not the focus of this study.

SELF SELECTION INTO NEIGHBOURHOODS

Respondents were presented with a series of neighbourhood preference factors and were asked to rate how important each factor was in their decision to move to their neighbourhood on a 5-point likert scale. We identified four neighbourhood preference factors that were related to physical activity, and matched these conceptually with walking for transit, errands, leisure, and overall walking: 1) having public transit stops within walking distance; 2) having retail and other services within walking distance; 3) having recreation facilities within walking distance; and 4) the ease of walking around the area (i.e. good foot paths, walking tracks, safe crossings).

COVARIATES

Individual-level socio-demographic and behavioural factors that were accounted for were age, sex, educational attainment (high-school education, trade, diploma, degree), low income (defined as having an income less than $30,000 annually) smoking status (non-smoker, former, current), as well as body weight index (BMI) (average, < 25 kg/m^2; overweight, 25–30 kg/m^2; obese, > 30 kg/m^2).

STATISTICAL ANALYSIS

First, we described Aus-ALE measures that were derived for the entire country. We then described the socio-demographic, behavioural and health characteristics of the AusDiab3 cohort stratified by those living in less favourable (ALE classes 1-3) versus more favourable ALEs (ALE classes 4-5). ALE classes were aggregated due to low cell counts in more favourable ALEs.

Then, we examined differences in the number of days in a typical week walked for transit, errands, leisure, and overall after accounting for individual-level factors. We used logit-link generalized linear models for a Bernoulli distribution with a binomial denominator of seven (representing the number of days in a week), and adjusted for age, sex, education, income, smoking status, BMI classification and diabetes status (no T2D, high risk, has T2D). Thereafter, we obtained marginal predictions from these models using Stata's *margins* command to predict the adjusted average days walked in the last week for residents of each ALE class.

We also deconstructed the potential for ALE to influence a) an individual's decision to partake in walking at all in the last week, from b) its capacity to encourage more frequent walking among walkers. Similar to a previous study (McCormack, 2017), we used a two-part hurdle approach (Baldwin, Fellingham, & Baldwin, 2016) to separate factors that influence the production of zero counts from those which influence the count itself. First, relationships between ALE (1-3 were considered less favourable, 4-5 were considered more favourable) and the odds of walking for each purpose (yes/no) were modeled using logistic regression. Second, the relationships between ALE and the number of days walked in the last week for each purpose among those who reported ever-walking for the specified purpose was modeled using a logit-link generalized linear model for a Bernoulli distribution with a binomial denominator of seven. We also assessed the extent to which neighbourhood self-selection might confound the relationship between ALEs and walking for both components. Each self-selection factor was aggregated to a dichotomous variable (1-3 assigned as “lower importance”, 4-5 assigned as “higher importance,”) and included in models which conceptually matched each purpose-specific walking outcome (Supplementary Table D.1).

Lastly, we determined whether the associations may differ for those who have T2D or are at higher risk for T2D by introducing product terms between ALE (2-level factor variable; less favourable ALE, more favourable ALE) and T2D status (3-level factor variable; no T2D, high risk, has T2D) in logit-link generalized linear models for a Bernoulli distribution with a 7-day denominator. We then predicted the number of days in a typical week walked for transit, errands, leisure, and overall using marginal predictions for the six ALE/T2D groups to facilitate interpretation of the models, allowing us to better characterise the nature and magnitude of the effect modification of T2D on the relationship between ALEs and walking for each purpose. The limitations of the sample size did not allow for us to apply the two-part hurdle approach to additionally examine effect modification of T2D on odds of walking separately from days walked. All models were adjusted for age, sex, education, income, smoking status, BMI classification and diabetes status. Analyses were conducted using Stata software version 16.1 (StataCorp, College Station, TX).

8.5 RESULTS

Aus-ALEs were derived for 54,723 neighbourhoods in Australia (Table 8.1). The majority were classified to lower and intermediate ALE classes 1 through 3, while only 6% were considered the most favourable for active living (ALE class 5). Very favourable neighbourhoods had, on average, three times the number of points of interest and housing densities than neighbourhoods in ALE class 4, which were still considered favourable for active living. Aus-ALE values for SA1 regions of three major cities are visualized in choropleth maps (Figure 8.1).

Table 8.1 Australian Active Living Environment (Aus-ALE) characteristics. (N = 54,723 neighbourhoods).

	N (%)	Intersections (SD)[a]	Points of Interest (SD)[a]	Housing density[a] (dwellings/km^2, SD)[a]
ALE				
1 (least favourable)	13,350 (24)	26.9 (0.6)	9.2 (0.3)	67.8 (1.3)
2	14,369 (26)	144.5 (1.3)	40.1 (0.7)	431.9 (1.7)
3	15,175 (28)	220.7 (1.5)	63.9 (1)	778.6 (1.7)
4	8,741 (16)	233.1 (1.7)	104.9 (2.1)	1289.9 (5.2)
5 (most favourable)	3,137 (6)	383.3 (6.1)	300.4 (11.3)	3192.8 (179.7)

[a] SD, standard deviation.

Figure 8.1 Aus-ALE measures for SA1 geographies of three major cities in Australia.
ALE class 1 = least favourable, ALE class 5 = most favourable.

Of the 4,614 participants of AusDiab3, complete information on all variables of interest was available for 4,138 respondents (90%). A further 672 individuals who reported having a disability (that could prevent them from walking) were excluded from the analysis, which resulted in a final sample of 3,466 respondents (75%, Table 8.2). A lower proportion of survey respondents lived in ALE classes 1 and 5 (17.7 and 1.3%). Over half (66%) of the sample resided in intermediate ALE classes 2 or 3. T2D prevalence was lower among respondents living in more favourable ALEs relative to less favourable ALEs (4.9 versus 5.9%). In contrast, more favourable ALEs had a greater proportion of people at higher risk of developing T2D than less favourable ALEs (6.9 versus 5.6%). A higher proportion of those living in more favourable ALEs had a bachelor or post-graduate degree (22.4% in less favourable ALEs, 36.6% in more favourable ALEs), while a higher proportion of those living in less favourable ALEs had training in a trade (29.7% in less favourable ALEs, 25.2% in more favourable ALEs). There were also higher proportions of current or former smokers and respondents considered overweight or obese in less favourable ALEs.

On average, the cohort reported walking 3.51 days (standard deviation, SD 2.67) in the last week. The highest number of days were walked for leisure (2.49 days, SD 2.51), followed by walking for errands (1.16 days, SD 1.89) and walking for transit (0.31days, SD 1.87). Those living in more favourable ALEs reported walked more overall, relative to those living in less favourable ALEs.

Table 8.2 Cohort characteristics for Chapter 8 (N = 3,466).

	Overall (%)	Less favourable ALE[a] (1-3, %)	More favourable ALE[a] (4-5, %)
ALE		2899 (83.6)[b]	567 (16.4)
1 (least favourable)	613 (17.7)		
2	1234 (35.6)		
3	1052 (30.4)		
4	523 (15.1)		
5 (most favourable)	44 (1.3)		
Diabetes status			
Low risk	3067 (88.5)	2567 (88.5)	500 (88.2)
High risk	201 (5.8)	162 (5.6)	39 (6.9)
T2D	198 (5.7)	170 (5.9)	28 (4.9)
Median age (years, SD)	58 (10.64)	58 (10.55)	59 (11.05)
Female	1933 (55.8)	1,613 (55.6)	320 (56.4)
Educational attainment			
Secondary	1098 (31.7)	961 (33.1)	137 (24.2)
Trade	1004 (29)	861 (29.7)	143 (25.2)
Diploma	509 (14.7)	428 (14.8)	81 (14.3)
Bachelor/post-graduate	855 (24.7)	649 (22.4)	206 (36.3)
Smoking status			
Never	2107 (60.8)	1743 (60.1)	364 (64.2)
Former	1162 (33.5)	985 (34)	177 (31.2)
Current	197 (5.7)	171 (5.9)	26 (4.6)
BMI group			
Under/average weight	1174 (33.9)	951 (32.8)	223 (39.3)
overweight	1427 (41.2)	1219 (42)	208 (36.7)
obese	865 (25.0)	729 (25.1)	136 (24)
Mean days walked (SD)			
for transit	0.31 (1.07)	0.22 (0.90)	0.79 (1.60)
for errands	1.16 (1.89)	0.96 (1.73)	2.18 (2.31)
for leisure	2.49 (2.51)	2.39 (2.49)	3.01 (2.57)
overall	3.15 (2.67)	2.94 (2.63)	4.12 (2.61)

[a] ALE classes 1-3 and 4 and 5 aggregated, considered less and more favourable for active living, respectively.
[b] Column percentages, unless otherwise specified.

Comparing the most favourable to least ALEs, living in progressively more favourable ALEs was associated with more days walked for transit (OR 27.89, 95% CI 19.06 to 40.82), for errands (OR 10.06, 95% CI 7.82 to 12.94), and overall (OR 3.37, 95% CI 2.62 to 4.33, Table 8.3). Only living in ALE class 4 was conclusively associated with more days walked per week for leisure (OR 1.43, 95% CI 1.31 to 1.57). Effect estimates for the relationship between ALE and walking were higher in magnitude than any other covariate we examined (Supplementary Table D.2).

Table 8.3 Associations between ALEs and days spent walking in the last week for transit, errands, leisure, and overall (N = 3,466).

	Transit		Errands		Leisure		Overall	
ALE class	OR	95% CI	OR	95% CI	OR	95% CI	OR	95% CI
1 (reference)	1.00							
2	2.27	(1.67, 3.09)	2.12	(1.87, 2.40)	1.03	(0.95, 1.11)	1.23	(1.14, 1.33)
3	4.08	(3.03, 5.51)	1.91	(1.68, 2.17)	0.95	(0.87, 1.03)	1.19	(1.10, 1.29)
4	8.43	(6.24, 11.39)	4.88	(4.28, 5.57)	1.43	(1.31, 1.57)	2.27	(2.07, 2.49)
5	27.89	(19.06, 40.82)	10.06	(7.82, 12.94)	1.14	(0.90, 1.45)	3.37	(2.62, 4.33)

Bolded values indicate P<0.05. Estimates are from four logit-linked generalized linear models specified for Bernoulli distribution with a binomial denominator of 7 days. Models adjusted for adjusted for age, sex, education, income, smoking status, BMI classification and diabetes status. ALE class 1 = least favourable (reference), ALE class 5 = most favourable. Boldface indicates statistical significance (p≤0.05).

The predicted number of days in the last week walked for each purpose, adjusted for covariates, are summarized in Figure 8.2. As reflected by the models, neighbourhoods in more favourable ALEs (classes 4 and 5) exhibited more days walked across all purposes, aside from walking for leisure. We observed both a positively graded pattern with ALE class, as well enduring differences between each walking purpose. Although the greatest effect estimates between the least and most favourable ALEs were observed for transit walking (Table 8.3), the largest difference in the average number of predicted days walked was observed for walking for errands (Figure 8.2). Similarities across ALE classes 1-3 and 4-5 reinforced our aggregation strategy into less favourable ALEs (1-3) and more favourable ALES (4-5) for subsequent models.

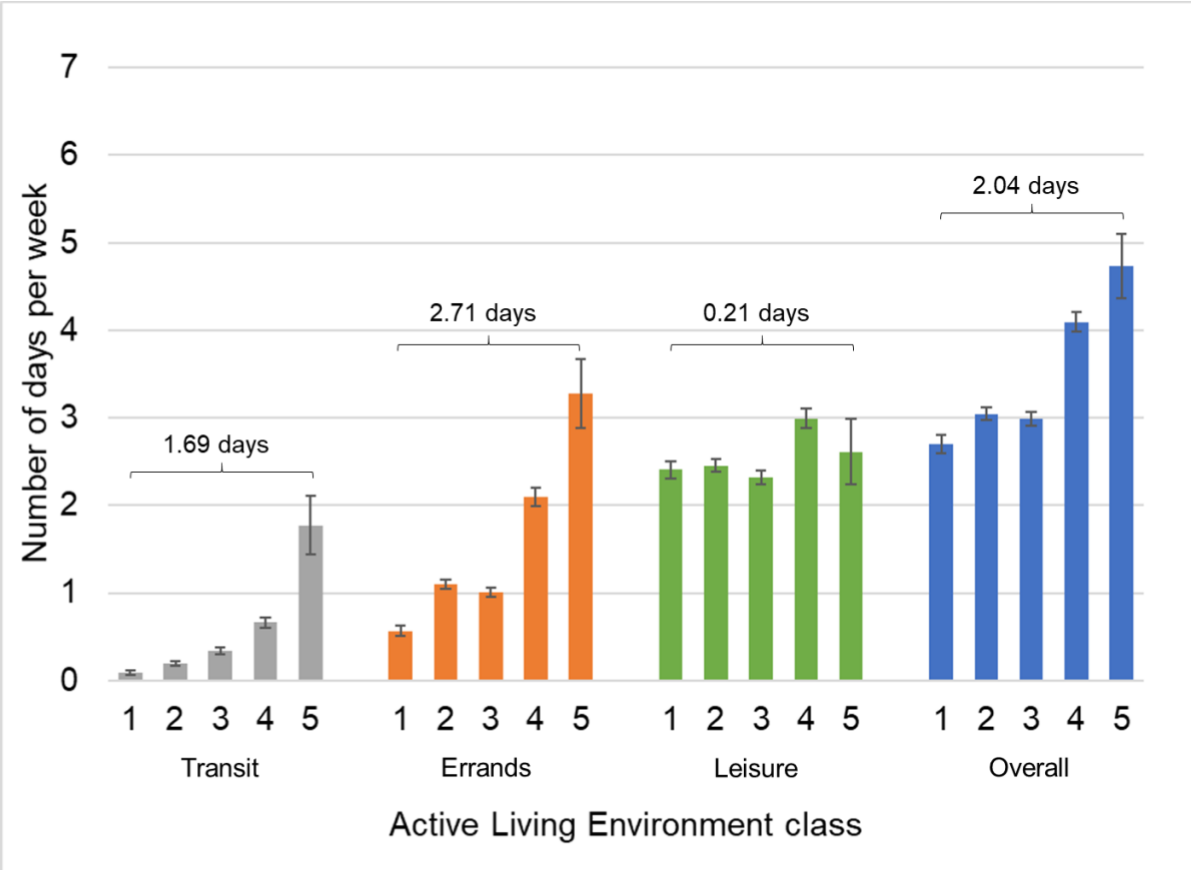

Figure 8.2 Adjusted average days walked in the last week for purpose.

Average marginal predictions for the average of the number of days walked in the last week for purpose by those living in the least favourable (class 1) to the most favourable (class 5) ALEs. The values indicated above each walking purpose is the difference between the number of days walked between the most and least favourable ALEs. Confidence intervals were calculated using the delta method. Predictions were obtained from models adjusted for age, sex, education, income, smoking status, BMI classification and diabetes status.

We then examined those who reported ever walking from those who reported never walking, and found that 410 (11.83%) ever walked for transit, 1342 (38.72%) ever walked for errands, 2264 (65.32%) ever walked for leisure and 2527 (72.91%) ever walked for any of the mentioned purposes. Models of ALE, dichotomized to less (i.e., ALEs 1 to 3) versus more favourable (i.e., ALEs 4 to 5), and odds of walking for purpose revealed strong associations between favourable ALEs and higher odds of ever-walking across all purposes (Figure 8.3). Favourable ALEs were associated with the highest increase in the odds of ever-walking for transit (OR 4.20, 95% CI 3.34 to 5.28) but were also strongly associated with walking for errands (OR 3.65, 95% CI 3.01 to 4.42). However, we saw little evidence of increasing days walked among transit walkers who lived in more favourable ALEs (OR 1.05, 95% CI 0.90, 1.23). More conclusive evidence of more days walked were present among those walking for errands (OR 1.37, 95% CI 0.25, 1.51), leisure walkers (OR 1.14, 95% CI 1.05, 1.24), and ever-walkers (OR 1.62, 95% CI 1.50, 1.76) living in more favourable ALEs.

Including neighbourhood self-selection variables had modest impacts on the associations between the ALE and walking for purpose (Supplementary Figure D.2, Figure D.3) but were important determinants of walking, independently of ALE class.

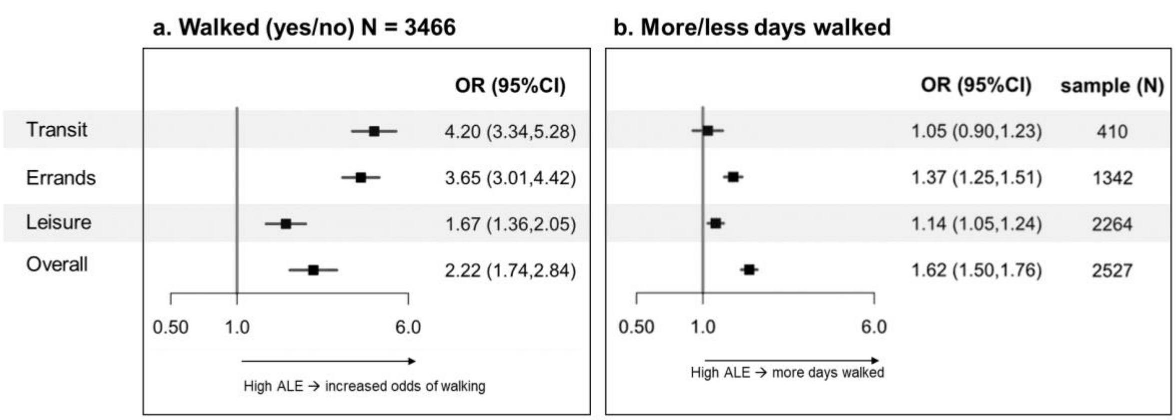

Figure 8.3 Association between ALEs and odds of walking for purpose, and number of days walked among walkers. Logistic models for the association between ALEs and odds of walking for purpose over the last week (panel a) and logit-link generalized linear models for the association between ALEs and the number of days walked for purpose over the last week (panel b). OR, odds ratios. ALEs were dichotomized into less favourable (ALE classes 1-3, reference) and more favourable (ALE classes 4-5. Models included product terms between ALE class (2-level factor variable) and T2D status (3-level factor variable; no T2D, high risk for T2D, has T2D).

Independent associations between ALEs and walking for purpose persisted in models that included an interaction term with T2D status (Table 8.4). Having T2D was independently associated with lower transit walking (OR 0.63, 95% CI 0.42 to 0.93), and was also inconclusively associated with lower errand walking (OR 0.88, 95% CI 0.73 to 1.05). High risk for T2D was independently associated with lower leisure walking (OR 0.78, 95% CI 0.68 to 0.90), and lower walking overall (OR 0.85, 95% CI 0.75 to 0.97). Conversely, high risk for T2D was also associated with more walking for errands (OR 1.22, 95% CI 1.03 to 1.44). We also found evidence of effect modification for ALEs and high-risk T2D status for errand walking, and ALEs and T2D status for leisure and overall walking.

Table 8.4 Independent associations of ALE and T2D status with days spent walking in the last week for transit, errands, leisure, and overall.
Modeled with product terms (N = 3,466).

	Transit		Errands		Leisure		Overall	
	OR	95% CI	OR	95% CI	OR	95% CI	OR	95% CI
ALE								
Less favourable (ref)	1.00		1.00		1.00		1.00	
More favourable	3.66	(3.20, 4.19)	2.97	(2.73, 3.23)	1.47	(1.36, 1.58)	2.07	(1.92, 2.23)
T2D status								
None (ref)	1.00		1.00		1.00		1.00	
High risk	1.07	(0.76, 1.50)	1.22	(1.03, 1.44)	0.78	(0.68, 0.90)	0.85	(0.75, 0.97)
T2D	0.63	(0.42, 0.93)	0.88	(0.73, 1.05)	1.02	(0.90, 1.15)	0.98	(0.87, 1.11)
ALE x high risk		P = 0.26		P < 0.01		P = 0.19		P = 0.53
ALE x T2D		P = 0.75		P = 0.99		P < 0.01		P < 0.01

Estimates are from four logit-linked generalized linear models with product terms between ALE class and T2D status specified for Bernoulli distribution with a binomial denominator of 7 days. Models adjusted for adjusted for age, sex, education, income, smoking status, BMI classification and diabetes status. ALE classes 1-3 = less favourable (reference), ALE class 4-5 = more favourable. Models included product terms between ALE class (2-level factor variable) and T2D status (3-level factor variable).

Marginal predictions for the number of days walked per week indicate that favourable ALEs were not necessarily associated with more days walked among those with T2D (Figure 8.4). The significant interaction for ALE and T2D with respect to leisure walking and overall walking resulted in reversed associations between ALE and walking. Those with T2D living in more favourable ALEs appeared to walk 0.84 fewer days for leisure and walked a similar number of days overall compared than those living in less favourable ALEs. The significant interaction for ALE and high risk for T2D with respect to errand walking diminished the differences in the number of days walked between those at high risk for T2D living in more favourable ALEs and less favourable ALEs. Those at lower risk of T2D living in favourable ALEs tended to walk 1.27 more days than those living in less favourable ALEs, while those at higher risk of T2D living in favourable ALEs tended to walk 0.69 more days than those living in less favourable ALEs.

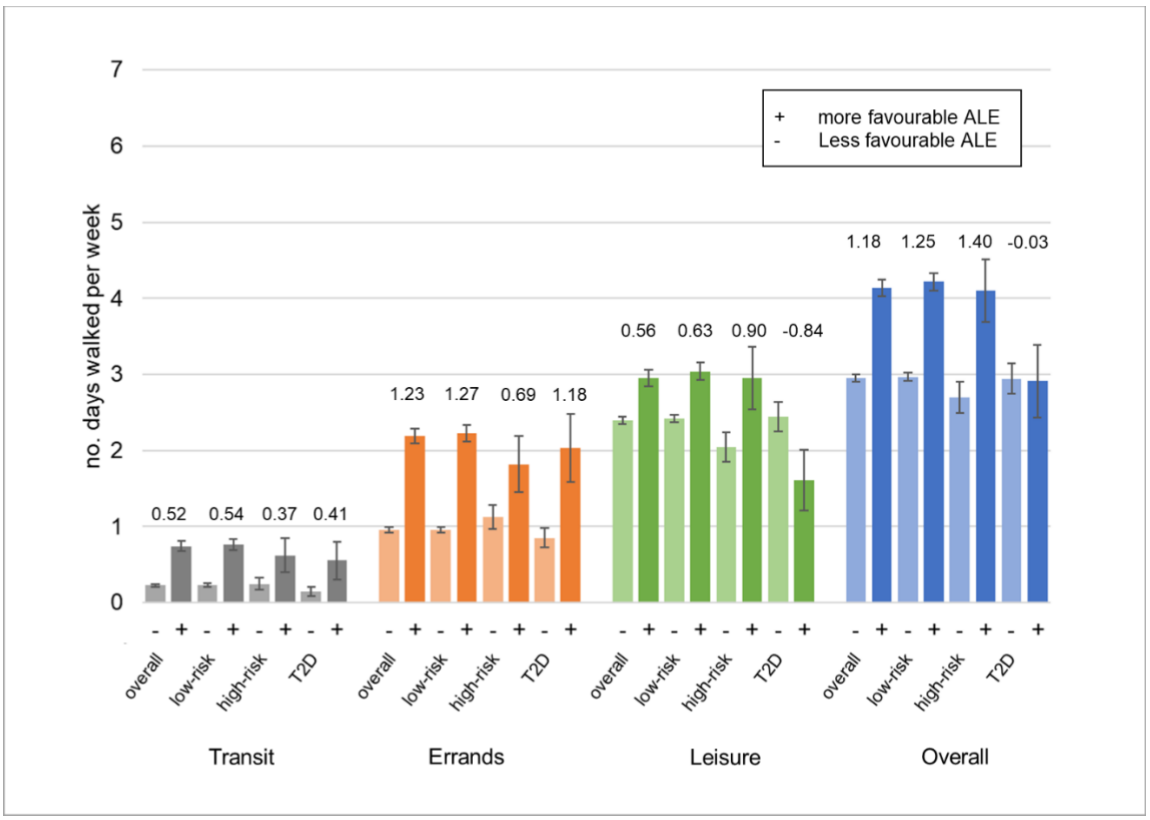

Figure 8.4 Adjusted average days walked in the last week for purpose by T2D status.

Average marginal predictions for the average of the number of days walked in the last week for purpose by cohort ("overall") by T2D status (low-risk, high-risk, T2D present), comparing those living less favourable (classes 1-3) to the more favourable (classes 4-5) active living environments (ALEs). Values listed above the bar graphs represent the difference in the number days walked comparing those living in more favourable ALES and less_favourable ALEs. Confidence intervals were calculated using the delta method. Predictions were from models which included product terms between ALE class (2-level factor variable) and T2D status (3-level factor variable) and were also adjusted for age, sex, education, income, smoking status, BMI classification and diabetes status.

8.6 DISCUSSION

In summary, we found that respondents who lived in neighbourhoods that were more conducive to active living was associated with more days walked for transport, errands, and overall. More favourable ALEs were associated with both higher odds of walking and more days walked in a given week for all purpose-specific walking except for walking for transit – for which favourable ALEs were associated with increased odds only. Similar to previous studies, adjusting for neighbourhood self-selection had modest impacts on effect estimates for ALEs (Giles-Corti et al., 2013; Owen et al., 2007; Sallis et al., 2009). Last, the positive associations between living in favourable ALEs and purpose-specific walking were either diminished (as in the case of errand walking for those at high risk for T2D) or reversed (as in the case of leisure walking for those with T2D). Transport and errand walking were consistently higher for those living in more favourable ALEs compared to those living in less favourable ALEs, regardless of T2D status.

We identified incremental increases for transport, errand, and overall walking from the least favourable to the most favourable neighbourhoods for active living. Consistent with previous studies (Moudon et al., 2006; Owen et al., 2007; Saelens & Handy, 2008; Sallis et al., 2009), the relationship between ALEs and leisure walking were less clear. Favourable neighbourhoods were conclusively associated with both the odds of walking and the number days walked among walkers with one exception. The odds of transit walking were much higher in more favourable ALEs, but there were no gains in the number of days walked for transit were among transit walkers in these neighbourhoods compared with less favourable ALEs. Similar patterns in transport walking have been observed in Canada (McCormack, 2017) and Latin America (Ferrari et al., 2020), and could mean that favourable ALEs act as a toggle for whether individuals use public transit or not, rather than a factor that increases transit walking among those already walking to transit-related destinations.

Walking for errands has not been as widely studied as an outcome separate and distinct from overall utilitarian walking and walking to work or to school. We found that favourable neighbourhoods for active living were associated with higher prevalence of errand walking and more days walked for errands. Previous Australian findings indicate that overall walking is driven by destination type (e.g., supermarkets and community resources) and distance from home, while the associations between transit stops and physical activity are modest (Gunn et al., 2017). Transit stops and stations may not contribute as substantially as other destination types toward achieving sufficient levels of physical activity (King, Bentley, Thornton, & Kavanagh, 2015). Our findings for errand walking are also congruent with a review of 46 studies that showed consistent links between utilitarian walking and the presence of retail and service destinations (Sugiyama, Neuhaus, Cole, Giles-Corti, & Owen, 2012). Local destinations and diverse land uses emerged in a recent systematic review as being the most strongly and consistently factors associated with positive physical activity outcomes in Australian adults (Zapata-Diomedi & Veerman, 2016). Trip-based data from Canada has found that the most common purpose for utilitarian walking is for shopping destinations, not walking to work (Millward, Spinney, & Scott, 2013). Nevertheless, transit and errand walking share many environmental predictors. Studies from Japan indicate that those living in places with higher residential density, land-use mix (Inoue et al., 2010) and perceived access to destinations with commuting and errands report more walking to commute and to run errands (Liao et al., 2018). Another study conducted in South Korea demonstrated that one-point increases in the propriety Walk Score® measure was associated with 1.5-1.8% increased odds of active transport for shopping (Kim, Kim, & Kim, 2020).

Adults with diabetes consistently report lower levels of physical activity compared to adults without diabetes (Kennerly & Kirk, 2018). A previous study of the AusDiab cohort showed 45% of individuals without diabetes reported insufficient levels of physical activity, whereas 60% of those with diabetes were insufficiently active(Magliano et al., 2008). Although the value of physical activity to chronic disease management is clear, many intrapersonal and environmental factors can impact adherence to medication and health behaviours (Ahola & Groop, 2013). Previous studies show that patients with T2D who live in neighbourhoods for active living are more physically active and walk more (Hajna, Ross, et al., 2016; Hosler et al., 2014). We found that those living in more favourable ALEs walked more for transport and walking for errands, regardless of T2D status and risk. However, those with T2D were less likely to walk for leisure in more favourable ALEs. These results suggest that ALEs could be most helpful for increasing walking rates related to utilitarian purposes for those with T2D. Our study is consistent with a study of T2D patients which found that found that neighbourhood walkability was related to self-reported active transportation, but not recreational walking (De Greef et al., 2011), as well as another study which found that living close-by to shops was important for increased transport walking in those with T2D (Taylor et al., 2008).

We found that those with T2D who lived in favourable ALEs were less likely to engage in leisure-time walking than those living in less favourable ALEs. This paradoxical finding could be a result of unmeasured neighbourhood factors that could discourage leisure walking in otherwise favourable built environments, such as crime (Foster et al., 2014). However, this may also be a result of altered health behaviours in response to being diagnosed with T2D. Patients who have knowledge of their diagnosis could be inclined to choose more structured or intentional exercise in their leisure time instead of walking. Although we were not able to test this theory, as it is out of the study's scope and variables available to us, we note that favourable ALEs are also more likely to have physical activity-related amenities like recreational centres that provide greater accessibility to such choices. The reversed relationship seen between ALEs and leisure walking for individuals with T2D, combined with the uptick in transit walking and errand walking in favourable ALEs, are likely to have produced the absence of difference in overall walking between favourable and less favourable ALEs seen for those with T2D in Figure 8.4. Unlike those with a T2D diagnosis, those we considered at higher risk of T2D in this study were not aware of their risk with respect to T2D. Not surprisingly, purpose-specific walking for those at risk of T2D appeared lower but generally similar to those without T2D - lower in less favourable ALEs and higher in more favourable ALEs across all walking purposes except for transit walking (Figure 8.4).

Strengths and Limitations

To our knowledge, this is the first study to compare the relationship between ALEs and purpose-specific walking rates between individuals with T2D, at risk of T2D, and without T2D. The strengths of this study include a large sample from an established health survey containing a rich source of sociodemographic, clinical and behavioural information specific to T2D. We also used a validated algorithm for identifying those at high risk for T2D (Chen et al., 2010). Novel measures of weekly walking for transit, errands, and leisure, and measures of neighbourhood preference available were leveraged to investigate previously understudied aspects of walking behaviour. We also employed new objective neighbourhood measures of active living friendliness derived using a validated and replicable methodology (Herrmann et al., 2019) from open data.

There are also limitations to bear in mind. While the present study investigates purpose-specific walking, the absence of weekly frequency and duration of walking for purpose did not allow us to derive differences in physical activity levels or energy expenditure. This is important to consider because the nature of walking for certain purposes tend to differ. For example, walking trips for transportation tends to involve walking faster, but also tend to be briefer in duration and shorter in distance than walking for leisure (Millward et al., 2013; Yang & Diez-Roux, 2012). These are factors that impact the quality and amount of physical activity achieved. Second, all walking measures used in this study were self-reported and subject to bias. However, we note that objective physical activity measurement techniques such as accelerometers and pedometers are not able to distinguish between different activities and activity purposes. Third, we noted previously that AUSDRISK used two physical activity variables as part of an algorithm to ascertain T2D risk (total time engaged in walking and as well as moderate or vigorous activity per week), which could have produced collider bias in estimating the relationship between ALEs and purpose-specific walking those at risk for T2D. Indeed, those classified as being at risk for T2D exhibited lower purpose specific walking levels compared to those without T2D (except for transit walking). While the variables used for the outcome measures in this study (specific to purpose), were distinct from those used in the algorithm (not specific to purpose), we remain cautious in our interpretation of the relatively reduced purpose-specific walking levels seen for those at risk for T2D. Last, the points of interest component of the ALE measure includes all destinations such as parks, shops, and schools, which arguably, are related to different purposes – leisure, errands, and transport, respectively. We chose to focus on a single measure of ALE for this study, but future work might consider examining neighbourhood features that are specific to purpose and behaviour (Giles-Corti, Timperio, Bull, & Pikora, 2005).

Ideas and policies for urban livability and their connections to health have grown in Australia (Badland et al., 2014; Giles-Corti et al., 2014). Our expectations of neighbourhoods have shifted from being traditionally zoned residential areas towards multi-purpose environments able to respond to housing as well as other needs, such as food, transit, services, and community. Grounded in the socio-ecological model of active living (Sallis et al., 2006), which articulates the importance of examining domain-specific physical activity that can be achieved in different contexts, we demonstrate that walking for transport, leisure, and errands are promising targets for increasing population-wide walking through ALEs. Notably, walking for errands was three times more prevalent than transit walking and consistently influenced by ALEs regardless of T2D risk and status. Hence, designing neighbourhoods with local destinations that facilitate walking for errands, would appear to be a priority. Although there are still gains to be made for enhancing neighbourhoods that will encourage greater leisure-time walking, the current study indicates that walking for errands may be importance to consider when designing built environment that promote walking for the general population as well as T2D patients. Moreover, encouraging sustainable forms of mobility, would have co-benefits for both public health and the environment.

8.7 REFERENCES

Ahola, A. J., & Groop, P. H. (2013). Barriers to self-management of diabetes. *Diabetic Medicine, 30*(4), 413-420. doi:10.1111/dme.12105

Australian Institute of Health and Welfare. (2020). *Diabetes*. Retrieved from Canberra: https://www.aihw.gov.au/reports/diabetes/diabetes

Australian Institute of Health Welfare. (2019). *Overweight and obesity: an interactive insight*. Retrieved from Canberra: https://www.aihw.gov.au/reports/overweight-obesity/overweight-and-obesity-an-interactive-insight

Australian Institute of Health Welfare. (2020). *Insufficient physical activity*. Retrieved from Canberra: https://www.aihw.gov.au/reports/risk-factors/insufficient-physical-activity

Avery, L., Flynn, D., van Wersch, A., Sniehotta, F. F., & Trenell, M. I. (2012). Changing physical activity behavior in type 2 diabetes: a systematic review and meta-analysis of behavioral interventions. *Diabetes Care, 35*(12), 2681-2689. doi:10.2337/dc11-2452

Badland, H., Whitzman, C., Lowe, M., Davern, M., Aye, L., Butterworth, I., Hes, D., & Giles-Corti, B. (2014). Urban liveability: Emerging lessons from Australia for exploring the potential for indicators to measure the social determinants of health. *Soc Sci Med, 111*, 64-73. doi:10.1016/j.socscimed.2014.04.003

Baldwin, S. A., Fellingham, G. W., & Baldwin, A. S. (2016). Statistical models for multilevel skewed physical activity data in health research and behavioral medicine. *Health Psychology, 35*(6), 552-562. doi:10.1037/hea0000292

Bauman, A., Ainsworth, B. E., Bull, F., Craig, C. L., Hagstromer, M., Sallis, J. F., Pratt, M., & Sjostrom, M. (2009). Progress and pitfalls in the use of the International Physical Activity Questionnaire (IPAQ) for adult physical activity surveillance. *Journal of Physical Activity and Health, 6 Suppl 1*, S5-8. doi:10.1123/jpah.6.s1.s5

Chandrabose, M., Rachele, J. N., Gunn, L., Kavanagh, A., Owen, N., Turrell, G., Giles-Corti, B., & Sugiyama, T. (2019). Built environment and cardio-metabolic health: systematic review and meta-analysis of longitudinal studies. *Obesity Reviews, 20*(1), 41-54. doi:10.1111/obr.12759

Chen, L., Magliano, D. J., Balkau, B., Colagiuri, S., Zimmet, P. Z., Tonkin, A. M., Mitchell, P., Phillips, P. J., & Shaw, J. E. (2010). AUSDRISK: an Australian Type 2 Diabetes Risk Assessment Tool based on demographic, lifestyle and simple anthropometric measures. *Medical Journal of Australia, 192*(4), 197-202. doi:10.5694/j.1326-5377.2010.tb03478.x

Colley, R. C., Butler, G., Garriguet, D., Prince, S. A., & Roberts, K. C. (2018). Comparison of self-reported and accelerometer-measured physical activity in Canadian adults. *Health Reports, 29*(12), 3-15.

De Greef, K., Van Dyck, D., Deforche, B., & De Bourdeaudhuij, I. (2011). Physical environmental correlates of self-reported and objectively assessed physical activity in Belgian type 2 diabetes patients. *Health and Social Care in the Community, 19*(2), 178-188. doi:10.1111/j.1365-2524.2010.00958.x

Donahue, K. E., Mielenz, T. J., Sloane, P. D., Callahan, L. F., & Devellis, R. F. (2006). Identifying supports and barriers to physical activity in patients at risk for diabetes. *Preventing Chronic Disease, 3*(4), A119.

Ferrari, G., Werneck, A. O., da Silva, D. R., Kovalskys, I., Gómez, G., Rigotti, A., Sanabria, L. Y. C., García, M. Y., Pareja, R. G., Herrera-Cuenca, M., Zimberg, I. Z., Guajardo, V., Pratt, M., Cristi-Montero, C., Rodríguez-Rodríguez, F., Marques, A., Cerin, E., Van Dyck, D., Pires, C., Fisberg, M., & on behalf of the, E. S. G. (2020). Is the perceived neighborhood built environment associated with domain-specific physical activity in Latin American adults? An eight-country observational study. *International Journal of Behavioral Nutrition and Physical Activity, 17*(1), 125. doi:10.1186/s12966-020-01030-6

Foster, S., Knuiman, M., Villanueva, K., Wood, L., Christian, H., & Giles-Corti, B. (2014). Does walkable neighbourhood design influence the association between objective crime and walking? *Int J Behav Nutr Phys Act, 11*, 100. doi:10.1186/s12966-014-0100-5

Giles-Corti, B., Badland, H., Mavoa, S., Turrell, G., Bull, F., Boruff, B., Pettit, C., Bauman, A., Hooper, P., Villanueva, K., Astell-Burt, T., Feng, X., Learnihan, V., Davey, R., Grenfell, R., & Thackway, S. (2014). Reconnecting urban planning with health: a protocol for the development and validation of national liveability indicators associated with noncommunicable disease risk behaviours and health outcomes. *Public Health Res Pract, 25*(1). doi:10.17061/phrp2511405

Giles-Corti, B., Bull, F., Knuiman, M., McCormack, G., Van Niel, K., Timperio, A., Christian, H., Foster, S., Divitini, M., Middleton, N., & Boruff, B. (2013). The influence of urban design on neighbourhood walking following residential relocation: longitudinal results from the RESIDE study. *Social Science and Medicine, 77*, 20-30. doi:10.1016/j.socscimed.2012.10.016

Giles-Corti, B., Timperio, A., Bull, F., & Pikora, T. (2005). Understanding physical activity environmental correlates: increased specificity for ecological models. *Exercise and Sport Sciences Reviews, 33*(4), 175-181. doi:10.1097/00003677-200510000-00005

Giles-Corti, B., Vernez-Moudon, A., Reis, R., Turrell, G., Dannenberg, A. L., Badland, H., Foster, S., Lowe, M., Sallis, J. F., Stevenson, M., & Owen, N. (2016). City planning and population health: a global challenge. *The Lancet, 388*(10062), 2912-2924. doi:10.1016/S0140-6736(16)30066-6

Gunn, L. D., King, T. L., Mavoa, S., Lamb, K. E., Giles-Corti, B., & Kavanagh, A. (2017). Identifying destination distances that support walking trips in local neighborhoods. *Journal of Transport & Health, 5*, 133-141. doi:10.1016/j.jth.2016.08.009

Hajna, S., Ross, N. A., Griffin, S. J., & Dasgupta, K. (2017). Lexical neutrality in environmental health research: Reflections on the term walkability. *BMC Public Health, 17*(1), 940. doi:10.1186/s12889-017-4943-y

Hajna, S., Ross, N. A., Joseph, L., Harper, S., & Dasgupta, K. (2016). Neighbourhood Walkability and Daily Steps in Adults with Type 2 Diabetes. *PloS One, 11*(3), e0151544. doi:10.1371/journal.pone.0151544

Heiss, V., & Petosa, R. (2014). Correlates of Physical Activity Among Adults With Type 2 Diabetes: A Systematic Literature Review. *American Journal of Health Education, 45*(5), 278-287. doi:10.1080/19325037.2014.933139

Herrmann, T., Gleckner, W., Wasfi, R. A., Thierry, B., Kestens, Y., & Ross, N. A. (2019). A pan-Canadian measure of active living environments using open data. *Health Reports, 30*(5), 16-25.

Hosler, A. S., Gallant, M. P., Riley-Jacome, M., & Rajulu, D. T. (2014). Relationship between objectively measured walkability and exercise walking among adults with diabetes. *Journal of Environmental and Public Health, 2014*, 542123. doi:10.1155/2014/542123

Hu, G., Eriksson, J., Barengo, N. C., Lakka, T. A., Valle, T. T., Nissinen, A., Jousilahti, P., & Tuomilehto, J. (2004). Occupational, commuting, and leisure-time physical activity in relation to total and cardiovascular mortality among Finnish subjects with type 2 diabetes. *Circulation, 110*(6), 666-673. doi:10.1161/01.CIR.0000138102.23783.94

Inoue, S., Ohya, Y., Odagiri, Y., Takamiya, T., Ishii, K., Kitabayashi, M., Suijo, K., Sallis, J. F., & Shimomitsu, T. (2010). Association between perceived neighborhood environment and walking among adults in 4 cities in Japan. *Journal of Epidemiology, 20*(4), 277-286. doi:10.2188/jea.je20090120

Kennerly, A.-M., & Kirk, A. (2018). Physical activity and sedentary behaviour of adults with type 2 diabetes: a systematic review. *Practical Diabetes, 35*(3), 86-89g. doi:10.1002/pdi.2169

Kim, E. J., Kim, J., & Kim, H. (2020). Neighborhood Walkability and Active Transportation: A Correlation Study in Leisure and Shopping Purposes. *International Journal of Environmental Research and Public Health, 17*(7). doi:10.3390/ijerph17072178

King, T. L., Bentley, R. J., Thornton, L. E., & Kavanagh, A. M. (2015). Does the presence and mix of destinations influence walking and physical activity? *International Journal of Behavioral Nutrition and Physical Activity, 12*, 115. doi:10.1186/s12966-015-0279-0

Korkiakangas, E. E., Alahuhta, M. A., & Laitinen, J. H. (2009). Barriers to regular exercise among adults at high risk or diagnosed with type 2 diabetes: a systematic review. *Health Promotion International, 24*(4), 416-427. doi:10.1093/heapro/dap031

Laatikainen, T., Dunbar, J. A., Chapman, A., Kilkkinen, A., Vartiainen, E., Heistaro, S., Philpot, B., Absetz, P., Bunker, S., O'Neil, A., Reddy, P., Best, J. D., & Janus, E. D. (2007). Prevention of type 2 diabetes by lifestyle intervention in an Australian primary health care setting: Greater Green Triangle (GGT) Diabetes Prevention Project. *BMC Public Health, 7*, 249. doi:10.1186/1471-2458-7-249

Liao, Y., Shibata, A., Ishii, K., Koohsari, M. J., Inoue, S., & Oka, K. (2018). Can neighborhood design support walking? Cross-sectional and prospective findings from Japan. *Journal of Transport & Health, 11*, 73-79. doi:10.1016/j.jth.2018.10.008

Magliano, D. J., Barr, E. L. M., Zimmet, P. Z., Cameron, A. J., Dunstan, D. W., Colagiuri, S., Jolley, D., Owen, N., Phillips, P., Tapp, R. J., Welborn, T. A., & Shaw, J. E. (2008). Glucose Indices, Health Behaviors, and Incidence of Diabetes in Australia. *The Australian Diabetes, Obesity and Lifestyle Study, 31*(2), 267-272. doi:10.2337/dc07-0912

McCormack, G. R. (2017). Neighbourhood built environment characteristics associated with different types of physical activity in Canadian adults. *Health Promotion and Chronic Disease Prevention in Canada-Research Policy and Practice, 37*(6), 175-185. doi:10.24095/hpcdp.37.6.01

McCormack, G. R., & Shiell, A. (2011). In search of causality: a systematic review of the relationship between the built environment and physical activity among adults. *International Journal of Behavioral Nutrition and Physical Activity, 8*, 125. doi:10.1186/1479-5868-8-125

Millward, H., Spinney, J., & Scott, D. (2013). Active-transport walking behavior: destinations, durations, distances. *Journal of Transport Geography, 28*, 101-110. doi:10.1016/j.jtrangeo.2012.11.012

Moudon, A. V., Lee, C., Cheadle, A. D., Garvin, C., Johnson, D., Schmid, T. L., Weathers, R. D., & Lin, L. (2006). Operational Definitions of Walkable Neighborhood: Theoretical and Empirical Insights. *Journal of Physical Activity and Health, 3*(s1), S99-S117. doi:10.1123/jpah.3.s1.s99

Muller-Riemenschneider, F., Pereira, G., Villanueva, K., Christian, H., Knuiman, M., Giles-Corti, B., & Bull, F. C. (2013). Neighborhood walkability and cardiometabolic risk factors in Australian adults: an observational study. *BMC Public Health, 13*, 755. doi:10.1186/1471-2458-13-755

OpenStreetMap Contributors. (2018). OpenStreetMap Base Data. Retrieved from https://www.OpenStreetMap.org

Owen, N., Cerin, E., Leslie, E., duToit, L., Coffee, N., Frank, L. D., Bauman, A. E., Hugo, G., Saelens, B. E., & Sallis, J. F. (2007). Neighborhood walkability and the walking behavior of Australian adults. *American Journal of Preventive Medicine, 33*(5), 387-395. doi:10.1016/j.amepre.2007.07.025

Saelens, B. E., & Handy, S. L. (2008). Built environment correlates of walking: a review. *Medicine and Science in Sports and Exercise, 40*(7 Suppl), S550-566. doi:10.1249/MSS.0b013e31817c67a4

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

Sallis, J. F., Saelens, B. E., Frank, L. D., Conway, T. L., Slymen, D. J., Cain, K. L., Chapman, J. E., & Kerr, J. (2009). Neighborhood built environment and income: examining multiple health outcomes. *Social Science and Medicine, 68*(7), 1285-1293. doi:10.1016/j.socscimed.2009.01.017

Sugiyama, T., Neuhaus, M., Cole, R., Giles-Corti, B., & Owen, N. (2012). Destination and route attributes associated with adults' walking: a review. *Medicine and Science in Sports and Exercise, 44*(7), 1275-1286. doi:10.1249/MSS.0b013e318247d286

Tanamas, S., Magliano, D., Lynch, B., Sethi, P., Willenberg, L., Polkinghorne, K., Chadban, S., Dunstan, D., & Shaw, J. (2013). *AusDiab 2012: The Australian Diabetes, Obesity and Lifestyle Study*. Retrieved from Melbourne: https://www.bakeridi.edu.au/Assets/Files/Baker%20IDI%20Ausdiab%20Report_interactive_FINAL.pdf

Taylor, L. M., Leslie, E., Plotnikoff, R. C., Owen, N., & Spence, J. C. (2008). Associations of perceived community environmental attributes with walking in a population-based sample of adults with type 2 diabetes. *Annals of Behavioral Medicine, 35*(2), 170-178. doi:10.1007/s12160-008-9021-3

Van Holle, V., Deforche, B., Van Cauwenberg, J., Goubert, L., Maes, L., Van de Weghe, N., & De Bourdeaudhuij, I. (2012). Relationship between the physical environment and different domains of physical activity in European adults: a systematic review. *BMC Public Health, 12,* 807. doi:10.1186/1471-2458-12-807

World Health Organization. (2019). *Global action plan on physical activity 2018-2030: more active people for a healthier world*: World Health Organization.

Yang, Y., & Diez-Roux, A. V. (2012). Walking Distance by Trip Purpose and Population Subgroups. *American Journal of Preventive Medicine, 43*(1), 11-19. doi:10.1016/j.amepre.2012.03.015

Zapata-Diomedi, B., & Veerman, J. L. (2016). The association between built environment features and physical activity in the Australian context: a synthesis of the literature. *BMC Public Health, 16*(1), 484. doi:10.1186/s12889-016-3154-2

Chapter 9

CONCLUSIONS

I examined relationships among neighbourhood environments, sociodemographic characteristics, and health-related behaviour with downstream health outcomes, specifically - mortality and hospitalization. I began with analyses of Canadian data and then expanded to studies of the UK and Australia. My overarching hypothesis was that favourable ALEs enable people to live more active lifestyles, which in turn, results in better cardiometabolic health outcomes. Linked population-based survey and administrative data enabled population-level studies of the built environment and health. I found that Canadians who live in more favourable ALEs walk more and are less likely to be hospitalized. Older women with T2D who live in more favourable ALEs have lower cardiometabolic mortality rates than those living in less favourable ALEs. I provide evidence that the association between favourable ALEs and cardiometabolic mortality is strongest for women with T2D. Using comparable cohorts from Wales UK and Canada, I showed that the inverse association between ALEs and hospitalization found for the Canadian cohort did not apply to the Welsh cohort. Lastly, I used an Australian biomedical cohort to demonstrate that favourable ALEs were associated with greater walking for errands and transit, regardless of having T2D or being at risk of T2D. The following findings address the four thesis objectives from 1.2 Objectives:

1. Favourable ALEs were associated with greater walking in Canada and Australia, and lower cardiometabolic mortality for older Canadian women with T2D;
2. Favourable ALEs were associated with lower hospitalization for all-causes and AMI in Canada;
3. Aside from the beneficial associations seen for older Canadian women with T2D related to cardiometabolic mortality, ALEs did not appear to be any more beneficial to the behaviours or hospitalization rates for those with or at risk for T2D compared to those without T2D.
4. The relationship between favourable ALEs and lower hospitalizations seen for Canada may not be generalizable to other countries, such as Wales UK.

9.1 Substantive Contributions

ALEs and Mortality

To my knowledge, Chapter 3 is the first individual-level study to examine associations between ALEs and premature cardiometabolic death. I showed that living in favourable neighbourhoods conferred a 22% reduction in the rate of death from cardiometabolic causes for older women (HR 0.78, 95% CI 0.63 to 0.97). As discussed in Chapter 3, gendered differences in daily activities (Chipperfield, 2008) may be an underlying reason as to why older women stand to benefit more from the built environments supporting such activities. These findings contribute substantive insight as to whether and how much neighbourhoods might support routine physical activity that will later translate into survival benefits for older women. Chapter 4 is the first study to examine ALE trends in mortality among groups stratified by T2D status. That mortality rates for women with T2D living in favourable ALEs approach that of women without T2D suggest these neighbourhoods could be instrumental for cardiometabolic survival in this population. The major substantive contribution of Chapter 4 is the evidence pointing to the importance of neighbourhoods for delaying cardiometabolic death in older women with T2D.

ALEs and Hospitalization

Chapter 5 demonstrates that, regardless of age and sex, adults age 45 and older who lived in progressively more favourable ALEs experienced lower odds of being hospitalized for any cause, AMI and CHF. Living in more favourable ALEs was associated with as much as a 24% reduction in the odds of an AMI-related hospitalization relative to the least favourable neighbourhoods (OR 0.76, 95% CI 0.65 to 0.90). This is a reduction that rivals the results of many lifestyle interventions and pharmaceutical approaches (Caldwell, Martinez, Foster, Sherling, & Hennekens, 2019). This study contributes to our substantive understanding of the degree to which built environments might help prevent major CVD events. Furthermore, no study to date has considered the possible confounding effect of living within close proximity to a hospital on the relationship between ALE and hospitalization. Chapter 6 set out to determine whether and to what extent living near a hospital obscures the associations seen in chapter 5. I showed that living within six kilometers to hospital is associated with slightly higher odds of hospitalization for cardiometabolic mortality. However, I also showed that the association between more favourable ALEs and lower odds of hospitalization was robust to living close to hospital. The theoretical contribution of this manuscript is geographical in nature and constitutes the first study to show that living close to hospital partially confounds the association between residing in favourable ALEs and lower odds of hospitalization for cardiometabolic diseases.

Role of Physical Activity and Walking

ALEs are thought to operate by supporting physical activity and walking, and in turn, improve cardiometabolic health outcomes. Few studies have the necessary environmental, behavioural, and health data to address this hypothetical pathway. This dissertation begins to examine this proposed mechanism for a large sample of Canadians. Chapters 3 and 5 reinforce the importance of ALEs for walking overall. This was demonstrated by the upward shift in the distribution of people who reported walking for leisure in more favourable ALEs, compared with the overall consistent levels of leisure time physical activity across ALE classes (Figure 3.2, Figure 5.3, Supplementary Figure A.3). However, mediation analyses of Chapter 5 attributed a relatively small proportion of the relationship between ALEs and hospitalization for AMI (3.2%) and CHF (10.7%) to leisure-time walking. This suggests that the physical activity derived from walking does not fully explain the relationship between ALEs and subsequent health outcomes, and implies that activities outside of walking for leisure, outside of walking, and outside of other leisure activities are important drivers of health outcomes. Results from the Australian cohort data of Chapter 8 demonstrated that living in neighbourhoods that were incrementally more conducive to active living was associated with more days walked for transport, errands, and overall, but showed the strongest relationship with walking for errands. Overall, this dissertation provides insight as to the extent to which ALEs function through the physical activity pathway, and emphasizes the importance of walking, specifically. This work also points to the importance of considering activities outside leisure-time or exercise.

BUILT ENVIRONMENTS FOR THOSE WITH OR AT RISK OF T2D

Overall, those with or at risk of T2D consistently reported lower rates of walking, exercise, and/or physical activity compared to those without T2D. In both Canada and Wales, those with T2D had elevated rates of hospitalization (Chapter 7) and in Canada, older women with T2D had elevated rates of premature cardiometabolic mortality (Chapter 4). Previous studies show that T2D patients who live in favourable ALEs may be more physically active and walk more than those living in less favourable ALEs (Hajna, Ross, et al., 2016; Hosler et al., 2014). However, whether people with or at risk of T2D stand to benefit especially from favourable ALEs across clinical, demographic, and geographic contexts is unclear.

Chapter 4 provides evidence that the benefits of ALEs are concentrated in older women with T2D for Canada. This may indicate that the built environment is a missing component to current secondary prevention strategies for older women with T2D. In contrast, Chapter 7's findings with respect to hospitalization and walking suggest that favourable ALEs are no more advantageous to those with T2D than to those without T2D. Although protective associations between ALEs and hospitalizations for cardiometabolic disease were seen for Canadians (Chapters 5 and 6), these associations were inconclusive but similar in direction and magnitude for Canadians with T2D (Chapter 7). The finding that ALEs were not especially beneficial to people with T2D in Wales is unsurprising, because no conclusive associations were seen between ALEs and hospitalization for Wales overall. Chapter 8 is one of the few studies to assess purpose-specific walking and is the only study to stratify by T2D status. The study showed that favourable ALEs were associated with increased weekly walking overall and for transport, errands, and leisure for Australians, but also showed that these gains were diminished for those with and at risk of T2D.

That favourable ALEs could potentially prevent cardiometabolic death in older women with T2D, but not be *especially* beneficial (relative to those without T2D) in terms of hospitalization or walking is not necessarily a contradiction. Rather, this may simply mean that the additional amount of physical activity derived from activities supported by ALEs could be restorative to the long-term health outcomes of those with T2D, particularly for older women with T2D. This dissertation suggests that ALEs may be a valuable consideration for prevention strategies aimed at those diagnosed with T2D or at risk of developing T2D.

Importance of Geographic Context

Having derived comparable measures for three countries and examined their associations with health behaviours and outcomes, key insights emerged. First, my results revealed overall positive relationships between favourable ALEs and walking in Canada (Chapter 3 and 5) and Australia Chapter 8. This corroborates previous cross-national studies demonstrating the association between ALEs and greater walking in a variety of different geographic contexts (Althoff et al., 2017; Sallis et al., 2016). However, my comparative study of Canada and Wales revealed some important departures. Although ALE class measures were produced from identical methodologies and similar data sources, Canada and Wales have fundamentally different geographies and are likely to impact behaviours in different ways. For example, the dwelling and destination densities of Can-ALE class 5 neighbourhoods (the most favourable for active-living) were much higher than those of Wal-ALE class 5 neighbourhoods. Wal-ALE class 5 seemed more similar to Can-ALE class 4 neighbourhoods. Each Can-ALE class also differed in compositional factors from its Wal-ALE counterpart (e.g., smoking status, educational attainment). As described in Chapter 7, distinct historical, geographic and social factors have shaped the built environments of Canada and Wales to be distinct, and have also produced different sociodemographic patterns across ALE classes in the two countries. These environments influence how people interact in and with their neighbourhoods. For example, Canada's most urban neighbourhoods are often in cities which have enjoyed investments in public transportation infrastructure and are often key centres of commerce. On the other hand, the most urban areas of Wales have a very different history that have not seen the same kinds of investments or development. Thus, it comes as little surprise that the behaviours and health outcomes across ALEs in Wales do not necessarily correspond to those of ALEs in Canada. Canadian respondents living in favourable ALEs exhibited lower odds of obesity at baseline as well as lower odds of hospitalization over the study period, while Welsh respondents exhibited less patterned differences in obesity prevalence across ALE classes, and higher odds of hospitalization in more favourable ALEs.

The results of this study suggest that the generalizability of built environment associations with health outcomes is limited. There is a need for a richer understanding of how ALEs and physical activity domains operate to produce different health outcomes in a variety of social, cultural, and policy settings.

9.2 METHODOLOGICAL CONTRIBUTIONS

LEVERAGING LINKED ADMINISTRATIVE DATA

This dissertation leveraged record-linked data to obtain detailed information on a wide range of socio-demographic characteristics and behaviours that are known correlates of both ALEs and health, such as education, income, and smoking status. Chapters 3 to 7 present a methodological advance over previous ecological studies in the use of record-linked data. Chapters 5 to 7 are thus far the only individual-level studies of ALEs and hospitalization. Importantly, the record linkage allowed for a reduction in the risk of misclassification bias associated with ecological approaches by using small administrative geographies to link individuals with their neighbourhoods. Record linked health surveys makes it possible to construct large population-based cohorts with high-quality measures appropriate for longitudinal analyses. Extracting information on health outcomes from administrative hospitalization data for research purposes bears unique challenges (e.g., data quality in terms of accuracy and coverage, event-oriented data structure, temporal differences in data collection). However, these data are objectively collected and are not subject to recall uncertainty and reporting biases of self-reported health measures, which can impact reliability.

USE OF GIS-DERIVED MEASURES OF THE BUILT ENVIRONMENT

Worldwide physical inactivity and the rapid shift toward urban environments signal a need for comparative studies to assess the robustness of the relationship between built environments and health to further inform policy action. Such studies are costly, resource-intensive, and lack comparable measures. To date, international research in this field has not considered using secondary data and record linkage approaches to produce standardized measures. Focusing on countries that share similar practices for collecting administrative health and geocoded data, I assembled comparable cohorts, variables, and measures for Canada, Wales UK, and Australia through research collaborations with the SAIL Databank (Wales) and the Baker Heart and Diabetes Institute (Australia). As previously described (Herrmann et al., 2019), the Can-ALE dataset are geography-based composite measures that are derived from high-quality open data sources. Using the same methodology, I led the development of the Wales Active Living Environment database (Wal-ALE) and the Australia Active Living Environment database (Aus-ALE). The use of national samples, paired with objective GIS-derived environmental measures, represents a methodological advancement in our ability to assess the neighbourhood's potential for influencing downstream individual-level health outcomes. Chapter 7 demonstrates the feasibility of using linked secondary data for international comparisons and has also resulted in new comparable ALE measures for Australia and Wales that can be used in future studies. The methodology and approach of deriving measures for hospital proximity using open data (Chapter 6) is also novel and will be highly applicable to future studies of the environmental determinants of hospitalization.

Availability of Longitudinal Health Outcomes

Cross-sectional studies are limited in their ability to account for the sequence of exposures and outcomes. Moreover, self-reported health outcomes are vulnerable to recall errors and bias. This dissertation used objective longitudinal health outcomes derived from administrative health databases. With the information on time to death and hospitalization, I was able to ensure, to some degree, that exposure to the built environment preceded the health event. I employed washout periods when possible. The use of baseline survey dates, hospitalization dates, and date of death allowed me to better address the conceptual framework that begins with exposure to the built environment and ends with a health outcome.

Applying New Comparative Approaches to Linked Population Data

The last overall strength of this dissertation is the unique approach to cross-national comparative analyses that can be applied to future international studies of population health. Chapter 7 makes a unique methodological innovation as the first study to use internationally sourced record linked data and open-source environmental data to produce two parallel, harmonized cohorts suitable for comparative analysis. It illustrates the value of record linkage initiatives for future international collaborative research. The comparative analysis in Chapter 7 was made possible through: 1) coordinated collaborations between two countries with organizational systems, ethics processes and computational infrastructure in place to link data; 2) parallel administrative and survey data holdings that contain similarly coded variables; 3) population-based samples that were adequately matched on time period, follow-up time, and demographic variables such as age and sex; and 4) comparably derived environmental ALE measures and hospitalization metrics.

9.3 LIMITATIONS

SINGLE BASELINE EXPOSURE AND BEHAVIOURAL MEASURES

There are three overarching limitations of this work that warrant consideration for future studies on built environments and health. The first is that, in contrast to the longitudinal hospitalization and mortality outcomes, baseline environmental and behavioural measures in this study were cross-sectional, available for a single timepoint. With respect to environmental measures, aspects of ALEs such as the road network are relatively enduring features of the built environment. The larger concern is exposure misclassification due to residential mobility. The average follow-up time was five years for the Canadian mortality and hospitalization studies, and 3.9-4.4 years for the comparative study of Wales and Canada. According to the 2016 Canadian census, 13% of the population reported moving in the last year before census response, and 38.2% of the population moved in the last five years of response (Statistics Canada, 2017a). This provides some clues as to the potential for misclassification, but does not provide insight into the extent to which individuals move to drastically different ALE classes (i.e., moving from a very favourable to a very unfavourable neighbourhood for active-living, and vice versa). It is also possible that this research may render disproportionately inaccurate estimates for frequent movers, which has been linked with important factors such as socioeconomic status and is a research area of particular interest to geographers (Morris, Manley, & Sabel, 2018). While it was not possible to account for residential moves after baseline, I was able to impose lag times for studies of mortality and hospitalization outcomes to increase the likelihood of a longer period of neighbourhood exposure.

CHALLENGES OF USING ADMINISTRATIVE DATA

The second key limitation of this research involves the well-known caveats of using secondary administrative hospital data. Due to the fact that administrative data is collected for non-research purposes, its use in health research is sensitive to incomplete information as well as the level of detail in health outcomes and utilization type (Gavrielov-Yusim & Friger, 2014; Jutte et al., 2011; Mazzali & Duca, 2015; Riley, 2009). The Discharge Abstract Database (DAD) is Canada's national database of hospital discharges, deaths, sign-outs, and transfers and contains administrative, clinical, and limited demographic data. If was first established in 1963 for the collection of information about acute hospitalizations in the Ontario (Canadian Institute for Health Information, 2012b). Acute inpatient hospitals across the country maintain provincially standardized records and are required to submit abstracts with key requested fields to the Canadian Institute of Health Information (CIHI) for incorporation into the DAD. The database does not include records from the province of Quebec. Although this province's omission is not trivial and typically comprises a quarter of all inpatient separations in Canada (Canadian Institute for Health Information, 2012c), it is unknown whether and to what extent their inclusion would alter our results.

It is also important to note that although the DAD reliably captures acute hospitalization, it does not capture emergency visits or primary care utilization. These are events that are useful for fully characterizing individual health care utilization and morbidity. Although records related to day procedures, long-term care, rehabilitation and mental health events were available in the DAD, these were excluded from our analyses due inconsistencies across regions, time, and reporting practices (Canadian Institute for Health Information, 2012c). A similar exclusion of day case procedures was imposed for the Wales PEDW database. Although one might argue that acute hospitalizations capture only a limited share of the total burden of chronic disease and health care services in Canada, acute admissions are hard outcomes that are most closely related to morbidity and mortality. Acute hospitalization events are also major drivers of health care costs.

The Canadian hospitalization data are further complicated by historical changes in the ICD diagnostic codes that occurred asynchronously across the country (Canadian Institute for Health Information, 2012d). For instance, select provinces and territories had previously coded hospitalizations using the *International Statistical Classification of Diseases and Related Health Problems, 9th Revision, Clinical Modification* (ICD-9-CM). Provinces began implementing the *International Statistical Classification of Diseases and Related Health Problems, 10th Revision for Canada* (ICD-10-CA) in 2000/2001. By the 2004/2005 fiscal year, all provinces and territories (except for Quebec) adopted the ICD-10-CA (Supplementary Figure F.1). Over the course of the analyses for this dissertation, I found marked differences in hospitalization frequencies within certain provinces (namely, Manitoba) before and after the transition to ICD-10-CA. Therefore, it was necessary to restrict the study period to 2004-2013, despite having data from 1999. This resulted in a roughly 10% exclusion of hospital records available.

Variations in Approaches to Measuring Physical activity

The last limitation relates to the measurement of physical activity. It is widely acknowledged that subjective measures are prone to reporting error and recall bias (Prince et al., 2008), and tend to provide inaccurate estimates of absolute physical activity (Sallis & Saelens, 2000). Moreover, self-reported measures across different studies have the potential to vary considerably in the types, frequency, and duration of physical activity measured. In contrast, sensor-based methods have the advantage of being objective, and are seen as more precise measures of absolute physical activity (Tudor-Locke, Williams, Reis, & Pluto, 2002). These measures are also amenable to comparisons across different studies (Hajna, Ross, Brazeau, et al., 2015).

Where readers need to exercise particular caution with respect to self-reported physical activity measures is in Chapter 7. I found that the physical activity measures that were available for Canada and Wales lacked comparability. Physical activity information in the CCHS from 2000 to 2011 (and up until 2014) was collected using the Minnesota Leisure Time Physical Activity Questionnaire, which asks respondents to recall their frequency and duration of different leisure-time physical activities over the past 3 months. Along with MET values that are assigned to different activities and are estimated based on that activity type's typical intensity, these quantities are used to calculate the average daily energy expended for the activity performed by the individual, corresponding to kcal/kg/day units. One of the advantages of using this method is the possibility for relative comparisons of different physical activity types, and the calculation of proportions and total physical activity levels. For Chapter 4, I leveraged these measures to compare leisure-time physical activity with leisure-time walking. In contrast, the WHS for Wales asks about respondents' light, moderate, and vigorous exercise or physical activity lasting at least 30 minutes over the last seven days. These are variables that are quite different from measures of leisure-time physical activity in the Canadian survey but were nevertheless used to classify those who did versus those who did not perform any physical activity in the last 3 months (Canada) or the last week (Wales). Furthermore, I confirmed that leisure-time walking, but not overall leisure-time physical activity, was associated with ALEs for Canada. Unfortunately, no walking variables existed for Wales, and thus I was restricted to using the less relevant but most comparable variable for Canada. While no comparative study was conducted for Australia, it is important to note that these measures of weekly purpose-specific walking were also different and could bear different relationships with ALEs, had survey items more similar to those of Canada or Wales been administered.

Self-reported physical activity remains one of the most practical and feasible approaches to large-scale studies for which sensor-based methods are impractical or costly (Valanou, Bamia, & Trichopoulou, 2006). Physical activity by self-report also remains necessary for differentiating between the types and domains of physical activity (e.g., leisure, exercise, utilitarian, transport) (Haskell, 2012b), which is crucial for our understanding of how built environments support routine physical activity (Sallis & Saelens, 2000).

9.4 FUTURE DIRECTIONS

This dissertation provides a basis for new research directions for ALEs, physical activity, and health, and many opportunities are imminent to extend this work. First, the findings indicate that favourable ALEs are related to lower mortality and lower hospitalization rates. However, Canada is a racially and ethnically diverse country and is also home to many immigrant populations. A previous study suggests that neighbourhoods that are less conducive to walking are especially associated with diabetes risk in recent immigrants living in low-income neighbourhoods (Booth et al., 2013). More work is necessary to fully determine relationships of ALE and health among important groups in Canada as a matter of health equity, especially considering the health disparities that exist for chronic conditions. For example, the lifetime risk of developing diabetes is five in ten people in the general population, but that risk is much higher for people of First Nations ancestry, which is eight in ten (Turin et al., 2016). These health inequalities are also related to and exacerbated by socioeconomic status. One Canadian study suggests lower-income women were more likely to develop T2D than high-income women over a 14-year period, even after adjusting for other demographic factors and obesity (Ross, Gilmour, & Dasgupta, 2010). Other groups have noted that highly walkable environments can overlap with the most deprived neighbourhoods (King & Clarke, 2015), calling for greater attention to both the contextual aspects of the built environment as well as sociodemographic composition.

Second, the creation of novel, comparably derived ALE measures for all of Canada, Wales and Australia make possible future comparative studies. International growth of urban environments, motorized transport, and sedentary lifestyles signal a need for increased comparative studies between countries. Future work could also include deriving these measures for other countries – especially those for which the built environment's impact on health have not been studied. Low- and middle-income countries are of particular importance because these are some of the places that are experiencing the most rapid changes in urban development as well as the steepest increases in obesity, diabetes, and other chronic conditions. Open-source geospatial data on road networks are approaching global completion (Barrington-Leigh & Millard-Ball, 2017), and will in turn make the derivation of these built environment measures more feasible worldwide.

Third and related to the previous direction, this work is proof that large-scale comparative studies with secondary data are possible. The available holdings of linked data repositories and centres such as the SAIL Databank (Lyons et al., 2009), Statistics Canada's Canadian Research Data Centre Network, and others like the Western Australia Data Linkage System (Holman, Bass, Rouse, & Hobbs, 1999; Holman et al., 2008) are sensible starting points for assembling data sets. Moreover, a future direction that relates to this dissertation specifically is examining, in parallel, those at higher risk for chronic diseases across different countries using population risk algorithms. This dissertation utilized both the DPoRT (Rosella et al., 2011) and AUSDRISK (Chen et al., 2010), but these have yet to be used in a single comparative study or considered for use with analogous risk tools for other populations such as the QDScore for England and Wales (Hippisley-Cox, Coupland, Robson, Sheikh, & Brindle, 2009).

9.5 POLICY IMPLICATIONS

Worldwide movement toward urban and suburban environments has turned a large proportion of our activities and time toward sedentary behaviours (Leon, 2008; Ng & Popkin, 2012). It is now widely acknowledged that obesity and chronic diseases are influenced by social factors, policy, and environmental conditions that promote physical inactivity and poor diet choices – or make physical activity and healthy diets difficult to achieve (Kolb & Martin, 2017; Swinburn et al., 2011). This dissertation sought to determine the extent to which our physical surroundings and neighbourhoods might help us meet our needs for physical activity.

The aim of these studies was to add to the growing evidence base for the relationship between neighbourhood environments and mortality, hospitalization, and chronic disease. I determined that favourable neighbourhoods for active living translate into observable differences in premature cardiometabolic mortality for older women with T2D. Policies that consider and advance the design of public spaces and built environments to be conducive to active living might expect long-term benefits to concentrate in women. In addition, my results suggest that secondary prevention strategies for patients with T2D could see greater success with a comprehensive audit of individual-level behaviours in the context of where they live and the resources patients have available to them to carry out favourable health behaviours.

Canada spends a substantial proportion of its health care resources on CVDs (Canadian Institute of Health Information, 2018) as is the case in other countries (Tarride et al., 2009). We carry excess expenses estimated to be $6.8 billion that relate to physical inactivity (Janssen, 2012). The potential for ALEs to reduce the odds of hospitalization for AMI by 24% and all-causes by 22%, as well as reduce all-cause admission rates among hospital users by as much as 13% suggests that our neighbourhoods could keep people out of hospital, and perhaps reduce our health care expenditures. However, my results indicate that ALEs are probably limited in their ability to reduce hospitalization frequency and intensity among those with prevalent cardiovascular conditions. Although similar reductions in hospitalization rates and costs have been observed in Australia, (Mazumdar et al., 2016; Yu et al., 2017) it is unlikely that the mitigating association of ALEs with health care utilization is generalizable to Wales and other countries.

The last policy implication of this work relates to the role that built environments play in how we carry out our daily activities. If we are to consider interventions and policies that enhance ALEs, this research suggests that we might best begin by identifying appropriate land-use and zoning avenues for new urban developments built for walking, but also encourage the addition of a variety of service and retail destinations amenable to utilitarian walking in particular. We might also work towards identifying and rectifying less-supportive environments with attention to which domains of walking and physical activity are most impeded by such neighbourhoods and why. Specifically, Chapter 8 suggests that Australia might see substantial increases in walking by focusing on built environment features and policies that enhance local retail and service destinations to promote errand-related activities. This research also suggests that although we might expect that a greater share of the population will use public transport with greater investments in infrastructure, such investments may translate to relatively smaller gains in overall physical activity levels of the population.

Whether the quality of neighbourhood environments becomes an actionable priority for municipal governments and policy makers could depend on our ability to communicate these findings in the language familiar to medicine, population health and public health. Astell-Burt and colleagues (2018) advocate for this approach. They present a number of population health interventions that have rendered reductions in chronic disease risk factors and incidence on par with those of medications (Astell-Burt, Rowbotham, & Hawe, 2018). In many ways, this dissertation attempts to do just that, and builds the case for ALEs as both a sensible and intervenable way to achieve the physical activity rates that lifestyle interventions have struggled to achieve (Schellenberg et al., 2013), reduce the burden of major cardiovascular events as effectively as statin-use (Taylor et al., 2013), or delay premature cardiometabolic death to the extent of metformin (Rodriguez-Gutierrez & Montori, 2016). Pharmaceutical advances and innovative lifestyle programs to modify health behaviours will always be major public health approaches. This work argues that investing in neighbourhoods to enable active lifestyles deserve a place in population health strategies for preventing widespread chronic disease.

Appendix A

SUPPLEMENTARY MATERIALS TO CHAPTER 3

Supplement to: Active living environments, physical activity and premature cardiometabolic mortality in Canada: a nation-wide cohort study

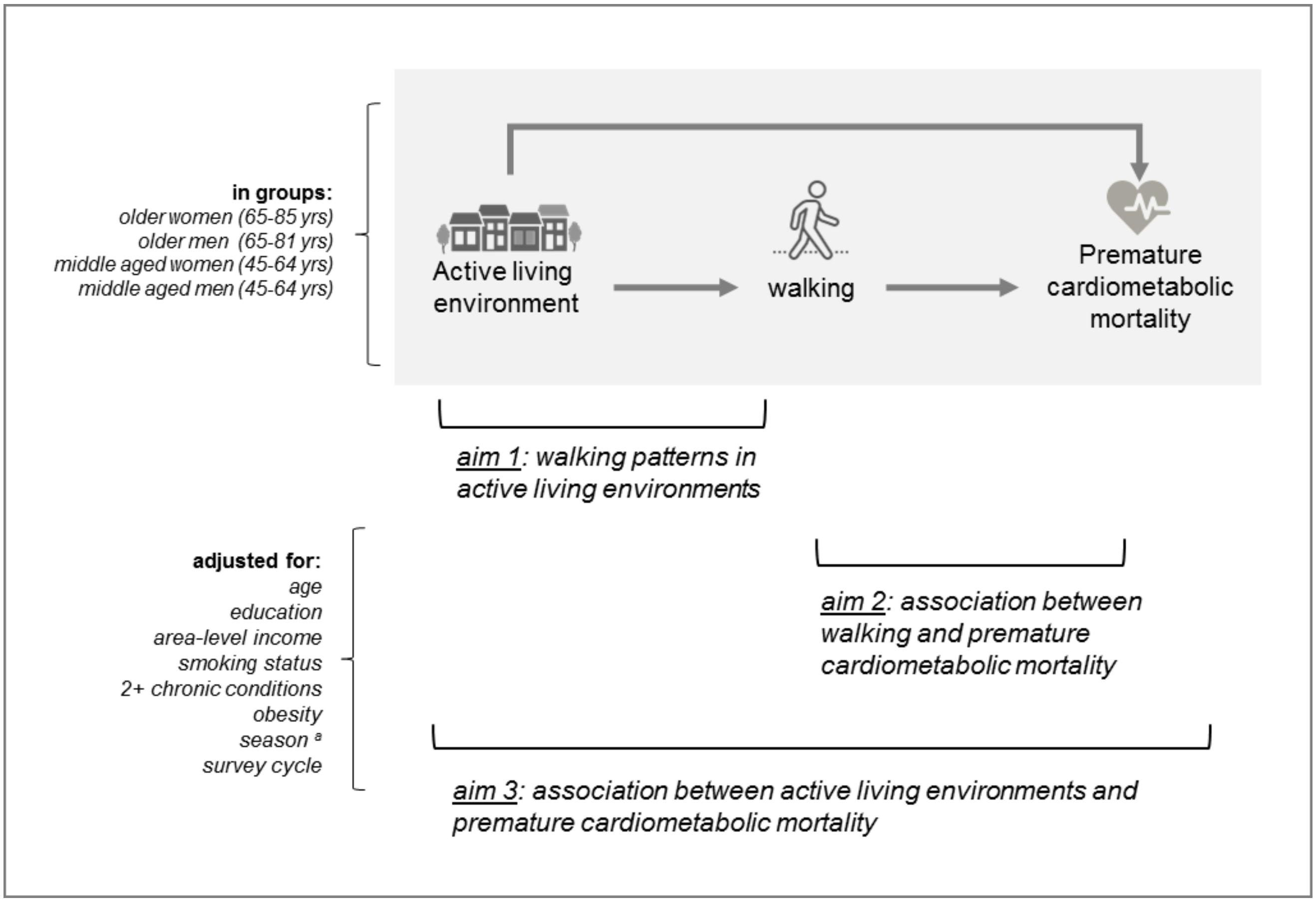

Figure A.1 Conceptual diagram and study design

Following the physical activity pathway, we examined whether higher average walking was reported in more favourable active living environments (aim 1), tested the association between walking and cardiometabolic mortality (aim 2), and tested the overall association between active living environments and cardiometabolic mortality (aim 3).

a Season of survey response was only adjusted for in models testing the association between walking and cardiometabolic mortality in aim 2.

$$\frac{150\ min}{week} = \frac{21.43\ min}{day} = \frac{0.36\ hours}{day}$$

$$\frac{\frac{91.5\ days}{3\ months} \times \frac{4\ months}{year} \times \frac{0.36\ hours}{day} \times\ 4\ MET}{365\ days} = \mathbf{1.44\ kcal/kg/day}$$

Figure A.2 Energy expenditure calculation

Calculation of energy expenditure cut-off consistent with recommended 150 min/week of moderate-vigorous physical activity.

Table A.1 Chapter 3 complete case analysis exclusions
Summary of individuals with missing data excluded from complete case analysis.

Variable	Number missing (%)			
	older women	older men	middle aged women	middle aged men
active living environment	250 (0.41)	235 (0.39)	775 (1.28)	815 (1.35)
smoking	140 (0.23)	115 (0.19)	100 (0.17)	125 (0.21)
education	710 (1.18)	515 (0.85)	665 (1.1)	775 (1.28)
obesity	2180 (3.61)	1115 (1.85)	3305 (5.47)	875 (1.45)
area-level income	225 (0.37)	190 (0.31)	325 (0.54)	295 (0.49)
walking	1890 (3.13)	2580 (4.27)	1335 (2.21)	2535 (4.2)
physical activity	1205 (1.99)	2220 (3.67)	820 (1.36)	2125 (3.52)
Total [a]	4560 (7.55)	3650 (6.04)	5900 (9.76)	4670 (7.73)

[a] Total number of individuals with missing data on any variable, excluded from the analysis. Some individuals were missing data on more than one variable.

Table A.2 Chapter 3 study sample stratified by ALE class

Characteristics of study population (N = 249,420)					
Characteristic	ALE 1	ALE 2	ALE 3	ALE 4	ALE 5
N	128,055	65,160	40,320	10,885	5,005
Age (years)	60.76 (10.00)	61.15 (10.41)	61.68 (10.61)	61.67 (10.76)	60.39 (10.52)
Median follow-up time (years)	6.26 (3.08)	6.29 (3.08)	6.24 (3.05)	6.24 (3.01)	6.26 (2.98)
Women	69 795 (54.5)	37 510 (57.6)	23 885 (59.2)	6370 (58.5)	2755 (55.0)
smoking status					
Never	33,390 (26.1)	18,195 (27.9)	12,030 (29.8)	3,490 (32.1)	1,375 (27.5)
former	66,980 (52.3)	33,535 (51.5)	19,590 (48.6)	5,050 (46.4)	2,325 (46.5)
Current	27,685 (21.6)	13,430 (20.6)	8,700 (21.6)	2,340 (21.5)	1,305 (26.1)
Obese	39,575 (30.9)	17,995 (27.6)	10,760 (26.7)	2,540 (23.3)	1,005 (20.1)
2+ chronic conditions	56,055 (43.8)	28,520 (43.8)	17,915 (44.4)	4,565 (41.9)	1,940 (38.8)
Average median household income (DA-level)	$ 71,954.76	$ 76,514.34	$ 66,769.94	$ 60,138.43	$ 56,901.52
>1 SD below median	10,365 (8.1)	9,075 (13.9)	9,275 (23)	2,895 (26.6)	1,475 (29.5)
Within 1 SD from median	106,105 (82.9)	44,850 (68.8)	27,090 (67.2)	7,425 (68.2)	3,310 (66.1)
<1 SD above median	11,585 (9.0)	11,230 (17.2)	3,955 (9.8)	560 (5.1)	215 (4.3)
Educational attainment					
Less than secondary	41,870 (32.7)	16,160 (24.8)	10,400 (25.8)	2,655 (24.4)	1,000 (20.0)
Secondary school	27,485 (21.5)	15,500 (23.8)	9,810 (24.3)	2,445 (22.5)	1,010 (20.2)
Degree/diploma	58,700 (45.8)	33,495 (51.4)	20,110 (49.9)	5,785 (53.1)	2,995 (59.8)

Data are n, n (%), mean (SD). All covariates are from survey response (baseline).

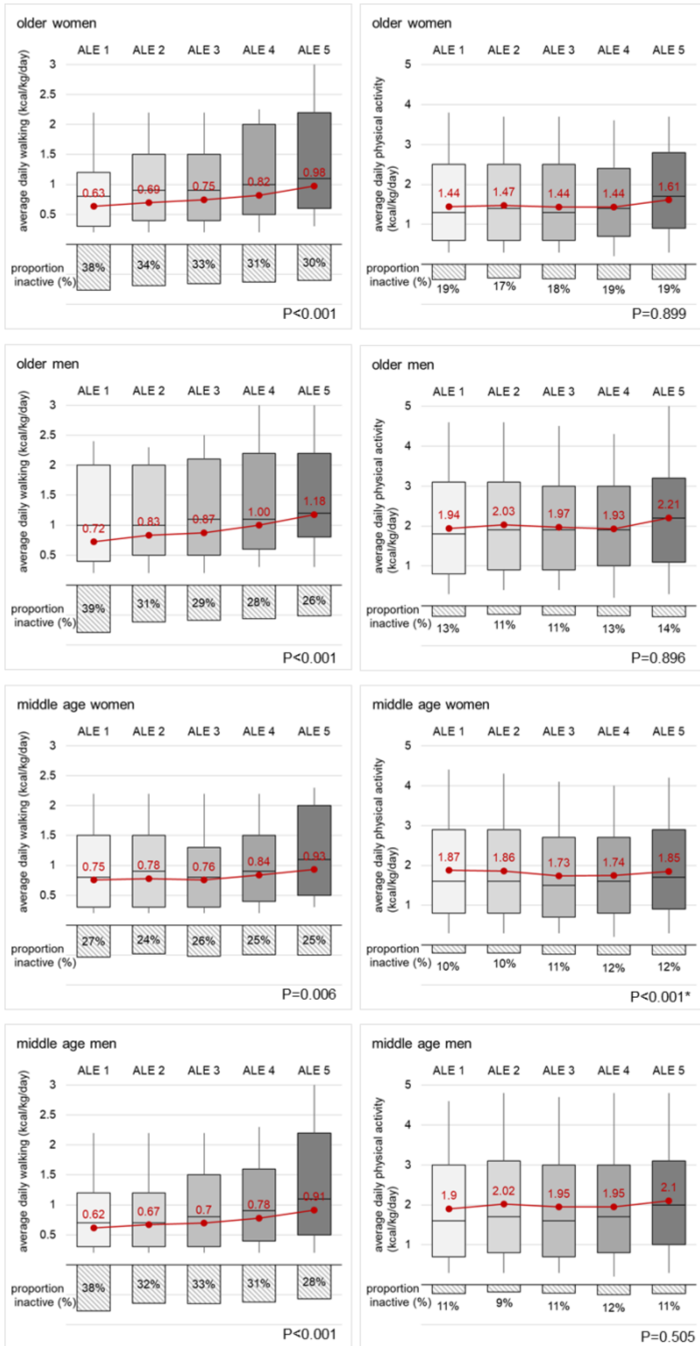

Figure A.3 Average daily energy expenditure, walking compared with physical activity

Active living environment (ALE) 1 represents the least favourable environment, while ALE 5 represents the most favourable environment. Panel (A) contains box plots, mean energy expenditure related to walking, and proportion that report no walking. Boxes represent the interquartile range (25th to 75th percentile) and the horizontal line represents the median. Note that upper and lower limits of the boxplots have been adjusted to represent the 90th and 10th percentile, respectively, for confidentiality purposes. Red markers and trend line represent means in each ALE class with test for positive trend (P<0.05). *Average daily energy expenditure for overall physical activity was inversely graded by ALE class for middle-aged women.

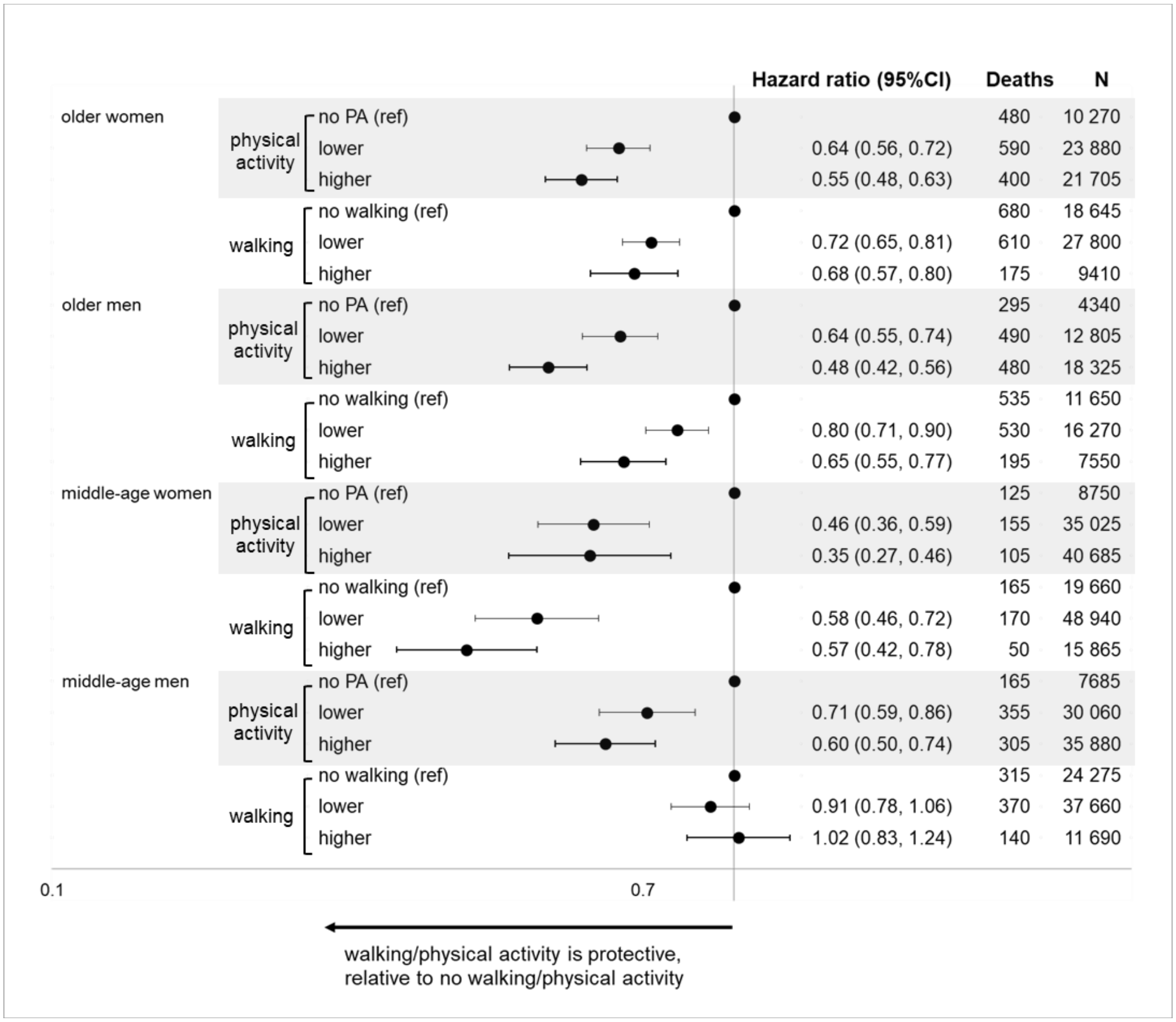

Figure A.4 Cox proportional hazards models of walking/overall physical activity and cardiometabolic death

Data are hazard ratios (95% CI). Models are adjusted for baseline age, education, income, the presence of two or more chronic conditions, obesity, season of survey response and survey cycle.

Table A.3 Cox proportional hazards and competing risks models.

Comparison of age-adjusted and fully adjusted estimates for the association between active living environment using cox proportional hazards and competing risks models.

Group	Model	Adjustment[a]	HR[b]	95% CI lower	95% CI upper
Older women	Cox	age	0.79	0.63	0.98
Older women	Cox	full	0.78	0.63	0.97
Older women	competing risks	age	0.78	0.63	0.97
Older women	competing risks	full	0.78	0.62	0.97
Older men	Cox	age	1.12	0.90	1.40
Older men	Cox	full	1.13	0.90	1.41
Older men	competing risks	age	1.13	0.90	1.40
Older men	competing risks	full	1.13	0.91	1.42
Middle age women	Cox	age	1.08	0.72	1.62
Middle age women	Cox	full	1.02	0.68	1.54
Middle age women	competing risks	age	1.08	0.72	1.62
Middle age women	competing risks	full	1.02	0.68	1.54
Middle age men	Cox	age	1.04	0.78	1.39
Middle age men	Cox	full	0.97	0.73	1.30
Middle age men	competing risks	age	1.04	0.78	1.38
Middle age men	competing risks	full	0.97	0.73	1.30

[a] *Age* indicates models were adjusted for age only. *Full* indicates models were adjusted for age, education, areal-level income, survey cycle, smoking status, obesity, and the presence of two or more chronic conditions.

[b] HR = hazard ratio between more favourable and less favourable active living environments.

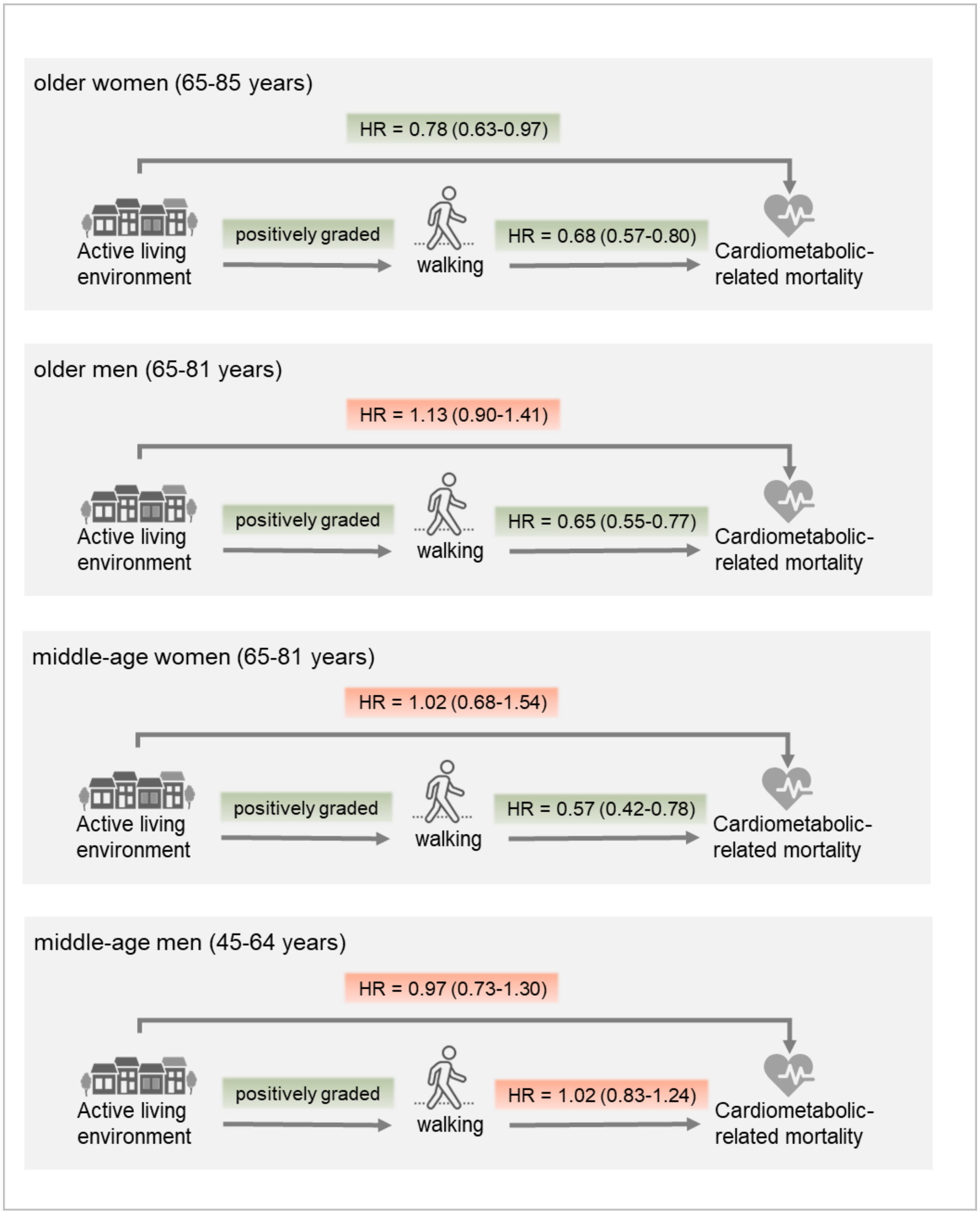

Figure A.5 Summary of findings for Chapter 3.

For each group, whether associations between 1) the active living environment and walking, 2) walking and premature cardiometabolic mortality, and 3) the active living environment and premature cardiometabolic mortality were conclusive (green) or inconclusive (orange). Estimates for the association between walking and mortality are adjusted hazard ratios comparing the highest walking levels and no walking. Estimates for the association between the active living environment and premature cardiometabolic mortality are adjusted hazard ratios. HR = hazard ratio.

Appendix B

SUPPLEMENTARY MATERIALS TO CHAPTER 5

Supplement to: Assessing Active Living Environments and Hospital Burden using Canadian Population-Based Linked Data

Table B.1 Summary of individuals with missing data excluded from complete case analysis.

Variable	Number missing	% missing
Active living environment	2,235	0.90%
education	2,535	1.02%
Area-level income	975	0.39%
smoking	585	0.24%
obesity	8,830	3.56%
physical activity	7,040	2.84%
walking	9,110	3.67%
Total [a]	20,075	8.09%

[a] Total number of individuals with missing data on any variable, excluded from the analysis. Some individuals were missing data on more than one variable.

Table B.2 Full logistic models.

	All cause			AMI			CHF			Stroke		
(N = 228,195)	Adjusted OR	95% CI	P	Adjusted OR	95% CI	P	Adjusted OR	95% CI	P	Adjusted OR	95% CI	P
ALE												
1 (reference)	1.00			1.00			1.00			1.00		
2	**0.92**	**0.90, 0.94**	<0.001	**0.93**	**0.87, 1.00**	0.036	0.99	0.91, 1.07	0.758	1.02	0.93, 1.11	0.734
3	**0.84**	**0.82, 0.87**	<0.001	**0.88**	**0.81, 0.95**	0.002	1.02	0.93, 1.12	0.687	**1.17**	**1.05, 1.29**	0.003
4	**0.78**	**0.74, 0.83**	<0.001	**0.76**	**0.65, 0.90**	0.001	0.87	0.73, 1.04	0.122	0.99	0.82, 1.20	0.956
5	**0.79**	**0.72, 0.86**	<0.001	0.79	0.62, 1.02	0.069	0.74	0.54, 1.02	0.066	1.03	0.76, 1.41	0.845
age	**1.02**	**1.01, 1.03**	<0.001	**1.03**	**1.01, 1.06**	0.006	**1.17**	**1.13, 1.21**	<0.001	**1.23**	**1.19, 1.28**	<0.001
age x age	**1.00**	**1.00, 1.00**	<0.001	1.00	1.00, 1.00	0.127	**1.00**	**1.00, 1.00**	0.007	**1.00**	**1.00, 1.00**	<0.001
Sex												
women	**0.82**	**0.80, 0.83**	<0.001	**0.48**	**0.45, 0.51**	<0.001	**0.64**	**0.60, 0.68**	<0.001	**0.73**	**0.68, 0.79**	<0.001
Education												
less than secondary (reference)	1.00			1.00			**1.00**			1.00		
secondary	**0.89**	**0.86, 0.91**	<0.001	**0.89**	**0.83, 0.96**	0.002	**0.89**	**0.82, 0.97**	0.005	0.92	0.84, 1.01	0.066
degree/diploma	**0.86**	**0.84, 0.88**	<0.001	**0.82**	**0.77, 0.87**	<0.001	**0.73**	**0.68, 0.79**	<0.001	**0.79**	**0.73, 0.86**	<0.001
income												
low (reference)	1.00			1.00			**1.00**			**1.00**		
middle	**0.85**	**0.82, 0.88**	<0.001	**0.87**	**0.80, 0.94**	<0.001	**0.89**	**0.81, 0.97**	0.007	**0.90**	**0.82, 0.99**	0.036
high	**0.75**	**0.72, 0.78**	<0.001	**0.69**	**0.61, 0.77**	<0.001	**0.72**	**0.62, 0.83**	<0.001	**0.76**	**0.65, 0.89**	<0.001
Smoking status												
never (reference)	1.00			1.00			**1.00**			1.00		
former	**1.19**	**1.16, 1.22**	<0.001	**1.11**	**1.04, 1.19**	0.002	**1.20**	**1.11, 1.29**	<0.001	1.01	0.93, 1.09	0.852
current	**1.67**	**1.62, 1.72**	<0.001	**2.07**	**1.92, 2.24**	<0.001	**1.75**	**1.58, 1.94**	<0.001	**1.73**	**1.56, 1.92**	<0.001
Has 2+ chronic conditions												
yes	**1.88**	**1.84, 1.91**	<0.001	**1.59**	**1.50, 1.68**	<0.001	**2.32**	**2.16, 2.49**	<0.001	**1.46**	**1.35, 1.57**	<0.001
Obese												
yes	**1.32**	**1.29, 1.35**	<0.001	**1.24**	**1.17, 1.32**	<0.001	**1.74**	**1.63, 1.86**	<0.001	**1.14**	**1.05, 1.23**	0.001
lives within 3 km of hospital	**1.06**	**1.03, 1.08**	<0.001	1.02	0.96, 1.08	0.555	1.01	0.94, 1.08	0.792	0.94	0.87, 1.02	0.116
Survey cycle												
1.1 (reference)	1.00			1.00			1.00			1.00		
2.1	**0.84**	**0.82, 0.87**	<0.001	**0.90**	**0.83, 0.97**	0.006	**0.76**	**0.69, 0.83**	<0.001	**0.80**	**0.73, 0.88**	<0.001
3.1	**0.76**	**0.74, 0.79**	<0.001	**0.87**	**0.81, 0.94**	0.001	**0.61**	**0.55, 0.66**	<0.001	**0.74**	**0.67, 0.82**	<0.001
4.1	**0.64**	**0.62, 0.66**	<0.001	**0.74**	**0.68, 0.80**	<0.001	**0.54**	**0.49, 0.60**	<0.001	**0.60**	**0.54, 0.67**	<0.001
2009	**0.56**	**0.54, 0.59**	<0.001	**0.73**	**0.64, 0.83**	<0.001	**0.47**	**0.40, 0.54**	<0.001	**0.56**	**0.47, 0.66**	<0.001
2010	**0.53**	**0.51, 0.55**	<0.001	**0.73**	**0.64, 0.84**	<0.001	**0.42**	**0.35, 0.50**	<0.001	**0.60**	**0.50, 0.72**	<0.001
2011	**0.49**	**0.47, 0.52**	<0.001	**0.61**	**0.51, 0.73**	<0.001	**0.46**	**0.38, 0.56**	<0.001	**0.46**	**0.36, 0.59**	<0.001

Table B.3 Full count models for hospitalizations.

	All cause (83,660)			**AMI (5,890)**			**CHF (4,535)**			**Stroke (3,480)**		
	Adjusted RR	95% CI	P	Adjusted RR	95% CI	P	Adjusted RR	95% CI	P	Adjusted RR	95% CI	P
ALE												
1 (reference)	1.00			1.00			1.00			1.00		
2	**0.92**	**0.90, 0.94**	<0.001	0.89	0.70, 1.13	0.347	0.97	0.85, 1.12	0.698	1.07	0.79, 1.44	0.676
3	**0.91**	**0.89, 0.94**	<0.001	0.83	0.63, 1.09	0.180	1.01	0.85, 1.20	0.905	1.21	0.85, 1.71	0.287
4	**0.87**	**0.83, 0.92**	<0.001	0.82	0.52, 1.30	0.403	1.14	0.87, 1.51	0.343	1.26	0.64, 2.47	0.506
5	**0.90**	**0.83, 0.97**	0.010	0.75	0.34, 1.67	0.486	1.23	0.68, 2.22	0.488	0.62	0.15, 2.57	0.515
age	**1.02**	**1.01, 1.03**	<0.001	0.98	0.9, 1.06	0.588	0.99	0.92, 1.07	0.867	0.95	0.82, 1.10	0.491
age x age	1.00	1.00, 1.00	0.676	1.00	1.00, 1.00	0.175	1.00	1.00, 1.00	0.762	1.00	1.00, 1.00	0.363
Sex												
women	**0.90**	**0.88, 0.92**	<0.001	0.85	0.7, 1.02	0.083	0.92	0.82, 1.04	0.179	1.15	0.87, 1.51	0.328
Education												
less than secondary (reference)	1.00			1.00			1.00			1.00		
secondary	**0.91**	**0.89, 0.94**	<0.001	1.01	0.79, 1.29	0.935	0.92	0.80, 1.07	0.286	1.25	0.91, 1.72	0.173
degree/diploma	**0.88**	**0.86, 0.9**	<0.001	0.92	0.74, 1.14	0.438	0.98	0.85, 1.12	0.736	1.11	0.82, 1.49	0.506
income												
low (reference)	1.00			1.00			1.00			1.00		
middle	**0.91**	**0.88, 0.93**	<0.001	0.85	0.67, 1.07	0.169	0.87	0.75, 1.00	0.051	1.23	0.84, 1.80	0.291
high	**0.82**	**0.79, 0.85**	<0.001	0.93	0.6, 1.43	0.734	0.87	0.69, 1.10	0.254	0.98	0.54, 1.76	0.937
Smoking status												
never (reference)	1.00			1.00			1.00			1.00		
former	**1.11**	**1.09, 1.14**	<0.001	**1.32**	**1.04, 1.66**	0.022	1.10	0.97, 1.25	0.154	0.93	0.68, 1.25	0.613
current	**1.39**	**1.35, 1.43**	<0.001	**1.38**	**1.05, 1.81**	0.023	1.04	0.83, 1.29	0.756	1.00	0.67, 1.50	0.992
Has 2+ chronic conditions												
yes	**1.45**	**1.42, 1.48**	<0.001	**1.81**	**1.46, 2.23**	<0.001	**1.35**	**1.18, 1.55**	<0.001	**1.44**	**1.09, 1.91**	0.011
Obese												
yes	**1.09**	**1.07, 1.11**	<0.001	**1.27**	**1.06, 1.53**	0.011	1.03	0.92, 1.16	0.573	0.96	0.71, 1.31	0.812
lives within 3km of hospital	**1.05**	**1.03, 1.07**	<0.001	1.18	0.97, 1.44	0.092	1.00	0.88, 1.13	0.956	0.88	0.68, 1.15	0.350
Survey cycle												
1.1 (reference)	1.00			1.00			1.00			1.00		
2.1	**0.93**	**0.91, 0.95**	<0.001	0.82	0.65, 1.04	0.096	**0.82**	**0.71, 0.95**	0.010	1.12	0.80, 1.56	0.526
3.1	**0.93**	**0.91, 0.96**	<0.001	**0.76**	**0.59, 0.97**	**0.030**	1.01	0.86, 1.19	0.891	0.88	0.59, 1.32	0.543
4.1	**1.04**	**1.01, 1.07**	0.020	**0.73**	**0.55, 0.97**	**0.031**	**1.23**	**1.02, 1.48**	0.028	1.30	0.85, 1.99	0.232
2009	**1.10**	**1.05, 1.15**	<0.001	0.87	0.57, 1.33	0.524	**1.61**	**1.22, 2.13**	0.001	1.45	0.74, 2.85	0.278
2010	**1.25**	**1.19, 1.31**	<0.001	0.66	0.34, 1.27	0.212	**1.42**	**1.00, 2.03**	0.050	0.62	0.20, 1.94	0.412
2011	**1.51**	**1.42, 1.61**	<0.001	0.78	0.28, 2.18	0.640	**1.86**	**1.26, 2.74**	0.002	1.25	0.31, 5.01	0.753

Table B.4 Full count models for cumulative length of stay.

	All cause (83,660)			**AMI (5,890)**			**CHF (4,535)**			**Stroke (3,480)**		
	Adjusted RR	95% CI	P	Adjusted RR	95% CI	P	Adjusted RR	95% CI	P	Adjusted RR	95% CI	P
ALE												
1 (reference)	1.00			1.00			1.00			1.00		
2	**0.93**	**0.9, 0.96**	<0.001	0.96	0.87, 1.07	0.469	0.94	0.85, 1.05	0.299	0.97	0.83, 1.14	0.726
3	**0.91**	**0.88, 0.94**	<0.001	0.95	0.85, 1.06	0.345	1.01	0.88, 1.16	0.900	**0.85**	**0.72, 1.00**	0.050
4	**0.92**	**0.86, 0.99**	0.022	**0.79**	**0.64, 0.96**	0.018	1.03	0.82, 1.30	0.803	0.96	0.73, 1.27	0.767
5	0.98	0.87, 1.10	0.722	0.99	0.71, 1.39	0.976	1.11	0.64, 1.91	0.707	0.93	0.57, 1.52	0.764
age	1.01	1.00, 1.02	0.170	1.00	0.96, 1.05	0.979	**0.94**	**0.90, 0.99**	0.022	0.98	0.93, 1.05	0.623
age x age	**1.00**	**1.00, 1.00**	<0.001	1.00	1.00, 1.00	0.265	**1.00**	**1.00, 1.00**	0.003	1.00	1.00, 1.00	0.269
Sex												
women	**0.92**	**0.89, 0.94**	<0.001	0.97	0.90, 1.05	0.503	0.97	0.88, 1.07	0.564	0.99	0.87, 1.14	0.936
Education												
less than secondary (reference)	1.00			1.00			1.00			1.00		
secondary	**0.89**	**0.86, 0.92**	<0.001	0.98	0.89, 1.08	0.733	0.88	0.78, 0.98	0.026	1.00	0.83, 1.20	0.969
degree/diploma	**0.85**	**0.83, 0.88**	<0.001	0.93	0.85, 1.01	0.096	**0.86**	**0.78, 0.95**	0.004	0.89	0.78, 1.02	0.092
income												
low (reference)	1.00			1.00			1.00			1.00		
middle	**0.86**	**0.83, 0.89**	<0.001	**0.88**	**0.79, 0.99**	0.026	0.96	0.83, 1.11	0.552	0.83	0.67, 1.04	0.105
high	**0.76**	**0.72, 0.80**	<0.001	0.85	0.72, 1.00	0.056	1.00	0.81, 1.24	0.990	0.77	0.57, 1.04	0.089
Smoking status												
never (reference)	1.00			1.00			1.00			1.00		
former	**1.08**	**1.05, 1.11**	<0.001	1.05	0.96, 1.15	0.308	0.99	0.89, 1.11	0.922	0.99	0.87, 1.14	0.915
current	**1.48**	**1.43, 1.54**	<0.001	**1.14**	**1.02, 1.28**	0.022	1.04	0.89, 1.21	0.620	1.05	0.88, 1.25	0.588
Has 2+ chronic conditions												
yes	**1.32**	**1.28, 1.35**	<0.001	**1.21**	**1.11, 1.31**	<0.001	**1.15**	**1.03, 1.27**	0.013	1.10	0.97, 1.24	0.146
Obese												
yes	**1.06**	**1.04, 1.09**	<0.001	1.08	1.00, 1.17	0.065	1.03	0.93, 1.14	0.591	0.94	0.82, 1.07	0.340
lives within 3km of hospital	**1.08**	**1.05, 1.10**	<0.001	1.02	0.94, 1.12	0.581	1.01	0.91, 1.12	0.839	1.06	0.93, 1.22	0.379
Survey cycle												
1.1 (reference)	1.00			1.00			1.00			1.00		
2.1	**0.88**	**0.85, 0.91**	<0.001	**0.89**	**0.81, 0.99**	0.034	**0.85**	**0.74, 0.96**	0.010	1.07	0.92, 1.25	0.357
3.1	**0.86**	**0.83, 0.90**	<0.001	**0.88**	**0.80, 0.97**	0.011	0.91	0.80, 1.05	0.188	1.16	0.97, 1.38	0.111
4.1	0.99	0.95, 1.02	0.450	**1.22**	**1.09, 1.36**	<0.001	1.11	0.96, 1.3	0.165	**1.51**	**1.26, 1.81**	<0.001
2009	1.05	1.00, 1.11	0.051	**1.51**	**1.22, 1.87**	<0.001	**1.36**	**1.08, 1.71**	0.008	**1.71**	**1.35, 2.15**	<0.001
2010	**1.27**	**1.19, 1.35**	<0.001	**1.97**	**1.55, 2.51**	<0.001	**1.52**	**1.21, 1.92**	<0.001	**2.15**	**1.60, 2.88**	<0.001
2011	**1.73**	**1.61, 1.85**	<0.001	**2.84**	**2.19, 3.70**	<0.001	**2.16**	**1.64, 2.84**	<0.001	**4.77**	**2.63, 8.65**	<0.001

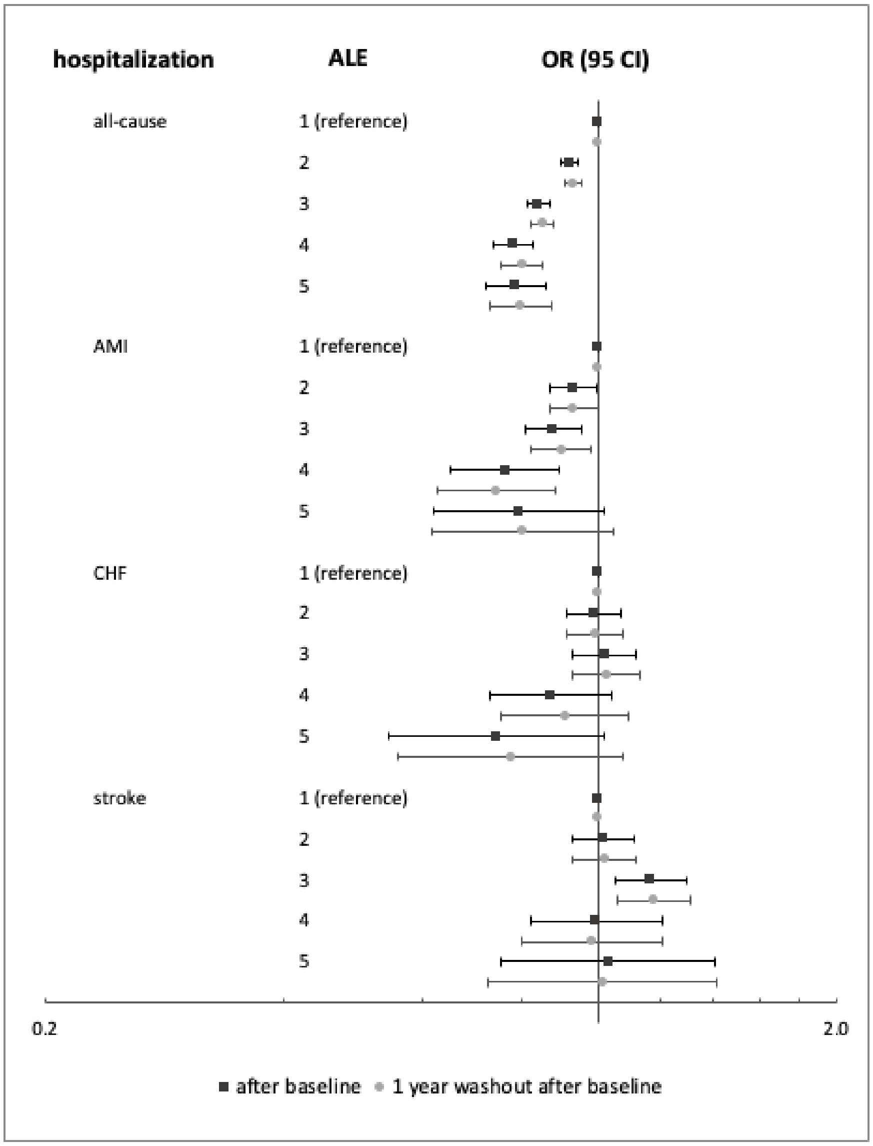

Figure B.1 Sensitivity analysis for logistic regressions with 1-year washout.

A comparison of logistic regression estimates of the relationship between active living environments (ALE) and odds of hospitalization for all-causes, acute myocardial infarction (AMI), stroke, and congestive heart failure (CHF) after survey response ("after baseline"), and 1-year after survey response ("1 year washout after baseline").

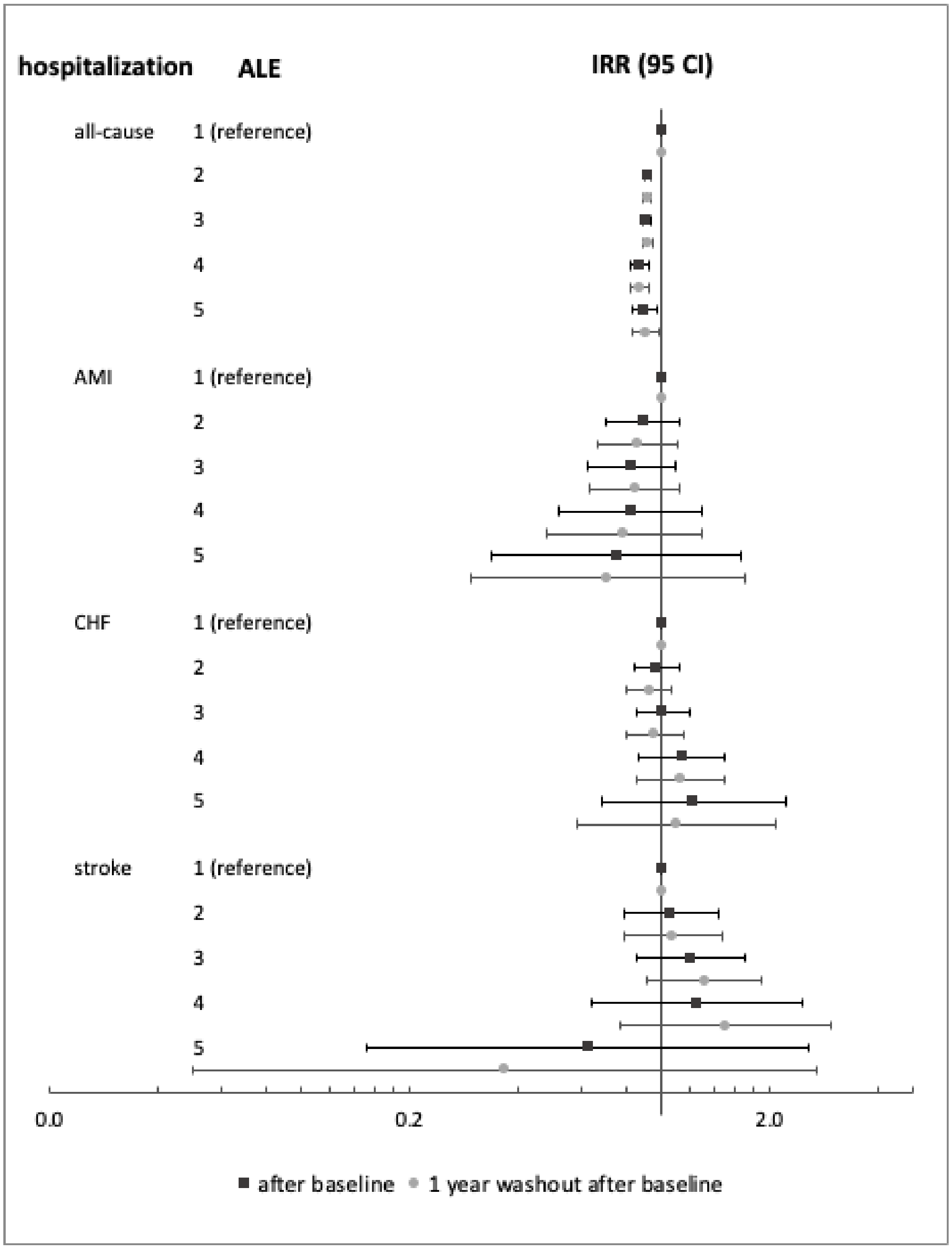

Figure B.2 Sensitivity analysis for count models of hospitalization events with 1-year washout. A comparison of truncated poisson regression estimates of the relationship between active living environments (ALE) and number of hospitalization events for all-causes, acute myocardial infarction (AMI), stroke, and congestive heart failure (CHF) after survey response ("after baseline"), and 1-year after survey response ("1 year washout after baseline") among those hospitalized.

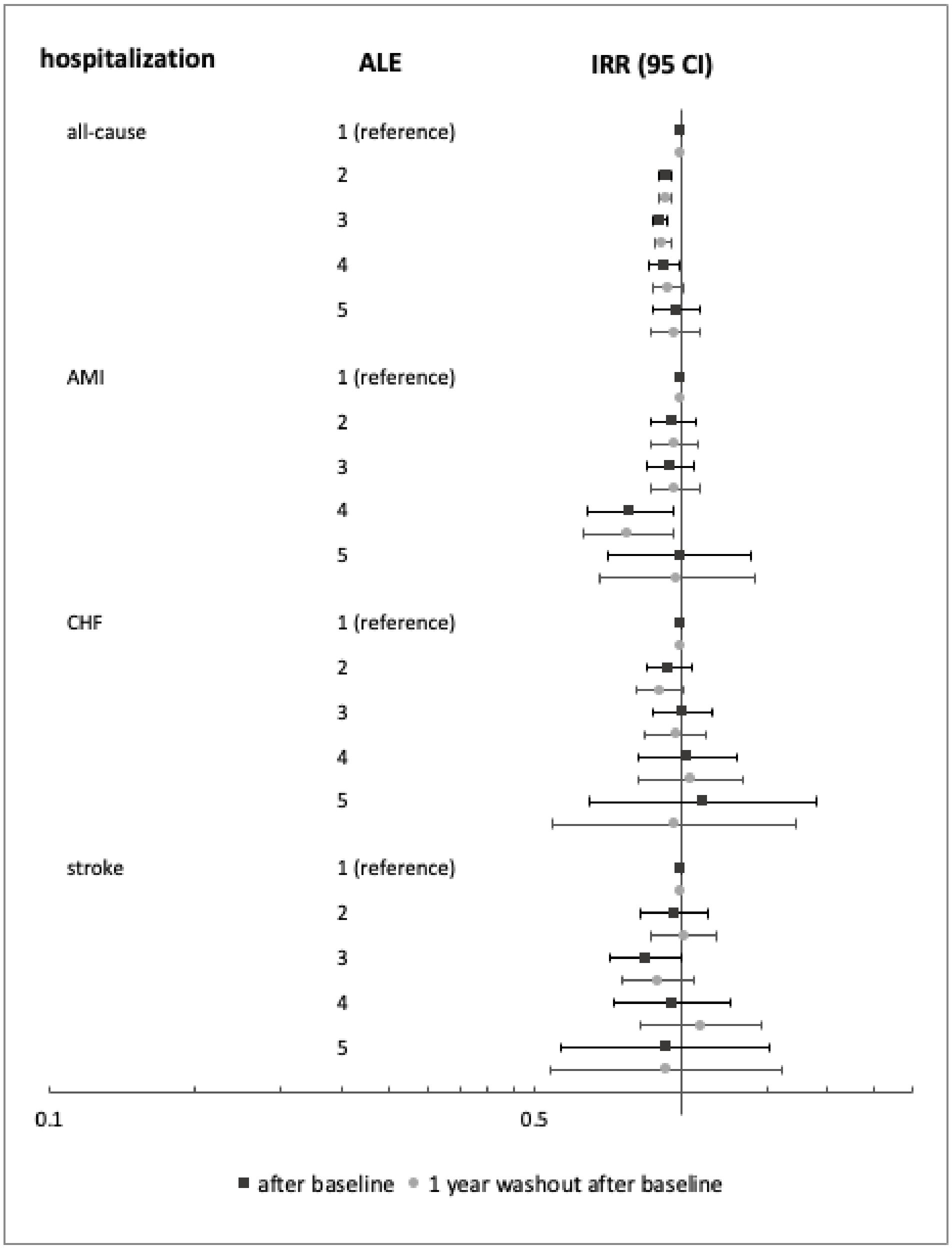

Figure B.3 Sensitivity analysis for count models of cumulative length of stay with 1-year washout. A comparison of truncated poisson regression estimates of the relationship between active living environments (ALE) and the cumulative number of days spent in hospital for all-causes, acute myocardial infarction (AMI), stroke, and congestive heart failure (CHF) after survey response ("after baseline"), and 1-year after survey response ("1 year washout after baseline") among those hospitalized.

Table B.5 Mediation analysis for the relationship between ALEs, walking or overall physical activity, and major CVD events with 1-year washout.

mediator	outcome	Total effect risk ratio	Excess relative risk due to mediation	Proportion effect due to mediation
walking	AMI	0.80 (0.69, 0.91)	-0.0048 (-0.0080, -0.0018)	**0.02**
physical activity	AMI	0.80 (0.69, 0.92)	0.0013 (0.0001, 0.0026)	-0.01
walking	CHF	0.88 (0.75, 1.02)	-0.0151 (-0.0196, -0.0106)	0.13
physical activity	CHF	0.89 (0.75, 1.03)	0.0040 (0.0008, 0.0071)	-0.04
walking	stroke	0.93 (0.80, 1.10)	-0.0066 (-0.0107, -0.0025)	0.10
physical activity	stroke	0.93 (0.77, 1.08)	0.0014 (-0.00004, 0.0028)	-0.02

Estimates for the pure indirect effects of active living environments, walking/overall physical activity, and hospitalization for major CVD events with a 1-year washout. Confidence intervals were calculated using the delta method. Boldface indicates statistical significance ($p \leq 0.05$). Hospitalizations were identified using the primary (most responsible) diagnosis. AMI, acute myocardial infarction, CHF, congestive heart failure.

Appendix C

SUPPLEMENTARY MATERIALS TO CHAPTER 6

Supplement to: Supplement to: Does living near hospital obscure the association between favourable Active Living Environments and lower hospitalization?

Table C.1 Summary of individuals with missing data excluded from complete case analysis.

Variable	Number missing	% missing
Active living environment	5,900	1.24%
education	3,795	0.80%
Area-level income	1,665	0.35%
smoking	880	0.19%
obesity	21,195	4.47%
Total [a]	31,985	6.74%

[a] Total number of individuals with missing data on any variable, excluded from the analysis. Some individuals were missing data on more than one variable.

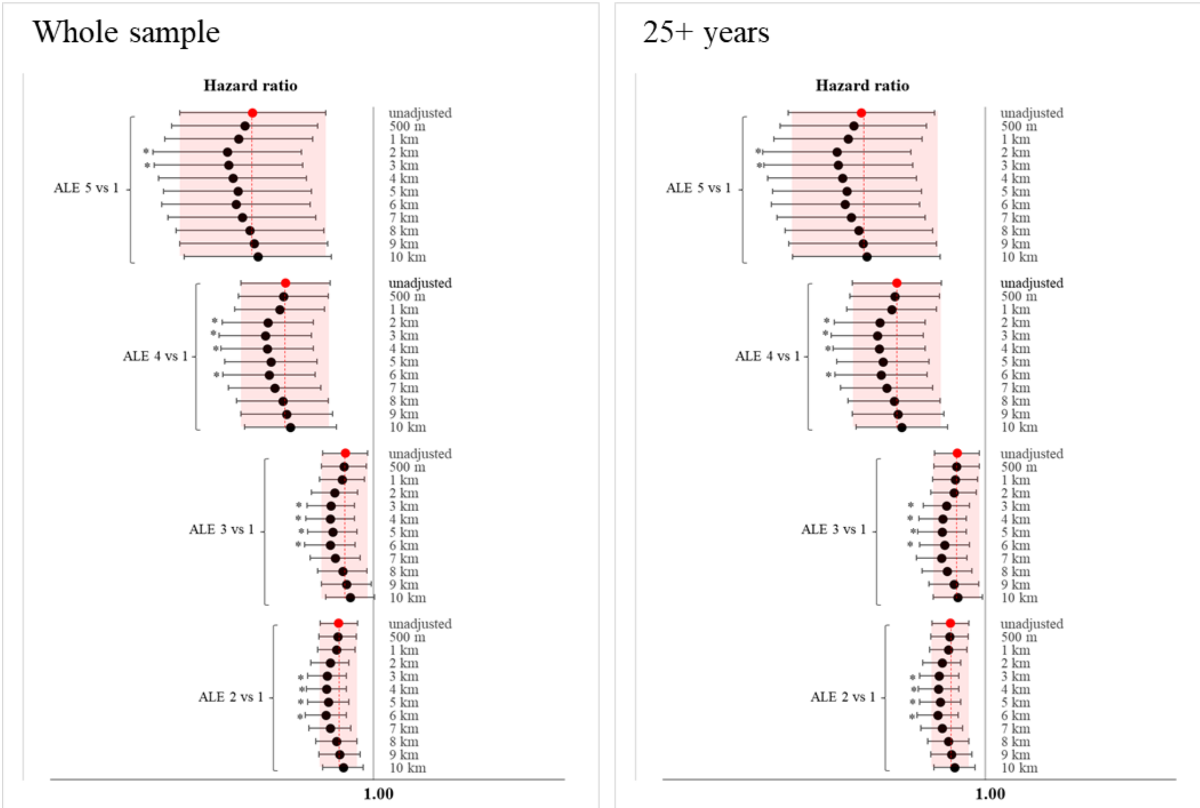

Figure C.1 Models of the whole sample compared with those 25 years and older.

Changes in the odds ratios (OR) for successive ALE classes relative to the least favourable ALE (ALE 1, reference) when indicator variables for increasing distances to hospital are included. OR, odds ratio, km, kilometer. Markers in red represent estimates from models unadjusted for distance to hospital, while stars indicate distances with the greatest change in estimate of the protective association between ALE and risk of cardiometabolic hospitalization. Adjusted for sex, age, survey cycle, educational attainment, race/ethnicity, smoking status, and obesity.

Appendix D

SUPPLEMENTARY MATERIALS TO CHAPTER 8

Supplement to: Active Living Environments and walking for purpose: The Australian Diabetes, Obesity and Lifestyle Study (AusDiab)

Research Ethics Board Office
James Administration Bldg.
845 Sherbrooke Street West. Rm 325
Montreal, QC H3A 0G4

Website: www.mcgill.ca/research/research/compliance/human/

Research Ethics Board 1
Certificate of Ethical Acceptability of Research Involving Humans

REB File #: 21-02-029

Project Title: International comparisons of neighbourhood environments, type 2 diabetes, and hospital burden

Principal Investigator: Sarah Meghan Hau-Sing Mah

Status: Ph.D. Student

Department: Geography

Faculty Supervisor: Prof. Nancy Ross

Collaborators/Other Researchers: Rebecca Bentley, Professor, University of Melbourne

Funding: Queen Elizabeth II Diamond Jubilee Scholarship ($6,000), Fonds de Recherche du Québec Santé Doctoral Training Award, Canadian Institutes of Health Research - Institute of Population and Public Health, through the Data Analysis Existing Databases Operating Grant, Professor Nancy Ross's funding from the Canadian Institutes of Health Research Canada Research Chairs Program.

Approval Period: **<u>February 26, 2021 to February 25, 2022</u>**

The REB-1 reviewed and approved this project by delegated review in accordance with the requirements of the McGill University Policy on the Ethical Conduct of Research Involving Human Participants and the Tri-Council Policy Statement: Ethical Conduct for Research Involving Humans.

Deanna Collin
Senior Ethics Review Administrator

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* Approval is granted only for the research and purposes described.
* Modifications to the approved research must be reviewed and approved by the REB before they can be implemented.
* A Request for Renewal form must be submitted before the above expiry date. Research cannot be conducted without a current ethics approval. Submit 2-3 weeks ahead of the expiry date.
* When a project has been completed or terminated, a Study Closure form must be submitted.
* Unanticipated issues that may increase the risk level to participants or that may have other ethical implications must be promptly reported to the REB. Serious adverse events experienced by a participant in conjunction with the research must be reported to the REB without delay.
* The REB must be promptly notified of any new information that may affect the welfare or consent of participants.
* The REB must be notified of any suspension or cancellation imposed by a funding agency or regulatory body that is related to this study.
* The REB must be notified of any findings that may have ethical implications or may affect the decision of the REB.

Figure D.1 McGill REB ethics approval.

Table D.1 Conceptually matched purpose-specific walking outcomes with neighbourhood preference variables

Construct	Days walked for purpose	Coding	Conceptually matched with…	Neighbourhood preference related to walking for purpose	Coding
	In the last week, on how many days did you walk in your local neighbourhood…	Days in a week, used as a dichotomous and continuous variable	→	*(Importance of) having these destinations within walking distance:*	Likert scale (1 = not important at all, 5 = very important), used as a dichotomous variable 1-3, 4-5
Walking for transit	…To get to or from a public transport stop? (e.g., bus, tram, train)		→	Public transport stops (e.g. bus, tram, train)	
Walking to run errands	…To get to or from a retail or other services? (e.g., post office, shops, café, supermarket, sport club)		→	Retail and other services (e.g. post office, shops, café, school, supermarket)	
Walking for leisure	…For leisure or exercise only? (e.g., along a walking track, in or around a park, around your neighbourhood streets)		→	Recreation facilities (e.g. parks, playground, pool, gym, sport club)	
Overall walking	... In total? (for any of the above reasons)		→	The ease of walking around the area (e.g. good foot paths, walking tracks, safe road crossings).	

Table D.2 Full model results from four logit-linked generalized linear models.
Specified for Bernoulli distribution with a binomial denominator of 7 days, N = 3,466.

	transit		retail		leisure		overall	
ALE class	OR	95% CI	OR	95% CI	OR	95% CI	OR	95% CI
2 vs 1	2.27	1.67, 3.09	2.12	1.87, 2.40	1.03	0.95, 1.11	1.23	1.14, 1.33
3 vs 1	4.08	3.03, 5.51	1.91	1.68, 2.17	0.95	0.87, 1.03	1.19	1.10, 1.29
4 vs 1	8.43	6.24, 11.39	4.88	4.28, 5.57	1.43	1.31, 1.57	2.27	2.07, 2.49
5 vs 1	27.89	19.06, 40.82	10.06	7.82, 12.94	1.14	0.90, 1.45	3.37	2.62, 4.33
Diabetes status								
High risk	0.96	0.73, 1.26	1.08	0.93, 1.25	0.82	0.72, 0.92	0.87	0.77, 0.98
T2D	0.61	0.44, 0.84	0.88	0.75, 1.03	0.89	0.79, 1.01	0.88	0.79, 0.99
Age (years)	1.01	1.00, 1.02	1.01	1.00, 1.01	1.02	1.01, 1.02	1.01	1.01, 1.01
Female	0.79	0.69, 0.90	0.92	0.85, 0.98	1.11	1.05, 1.18	1.02	0.96, 1.07
Education								
Trade	0.62	0.52, 0.75	1.04	0.95, 1.14	1.01	0.94, 1.09	0.97	0.90, 1.03
Diploma	1.15	0.95, 1.39	1.03	0.93, 1.15	1.00	0.92, 1.09	0.99	0.91, 1.07
Bachelor/ post-grad	1.24	1.05, 1.46	0.9	0.82, 0.99	1.10	1.02, 1.19	1.14	1.06, 1.22
Smoking status								
Former	1.01	0.88, 1.16	1.26	1.09, 1.46	1.17	1.11, 1.24	0.9	0.80, 1.01
Current	0.91	0.67, 1.23	1.12	1.04, 1.20	0.77	0.68, 0.88	1.12	1.06, 1.19
BMI group								
overweight	0.74	0.64, 0.85	1.00	0.92, 1.09	1.01	0.95, 1.07	0.95	0.90, 1.01
obese	0.83	0.7,0.98	0.87	0.79, 0.95	0.74	0.69, 0.80	0.76	0.71, 0.82

Models adjusted for adjusted for age, sex, education, income, smoking status, BMI classification and diabetes status.

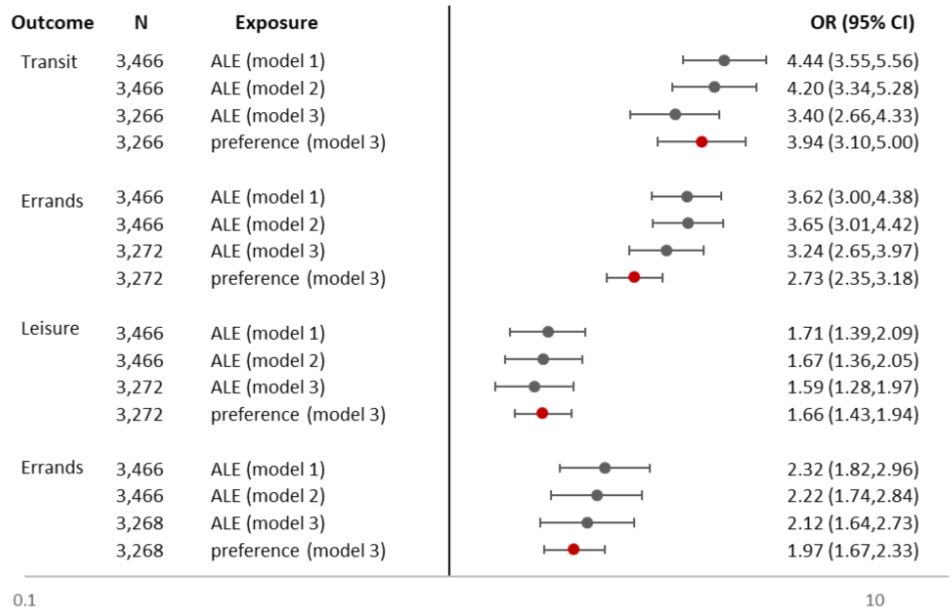

Figure D.2 Logistic models for ALEs, neighbourhood preference, and odds of purpose-specific walking.

Association of living in a favourable ALE (black markers) with odds of purpose specific walking, adjusted for age and sex (model 1), adjusted for all individual-level covariates (model 2), and adjusted for neighbourhood preference (model 3) for walking for transit, errands, leisure, and overall. The red markers are effect estimates for neighbourhood preference (model 3). Modeled using logistic regression.

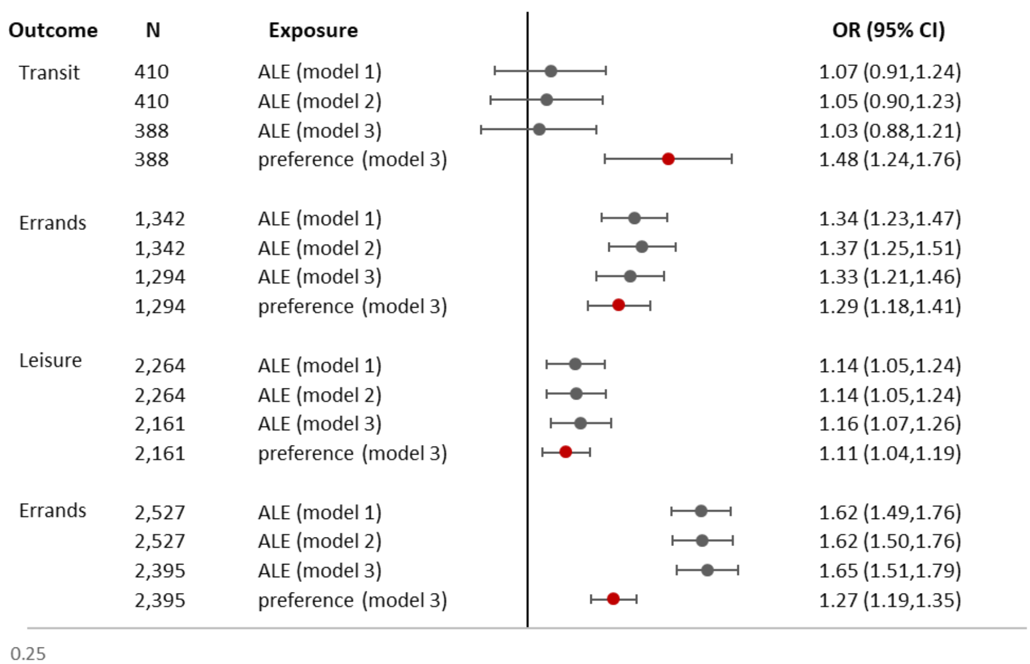

Figure D.3 Logistic models for ALEs, neighbourhood preference, and days walked among walkers.

Association of living in a favourable ALE (black markers) with days walked for purpose among walkers, adjusted for age and sex (model 1), adjusted for all individual-level covariates (model 2), and adjusted for neighbourhood preference (model 3) for walking for transit, errands, leisure, and overall. The red markers are effect estimates for neighbourhood preference (model 3). Modeled using logit-link generalized linear models.

REFERENCES

Abarca-Gómez, L., Abdeen, Z. A., Hamid, Z. A., Abu-Rmeileh, N. M., Acosta-Cazares, B., Acuin, C., Adams, R. J., Aekplakorn, W., Afsana, K., & Aguilar-Salinas, C. A. (2017). Worldwide trends in body-mass index, underweight, overweight, and obesity from 1975 to 2016: a pooled analysis of 2416 population-based measurement studies in 128· 9 million children, adolescents, and adults. *The Lancet, 390*(10113), 2627-2642. doi:10.1016/S0140-6736(17)32129-3

Abioye, A. I., Hajifathalian, K., & Danaei, G. (2013). Do mass media campaigns improve physical activity? a systematic review and meta-analysis. *Archives of Public Health, 71*(1), 20. doi:10.1186/0778-7367-71-20

Aboderin, I., Kalache, A., Ben Shlomo, Y., Lynch, J., Yajnik, C., Kuh, D., & Yach, D. (2002). Life Course Perspectives on Coronary Heart Disease, Stroke and Diabetes: Key issues and implications for policy and research. In. Geneva: World Health Organisation.

Aday, L. A., & Cornelius, L. J. (2006). *Designing and conducting health surveys: A comprehensive guide* (3rd ed.). San Francisco: Jossey-Bass.

Ahola, A. J., & Groop, P. H. (2013). Barriers to self-management of diabetes. *Diabetic Medicine, 30*(4), 413-420. doi:10.1111/dme.12105

Alberti, K. G. M. M., Eckel, R. H., Grundy, S. M., Zimmet, P. Z., Cleeman, J. I., Donato, K. A., Fruchart, J.-C., James, W. P. T., Loria, C. M., & Smith, S. C. (2009). Harmonizing the Metabolic Syndrome. *Circulation, 120*(16), 1640-1645. doi:10.1161/CIRCULATIONAHA.109.192644

Alfonzo, M. A. (2005). To Walk or Not to Walk? The Hierarchy of Walking Needs. *Environment and Behavior, 37*(6), 808-836. doi:10.1177/0013916504274016

Almdal, T., Scharling, H., Jensen, J. S., & Vestergaard, H. (2004). The independent effect of type 2 diabetes mellitus on ischemic heart disease, stroke, and death: a population-based study of 13,000 men and women with 20 years of follow-up. *Archives of Internal Medicine, 164*(13), 1422-1426. doi:10.1001/archinte.164.13.1422

Althoff, T., Sosic, R., Hicks, J. L., King, A. C., Delp, S. L., & Leskovec, J. (2017). Large-scale physical activity data reveal worldwide activity inequality. *Nature, 547*(7663), 336-339. doi:10.1038/nature23018

Alves, A. J., Viana, J. L., Cavalcante, S. L., Oliveira, N. L., Duarte, J. A., Mota, J., Oliveira, J., & Ribeiro, F. (2016). Physical activity in primary and secondary prevention of cardiovascular disease: Overview updated. *World Journal of Cardiology, 8*(10), 575-583. doi:10.4330/wjc.v8.i10.575

Andersen, R. M. (1995). Revisiting the behavioral model and access to medical care: does it matter? *Journal of Health and Social Behavior, 36*(1), 1-10. doi:10.2307/2137284

Andersen, R. M. (2008). National health surveys and the Behavioral Model of Health Services Use. *Medical Care, 46*(7), 647-653. doi:10.1097/MLR.0b013e31817a835d

Arem, H., Moore, S. C., Patel, A., Hartge, P., Berrington de Gonzalez, A., Visvanathan, K., Campbell, P. T., Freedman, M., Weiderpass, E., Adami, H. O., Linet, M. S., Lee, I. M., & Matthews, C. E. (2015). Leisure time physical activity and mortality: a detailed pooled analysis of the dose-response relationship. *JAMA internal medicine*, *175*(6), 959-967. doi:10.1001/jamainternmed.2015.0533

Arena, R., Myers, J., Forman, D. E., Lavie, C. J., & Guazzi, M. (2013). Should high-intensity-aerobic interval training become the clinical standard in heart failure? *Heart Failure Reviews, 18*(1), 95-105. doi:10.1007/s10741-012-9333-z

Astell-Burt, T., Rowbotham, S., & Hawe, P. (2018). Communicating the benefits of population health interventions: The health effects can be on par with those of medication. *SSM Population Health, 6*, 54-62. doi:10.1016/j.ssmph.2018.06.002

Auchincloss, A. H., Diez Roux, A. V., Brown, D. G., Erdmann, C. A., & Bertoni, A. G. (2008). Neighborhood resources for physical activity and healthy foods and their association with insulin resistance. *Epidemiology, 19*(1), 146-157. doi:10.1097/EDE.0b013e31815c480

Aune, D., Norat, T., Leitzmann, M., Tonstad, S., & Vatten, L. J. (2015). Physical activity and the risk of type 2 diabetes: a systematic review and dose–response meta-analysis. *European Journal of Epidemiology, 30*(7), 529-542. doi:10.1007/s10654-015-0056-z

Australian Institute of Health and Welfare. (2020). *Diabetes*. Retrieved from Canberra: https://www.aihw.gov.au/reports/diabetes/diabetes

Australian Institute of Health Welfare. (2019). *Overweight and obesity: an interactive insight*. Retrieved from Canberra: https://www.aihw.gov.au/reports/overweight-obesity/overweight-and-obesity-an-interactive-insight

Australian Institute of Health Welfare. (2020). *Insufficient physical activity*. Retrieved from Canberra: https://www.aihw.gov.au/reports/risk-factors/insufficient-physical-activity

Avery, L., Flynn, D., van Wersch, A., Sniehotta, F. F., & Trenell, M. I. (2012). Changing physical activity behavior in type 2 diabetes: a systematic review and meta-analysis of behavioral interventions. *Diabetes Care, 35*(12), 2681-2689. doi:10.2337/dc11-2452

Aziz, Z., Absetz, P., Oldroyd, J., Pronk, N. P., & Oldenburg, B. (2015). A systematic review of real-world diabetes prevention programs: learnings from the last 15 years. *Implement Sci, 10*, 172. doi:10.1186/s13012-015-0354-6

Badland, H., & Schofield, G. (2005). Transport, urban design, and physical activity: an evidence-based update. *Transportation Research Part D-Transport and Environment, 10*(3), 177-196. doi:10.1016/j.trd.2004.12.001

Badland, H., Whitzman, C., Lowe, M., Davern, M., Aye, L., Butterworth, I., Hes, D., & Giles-Corti, B. (2014). Urban liveability: Emerging lessons from Australia for exploring the potential for indicators to measure the social determinants of health. *Soc Sci Med, 111*, 64-73. doi:10.1016/j.socscimed.2014.04.003

Baldwin, S. A., Fellingham, G. W., & Baldwin, A. S. (2016). Statistical models for multilevel skewed physical activity data in health research and behavioral medicine. *Health Psychology, 35*(6), 552-562. doi:10.1037/hea0000292

Barbosa, J., Guerra, P. H., Santos, C. D., Nunes, A., Turrell, G., & Florindo, A. A. (2019). Walkability, Overweight, and Obesity in Adults: A Systematic Review of Observational Studies. *International Journal of Environmental Research and Public Health, 16*(17), 17. doi:10.3390/ijerph16173135

Barnett, D. W., Barnett, A., Nathan, A., Van Cauwenberg, J., & Cerin, E. (2017). Built environmental correlates of older adults' total physical activity and walking: a systematic review and meta-analysis. *International Journal of Behavioral Nutrition and Physical Activity, 14*(1), 103. doi:10.1186/s12966-017-0558-z

Barrett-Connor, E. (2013). Gender differences and disparities in all-cause and coronary heart disease mortality: epidemiological aspects. *Best Practice & Research Clinical Endocrinology & Metabolism, 27*(4), 481-500. doi:10.1016/j.beem.2013.05.013

Barrington-Leigh, C., & Millard-Ball, A. (2015). A century of sprawl in the United States. *Proceedings of the National Academy of Sciences of the United States of America, 112*(27), 8244-8249. doi:10.1073/pnas.1504033112

Barrington-Leigh, C., & Millard-Ball, A. (2017). The world's user-generated road map is more than 80% complete. *Plos One, 12*(8), e0180698. doi:10.1371/journal.pone.0180698

Bauman, A., Ainsworth, B. E., Bull, F., Craig, C. L., Hagstromer, M., Sallis, J. F., Pratt, M., & Sjostrom, M. (2009). Progress and pitfalls in the use of the International Physical Activity Questionnaire (IPAQ) for adult physical activity surveillance. *Journal of Physical Activity and Health, 6 Suppl 1*, S5-8. doi:10.1123/jpah.6.s1.s5

Baxter, J., & Boyce, S. (2011). The ageing population in Wales. In O. Roberts (Ed.), *Key Issues for the Fourth Assembly*: Research Service National Assembly for Wales.

Belanger, M., Townsend, N., & Foster, C. (2011). Age-related differences in physical activity profiles of English adults. *Preventive Medicine, 52*(3-4), 247-249. doi:10.1016/j.ypmed.2011.02.008

Ben-Shlomo, Y., & Kuh, D. (2002). A life course approach to chronic disease epidemiology: conceptual models, empirical challenges and interdisciplinary perspectives. *International Journal of Epidemiology, 31*(2), 285-293. doi:10.1093/ije/31.2.285

Bilal, U., Auchincloss, A. H., & Diez-Roux, A. V. (2018). Neighborhood Environments and Diabetes Risk and Control. *Current Diabetes Reports, 18*(9), 62. doi:10.1007/s11892-018-1032-2

Bird, E. L., Baker, G., Mutrie, N., Ogilvie, D., Sahlqvist, S., & Powell, J. (2013). Behavior change techniques used to promote walking and cycling: a systematic review. *Health Psychol, 32*(8), 829-838. doi:10.1037/a0032078

Black, C., & Roos, L. L. (2005). Linking and combining data to develop statistics for understanding the population's health. *Health Statistics: Shaping Policy and Practice to Improve the Population's Health*, 214-240.

Boerefijn, W. N. A. (2010). *The foundation, planning and building of new towns in the 13th and 14th centuries in Europe: an architectural-historical research into urban form and its creation*: Universiteit van Amsterdam [Host].

Boone-Heinonen, J., Gordon-Larsen, P., Guilkey, D. K., Jacobs, D. R., Jr., & Popkin, B. M. (2011). Environment and Physical Activity Dynamics: The Role of Residential Self-selection. *Psychology of Sport and Exercise, 12*(1), 54-60. doi:10.1016/j.psychsport.2009.09.003

Booth, G. L., Creatore, M. I., Luo, J., Fazli, G. S., Johns, A., Rosella, L. C., Glazier, R. H., Moineddin, R., Gozdyra, P., & Austin, P. C. (2019). Neighbourhood walkability and the incidence of diabetes: an inverse probability of treatment weighting analysis. *Journal of Epidemiology and Community Health, 73*(4), 287-294. doi:10.1136/jech-2018-210510

Booth, G. L., Creatore, M. I., Moineddin, R., Gozdyra, P., Weyman, J. T., Matheson, F. I., & Glazier, R. H. (2013). Unwalkable neighborhoods, poverty, and the risk of diabetes among recent immigrants to Canada compared with long-term residents. *Diabetes Care, 36*(2), 302-308. doi:10.2337/dc12-0777

Braun, L. M., Rodriguez, D. A., Evenson, K. R., Hirsch, J. A., Moore, K. A., & Diez Roux, A. V. (2016). Walkability and cardiometabolic risk factors: Cross-sectional and longitudinal associations from the Multi-Ethnic Study of Atherosclerosis. *Health Place, 39*, 9-17. doi:10.1016/j.healthplace.2016.02.006

Buajitti, E., Watson, T., Kornas, K., Bornbaum, C., Henry, D., & Rosella, L. C. (2018). Ontario Atlas of Adult Mortality, 1992-2015: Trends in Local Health Integration Networks.

Bull, F. C., Maslin, T. S., & Armstrong, T. (2009). Global Physical Activity Questionnaire (GPAQ): Nine Country Reliability and Validity Study. *Journal of Physical Activity & Health, 6*(6), 790-804. doi:10.1123/jpah.6.6.790

Calderwood, L., & Lessof, C. (2009). Enhancing Longitudinal Surveys by Linking to Administrative Data. In *Methodology of Longitudinal Surveys* (pp. 55-72): John Wiley & Sons, Ltd.

Caldwell, M., Martinez, L., Foster, J. G., Sherling, D., & Hennekens, C. H. (2019). Prospects for the Primary Prevention of Myocardial Infarction and Stroke. *Journal of Cardiovascular Pharmacology and Therapeutics, 24*(3), 207-214. doi:10.1177/1074248418817344

Calling, S., Li, X., Kawakami, N., Hamano, T., & Sundquist, K. (2016). Impact of neighborhood resources on cardiovascular disease: a nationwide six-year follow-up. *Bmc Public Health, 16*, 634. doi:10.1186/s12889-016-3293-5

Canadian Diabetes Association Clinical Practice Guidelines Expert Committee. (2013). Canadian Diabetes Association 2013 clinical practice guidelines for the prevention and management of diabetes in Canada. *Canadian Journal of Diabetes, 37*.

Canadian Institute for Health Information. (2012a). *Canadian Coding Standards for CD-10-CA and CCI for 2012*. Ottawa: CIHI

Canadian Institute for Health Information. (2012b). *Clinical administrative databases – Privacy impact assessment*. Ottawa, ON: CIHI

Canadian Institute for Health Information. (2012c). *Data Quality Documentation, Discharge Abstract Database-Multi-Year Information*. Ottawa, ON: CIHI

Canadian Institute for Health Information. (2012d). *Data Quality Documentation, Discharge Abstract Database-Multi-Year Information*. Retrieved from Ottawa, ON:

Canadian Institute for Health Information. (2012e). Hospital Cost Drivers Technical Report. In: CIHI Ottawa, Canada.

Canadian Institute for Health Information. (2015). International Comparisons: A Focus on Diabetes. *CIHI*.

Canadian Institute for Health Information. (2019). *National Health Expenditure Trends, 1975 to 2019*. Retrieved from Ottawa: https://www.cihi.ca/en/national-health-expenditure-trends-1975-to-2019

Canadian Institute for Health Information. (2020). Health Indicators: What's the difference between metrics, indicators and performance indicators? Retrieved from https://www.cihi.ca/en/health-indicators

Canadian Institute of Health Information. (2018). *Inpatient hospitalization, surgery, newborn, alternate level of care and childbirth statistics, 2017-2018.* Retrieved from https://www.cihi.ca/sites/default/files/document/dad-hmdb-childbirth-quick-stats-2017-2018-snapshot-en-web.pdf

Carlin, A., Perchoux, C., Puggina, A., Aleksovska, K., Buck, C., Burns, C., Cardon, G., Chantal, S., Ciarapica, D., Condello, G., Coppinger, T., Cortis, C., D'Haese, S., De Craemer, M., Di Blasio, A., Hansen, S., Iacoviello, L., Issartel, J., Izzicupo, P., Jaeschke, L., Kanning, M., Kennedy, A., Lakerveld, J., Chun Man Ling, F., Luzak, A., Napolitano, G., Nazare, J. A., Pischon, T., Polito, A., Sannella, A., Schulz, H., Sohun, R., Steinbrecher, A., Schlicht, W., Ricciardi, W., MacDonncha, C., Capranica, L., & Boccia, S. (2017). A life course examination of the physical environmental determinants of physical activity behaviour: A "Determinants of Diet and Physical Activity" (DEDIPAC) umbrella systematic literature review. *Plos One, 12*(8), e0182083. doi:10.1371/journal.pone.0182083

Caspersen, C. J., Powell, K. E., & Christenson, G. M. (1985). Physical activity, exercise, and physical fitness: definitions and distinctions for health-related research. *Public health reports (Washington, D.C. : 1974), 100*(2), 126-131.

Celis-Morales, C. A., Lyall, D. M., Welsh, P., Anderson, J., Steell, L., Guo, Y., Maldonado, R., Mackay, D. F., Pell, J. P., Sattar, N., & Gill, J. M. R. (2017). Association between active commuting and incident cardiovascular disease, cancer, and mortality: prospective cohort study. *BMJ, 357*, j1456. doi:10.1136/bmj.j1456

Center for Surveillance and Applied Research. (2020). Physical Activity, Sedentary Behaviour and Sleep (PASS) Indicators Data Tool, 2020 Edition. *Public Health Infobase.* Retrieved from https://health-infobase.canada.ca/pass/data-tool?index=1

Cervero, R., & Kockelman, K. (1997). Travel demand and the 3Ds: density, diversity, and design. *Transportation Research Part D-Transport and Environment, 2*(3), 199-219. doi:10.1016/S1361-9209(97)00009-6

Chan, L., Hart, L. G., & Goodman, D. C. (2006). Geographic access to health care for rural Medicare beneficiaries. *Journal of Rural Health, 22*(2), 140-146. doi:10.1111/j.1748-0361.2006.00022.x

Chandrabose, M., Cerin, E., Mavoa, S., Dunstan, D., Carver, A., Turrell, G., Owen, N., Giles-Corti, B., & Sugiyama, T. (2019). Neighborhood walkability and 12-year changes in cardio-metabolic risk: the mediating role of physical activity. *Int J Behav Nutr Phys Act, 16*(1), 86. doi:10.1186/s12966-019-0849-7

Chandrabose, M., Rachele, J. N., Gunn, L., Kavanagh, A., Owen, N., Turrell, G., Giles-Corti, B., & Sugiyama, T. (2019). Built environment and cardio-metabolic health: systematic review and meta-analysis of longitudinal studies. *Obesity Reviews, 20*(1), 41-54. doi:10.1111/obr.12759

Chen, L., Magliano, D. J., Balkau, B., Colagiuri, S., Zimmet, P. Z., Tonkin, A. M., Mitchell, P., Phillips, P. J., & Shaw, J. E. (2010). AUSDRISK: an Australian Type 2 Diabetes Risk Assessment Tool based on demographic, lifestyle and simple anthropometric measures. *Medical Journal of Australia*, *192*(4), 197-202. doi:10.5694/j.1326-5377.2010.tb03478.x

Cherry, G., & Rogers, A. W. (2003). *Rural change and planning: England and Wales in the twentieth century* (Vol. 19): Routledge.

Chipperfield, J. G. (2008). Everyday physical activity as a predictor of late-life mortality. *Gerontologist, 48*(3), 349-357. doi:10.1093/geront/48.3.349

Chiu, M., Rezai, M. R., Maclagan, L. C., Austin, P. C., Shah, B. R., Redelmeier, D. A., & Tu, J. V. (2016). Moving to a Highly Walkable Neighborhood and Incidence of Hypertension: A Propensity-Score Matched Cohort Study. *Environmental Health Perspectives, 124*(6), 754-760. doi:10.1289/ehp.1510425

Chiu, M., Shah, B. R., Maclagan, L. C., Rezai, M. R., Austin, P. C., & Tu, J. V. (2015). Walk Score (R) and the prevalence of utilitarian walking and obesity among Ontario adults: A cross-sectional study. *Health Reports*, *26*(7), 3-10.

Chong, S., Mazumdar, S., Ding, D., Morgan, G., Comino, E. J., Bauman, A., & Jalaludin, B. (2019). Neighbourhood greenspace and physical activity and sedentary behaviour among older adults with a recent diagnosis of type 2 diabetes: a prospective analysis. *Bmj Open*, *9*(11), e028947. doi:10.1136/bmjopen-2019-028947

Church, T. S., Thomas, D. M., Tudor-Locke, C., Katzmarzyk, P. T., Earnest, C. P., Rodarte, R. Q., Martin, C. K., Blair, S. N., & Bouchard, C. (2011). Trends over 5 Decades in US Occupation-Related Physical Activity and Their Associations with Obesity. *Plos One, 6*(5), 7. doi:10.1371/journal.pone.0019657

Colley, R. C., Butler, G., Garriguet, D., Prince, S. A., & Roberts, K. C. (2018). Comparison of self-reported and accelerometer-measured physical activity in Canadian adults. *Health Reports, 29*(12), 3-15.

Colley, R. C., Christidis, T., Michaud, I., Tjepkema, M., & Ross, N. A. (2019a). The association between walkable neighbourhoods and physical activity across the lifespan. *Health Reports, 30*(9), 3-13. doi:10.25318/82-003-x201900900001-eng

Colley, R. C., Christidis, T., Michaud, I., Tjepkema, M., & Ross, N. A. (2019b). An examination of the associations between walkable neighbourhoods and obesity and self-rated health in Canadians. *Health Reports, 30*(9), 14-24. doi:10.25318/82-003-x201900900002-eng

Colley, R. C., Garriguet, D., Janssen, I., Craig, C. L., Clarke, J., & Tremblay, M. S. (2011). Physical activity of Canadian adults: accelerometer results from the 2007 to 2009 Canadian Health Measures Survey. *Health Rep, 22*(1), 7-14.

Conn, V. S., Hafdahl, A. R., & Mehr, D. R. (2011). Interventions to Increase Physical Activity Among Healthy Adults: Meta-Analysis of Outcomes. *American Journal of Public Health, 101*(4), 751-758. doi:10.2105/ajph.2010.194381

Connor Gorber, S., Shields, M., Tremblay, M. S., & McDowell, I. (2008). The feasibility of establishing correction factors to adjust self-reported estimates of obesity. *Health Reports, 19*(3), 71-82.

Craig, C. L., Marshall, A. L., Sjöström, M., Bauman, A. E., Booth, M. L., Ainsworth, B. E., Pratt, M., Ekelund, U., Yngve, A., & Sallis, J. F. (2003). International physical activity questionnaire: 12-country reliability and validity. *Medicine & science in sports & exercise, 35*(8), 1381-1395. doi:10.1249/01.MSS.0000078924.61453.FB

Creatore, M. I., Glazier, R. H., Moineddin, R., Fazli, G. S., Johns, A., Gozdyra, P., Matheson, F. I., Kaufman-Shriqui, V., Rosella, L. C., Manuel, D. G., & Booth, G. L. (2016). Association of Neighborhood Walkability With Change in Overweight, Obesity, and Diabetes. *JAMA, 315*(20), 2211-2220. doi:10.1001/jama.2016.5898

Cromley, E. K., & McLafferty, S. L. (2011). *GIS and public health*: Guilford Press.

Croucher, K., Wallace, A., & Duffy, S. (2012). The influence of land use mix, density and urban design on health: a critical literature review. *York: University of York*.

Cutchin, M. P. (2007). The need for the "new health geography" in epidemiologic studies of environment and health. *Health Place, 13*(3), 725-742. doi:10.1016/j.healthplace.2006.11.003

De Greef, K., Van Dyck, D., Deforche, B., & De Bourdeaudhuij, I. (2011). Physical environmental correlates of self-reported and objectively assessed physical activity in Belgian type 2 diabetes patients. *Health and Social Care in the Community, 19*(2), 178-188. doi:10.1111/j.1365-2524.2010.00958.x

de Sa, E., & Ardern, C. I. (2014). Neighbourhood walkability, leisure-time and transport-related physical activity in a mixed urban-rural area. *PeerJ, 2*, e440. doi:10.7717/peerj.440

Dempsey, P. C., Larsen, R. N., Sethi, P., Sacre, J. W., Straznicky, N. E., Cohen, N. D., Cerin, E., Lambert, G. W., Owen, N., Kingwell, B. A., & Dunstan, D. W. (2016). Benefits for Type 2 Diabetes of Interrupting Prolonged Sitting With Brief Bouts of Light Walking or Simple Resistance Activities. *Diabetes Care, 39*(6), 964-972. doi:10.2337/dc15-2336

den Braver, N. R., Lakerveld, J., Rutters, F., Schoonmade, L. J., Brug, J., & Beulens, J. W. J. (2018). Built environmental characteristics and diabetes: a systematic review and meta-analysis. *BMC Medicine, 16*(1), 12. doi:10.1186/s12916-017-0997-z

Dendup, T., Feng, X., Clingan, S., & Astell-Burt, T. (2018). Environmental Risk Factors for Developing Type 2 Diabetes Mellitus: A Systematic Review. *International Journal of Environmental Research and Public Health, 15*(1). doi:10.3390/ijerph15010078

Department for Transport. (2016). *Transport Statistics Great Britain: 2016.* London: Department for Transport Retrieved from https://www.gov.uk/government/statistics/transport-statistics-great-britain-2016

Deshpande, A. D., Baker, E. A., Lovegreen, S. L., & Brownson, R. C. (2005). Environmental correlates of physical activity among individuals with diabetes in the rural midwest. *Diabetes Care, 28*(5), 1012-1018. doi:10.2337/diacare.28.5.1012

Diez Roux, A. V., & Mair, C. (2010). Neighborhoods and health. *Ann N Y Acad Sci, 1186*, 125-145. doi:10.1111/j.1749-6632.2009.05333.x

DiMasi, J. A., Grabowski, H. G., & Hansen, R. W. (2016). Innovation in the pharmaceutical industry: New estimates of R&D costs. *Journal of Health Economics, 47*, 20-33. doi:10.1016/j.jhealeco.2016.01.012

Ding, D., Lawson, K. D., Kolbe-Alexander, T. L., Finkelstein, E. A., Katzmarzyk, P. T., van Mechelen, W., & Pratt, M. (2016). The economic burden of physical inactivity: a global analysis of major non-communicable diseases. *The Lancet, 388*(10051), 1311-1324. doi:10.1016/s0140-6736(16)30383-x

Discacciati, A., Bellavia, A., Lee, J. J., Mazumdar, M., & Valeri, L. (2018). Med4way: a Stata command to investigate mediating and interactive mechanisms using the four-way effect decomposition. *Int J Epidemiol*. doi:10.1093/ije/dyy236

Dixon, B. N., Ugwoaba, U. A., Brockmann, A. N., & Ross, K. M. (2020). Associations between the built environment and dietary intake, physical activity, and obesity: A scoping review of reviews. *Obesity Reviews*. doi:10.1111/obr.13171

Donahue, K. E., Mielenz, T. J., Sloane, P. D., Callahan, L. F., & Devellis, R. F. (2006). Identifying supports and barriers to physical activity in patients at risk for diabetes. *Preventing Chronic Disease, 3*(4), A119.

Dummer, T. J. (2008). Health geography: supporting public health policy and planning. *Canadian Medical Association Journal, 178*(9), 1177-1180. doi:10.1503/cmaj.071783

Duncan, D. T., & Kawachi, I. (2018). *Neighborhoods and health*. Oxford, UK: Oxford University Press.

Durstine, J. L., Gordon, B., Wang, Z., & Luo, X. (2013). Chronic disease and the link to physical activity. *Journal of Sport and Health Science, 2*(1), 3-11. doi:10.1016/j.jshs.2012.07.009

Fair. (1995). An overview of record linkage in Canada. *Turning administrative systems into information systems. Washington (DC): Statistics of Income, Internal Revenue Services*, 139-150.

Farkas, B., Wagner, D. J., Nettel-Aguirre, A., Friedenreich, C., & McCormack, G. R. (2019). A systematized literature review on the associations between neighbourhood built characteristics and walking among Canadian adults. *Health Promotion and Chronic Disease Prevention in Canada-Research Policy and Practice, 39*(1), 1-14. doi:10.24095/hpcdp.39.1.01

Fecht, D., Fortunato, L., Morley, D., Hansell, A. L., & Gulliver, J. (2016). Associations between urban metrics and mortality rates in England. *Environmental Health, 15*(1), S34. doi:10.1186/s12940-016-0106-3

Fellegi, I. (1997). Record linkage and public policy—a dynamic evolution. In *Record Linkage Techniques* (pp. 3-12).

Fellegi, I., & Sunter, A. (1969). A Theory for Record Linkage. *Journal of the American Statistical Association, 64*(328), 1183-1210. doi:10.2307/2286061

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

Ferrari, G., Werneck, A. O., da Silva, D. R., Kovalskys, I., Gómez, G., Rigotti, A., Sanabria, L. Y. C., García, M. Y., Pareja, R. G., Herrera-Cuenca, M., Zimberg, I. Z., Guajardo, V., Pratt, M., Cristi-Montero, C., Rodríguez-Rodríguez, F., Marques, A., Cerin, E., Van Dyck, D., Pires, C., Fisberg, M., & on behalf of the, E. S. G. (2020). Is the perceived neighborhood built environment associated with domain-specific physical activity in Latin American adults? An eight-country observational study. *International Journal of Behavioral Nutrition and Physical Activity, 17*(1), 125. doi:10.1186/s12966-020-01030-6

Forouhi, N., Hall, E., & McKeigue, P. (2004). A life course approach to diabetes. In *A Life Course Approach to Chronic Disease Epidemiology* (2 ed.). Oxford: Oxford University Press.

Foster, S., Knuiman, M., Villanueva, K., Wood, L., Christian, H., & Giles-Corti, B. (2014). Does walkable neighbourhood design influence the association between objective crime and walking? *Int J Behav Nutr Phys Act, 11*, 100. doi:10.1186/s12966-014-0100-5

Frumkin, H., Bratman, G. N., Breslow, S. J., Cochran, B., Kahn, P. H., Jr., Lawler, J. J., Levin, P. S., Tandon, P. S., Varanasi, U., Wolf, K. L., & Wood, S. A. (2017). Nature Contact and Human Health: A Research Agenda. *Environmental Health Perspectives, 125*(7), 075001. doi:10.1289/EHP1663

Fry, R., Akbari, A., Mah, S., & Ross, N. (2018). Measuring Active Living Environments: An international comparison between Canada and Wales. *International Journal of Population Data Science, 3*(2).

Gaglioti, A. H., Xu, J., Rollins, L., Baltrus, P., O'Connell, L. K., Cooper, D. L., Hopkins, J., Botchwey, N. D., & Akintobi, T. H. (2018). Neighborhood Environmental Health and Premature Death From Cardiovascular Disease. *Preventing Chronic Disease, 15*, E17. doi:10.5888/pcd15.170220

Gariepy, G., Kaufman, J. S., Blair, A., Kestens, Y., & Schmitz, N. (2015). Place and health in diabetes: the neighbourhood environment and risk of depression in adults with Type 2 diabetes. *Diabetic Medicine, 32*(7), 944-950. doi:10.1111/dme.12650

Garriguet, D., Tremblay, S., & Colley, R. C. (2015). Comparison of Physical Activity Adult Questionnaire results with accelerometer data. *Health Reports, 26*(7), 11-17.

Gary-Webb, T. L., Baptiste-Roberts, K., Pham, L., Wesche-Thobaben, J., Patricio, J., Pi-Sunyer, F. X., Brown, A. F., Jones-Corneille, L., Brancati, F. L., & the Look, A. R. G. (2011). Neighborhood Socioeconomic Status, Depression, and Health Status in the Look AHEAD

(Action for Health in Diabetes) Study. *Bmc Public Health, 11*(1), 349. doi:10.1186/1471-2458-11-349

Gassasse, Z., Smith, D., Finer, S., & Gallo, V. (2017). Association between urbanisation and type 2 diabetes: an ecological study. *BMJ Global Health, 2*(4), e000473. doi:10.1136/bmjgh-2017-000473

Gauvin, L., Richard, L., Craig, C. L., Spivock, M., Riva, M., Forster, M., Laforest, S., Laberge, S., Fournel, M. C., Gagnon, H., Gagne, S., & Potvin, L. (2005). From walkability to active living potential: an "ecometric" validation study. *Am J Prev Med, 28*(2 Suppl 2), 126-133. doi:10.1016/j.amepre.2004.10.029

Gavrielov-Yusim, N., & Friger, M. (2014). Use of administrative medical databases in population-based research. *Journal of Epidemiology and Community Health, 68*(3), 283-287. doi:10.1136/jech-2013-202744

Gesler, W. M. (1992). Therapeutic landscapes: Medical issues in light of the new cultural geography. *Soc Sci Med, 34*(7), 735-746. doi:https://doi.org/10.1016/0277-9536(92)90360-3

Giles-Corti, B., Badland, H., Mavoa, S., Turrell, G., Bull, F., Boruff, B., Pettit, C., Bauman, A., Hooper, P., Villanueva, K., Astell-Burt, T., Feng, X., Learnihan, V., Davey, R., Grenfell, R., & Thackway, S. (2014). Reconnecting urban planning with health: a protocol for the development and validation of national liveability indicators associated with noncommunicable disease risk behaviours and health outcomes. *Public Health Res Pract, 25*(1). doi:10.17061/phrp2511405

Giles-Corti, B., Bull, F., Knuiman, M., McCormack, G., Van Niel, K., Timperio, A., Christian, H., Foster, S., Divitini, M., Middleton, N., & Boruff, B. (2013). The influence of urban design on neighbourhood walking following residential relocation: longitudinal results from the RESIDE study. *Social Science and Medicine, 77*, 20-30. doi:10.1016/j.socscimed.2012.10.016

Giles-Corti, B., Timperio, A., Bull, F., & Pikora, T. (2005). Understanding physical activity environmental correlates: increased specificity for ecological models. *Exercise and Sport Sciences Reviews, 33*(4), 175-181. doi:10.1097/00003677-200510000-00005

Giles-Corti, B., Vernez-Moudon, A., Reis, R., Turrell, G., Dannenberg, A. L., Badland, H., Foster, S., Lowe, M., Sallis, J. F., Stevenson, M., & Owen, N. (2016). City planning and population health: a global challenge. *The Lancet, 388*(10062), 2912-2924. doi:10.1016/S0140-6736(16)30066-6

Glanz, K., Rimer, B. K., & Viswanath, K. (2015). *Health Behavior: Theory, Research, and Practice* (Fifth edition. ed.). San Francisco, CA: Jossey-Bass, a Wiley Brand.

Glazier, R. H., Creatore, M. I., Weyman, J. T., Fazli, G., Matheson, F. I., Gozdyra, P., Moineddin, R., Kaufman-Shriqui, V., & Booth, G. L. (2014). Density, destinations or both? A comparison of measures of walkability in relation to transportation behaviors, obesity and diabetes in Toronto, Canada. *Plos One*, *9*(1), e85295. doi:10.1371/journal.pone.0085295

Goodman, D. C., Fisher, E., Stukel, T. A., & Chang, C. (1997). The distance to community medical care and the likelihood of hospitalization: is closer always better? *American Journal of Public Health*, *87*(7), 1144-1150. doi:10.2105/ajph.87.7.1144

Government of Canada. (2014). *Action for seniors report*. Retrieved from https://www.canada.ca/en/employment-social-development/programs/seniors-action-report.html

Grasser, G., Van Dyck, D., Titze, S., & Stronegger, W. (2013). Objectively measured walkability and active transport and weight-related outcomes in adults: a systematic review. *International Journal of Public Health*, *58*(4), 615-625. doi:10.1007/s00038-012-0435-0

Greaves, C. J., Sheppard, K. E., Abraham, C., Hardeman, W., Roden, M., Evans, P. H., Schwarz, P., & Group, I. S. (2011). Systematic review of reviews of intervention components associated with increased effectiveness in dietary and physical activity interventions. *Bmc Public Health*, *11*, 119. doi:10.1186/1471-2458-11-119

Green, E., Ritchie, F., Mytton, J., Webber, D. J., Deave, T., Montgomery, A., Woolfrey, L., & Chowdhury, S. (2015). *Enabling data linkage to maximise the value of public health research data*. Retrieved from London: http://eprints.uwe.ac.uk/25387

Gregg, E. W., Gerzoff, R. B., Caspersen, C. J., Williamson, D. F., & Narayan, K. M. (2003). Relationship of walking to mortality among US adults with diabetes. *Archives of Internal Medicine*, *163*(12), 1440-1447. doi:10.1001/archinte.163.12.1440

Gregg, E. W., Gu, Q., Cheng, Y. J., Narayan, K. M., & Cowie, C. C. (2007). Mortality trends in men and women with diabetes, 1971 to 2000. *Ann Intern Med*, *147*(3), 149-155. doi:10.7326/0003-4819-147-3-200708070-00167

Griffin, B. A., Eibner, C., Bird, C. E., Jewell, A., Margolis, K., Shih, R., Ellen Slaughter, M., Whitsel, E. A., Allison, M., & Escarce, J. J. (2013). The relationship between urban sprawl and coronary heart disease in women. *Health Place*, *20*, 51-61. doi:10.1016/j.healthplace.2012.11.003

Grimm, N. B., Faeth, S. H., Golubiewski, N. E., Redman, C. L., Wu, J., Bai, X., & Briggs, J. M. (2008). Global change and the ecology of cities. *Science*, *319*(5864), 756-760. doi:10.1126/science.1150195

Gunn, L. D., King, T. L., Mavoa, S., Lamb, K. E., Giles-Corti, B., & Kavanagh, A. (2017). Identifying destination distances that support walking trips in local neighborhoods. *Journal of Transport & Health, 5*, 133-141. doi:10.1016/j.jth.2016.08.009

Guthold, R., Stevens, G. A., Riley, L. M., & Bull, F. C. (2018). Worldwide trends in insufficient physical activity from 2001 to 2016: a pooled analysis of 358 population-based surveys with 1.9 million participants. *Lancet Global Health, 6*(10), E1077-E1086. doi:10.1016/S2214-109x(18)30357-7

Hagger, M. S. (2016). Non-conscious processes and dual-process theories in health psychology. *Health Psychology Review, 10*(4), 375-380. doi:10.1080/17437199.2016.1244647

Hajna, S., Dasgupta, K., & Ross, N. A. (2018). Laboratory-Assessed Markers of Cardiometabolic Health and Associations with GIS-Based Measures of Active-Living Environments. *International Journal of Environmental Research and Public Health, 15*(10). doi:10.3390/ijerph15102079

Hajna, S., Kestens, Y., Daskalopoulou, S. S., Joseph, L., Thierry, B., Sherman, M., Trudeau, L., Rabasa-Lhoret, R., Meissner, L., Bacon, S. L., Gauvin, L., Ross, N. A., Dasgupta, K., Diabetes, G. P. S., & Walkablilty Study, G. (2016). Neighbourhood walkability and home neighbourhood-based physical activity: an observational study of adults with type 2 diabetes. *Bmc Public Health, 16*, 957. doi:10.1186/s12889-016-3603-y

Hajna, S., Ross, N. A., Brazeau, A. S., Belisle, P., Joseph, L., & Dasgupta, K. (2015). Associations between neighbourhood walkability and daily steps in adults: a systematic review and meta-analysis. *Bmc Public Health, 15*, 768. doi:10.1186/s12889-015-2082-x

Hajna, S., Ross, N. A., Griffin, S. J., & Dasgupta, K. (2017). Lexical neutrality in environmental health research: Reflections on the term walkability. *Bmc Public Health, 17*(1), 940. doi:10.1186/s12889-017-4943-y

Hajna, S., Ross, N. A., Joseph, L., Harper, S., & Dasgupta, K. (2015). Neighbourhood walkability, daily steps and utilitarian walking in Canadian adults. *Bmj Open, 5*(11), e008964. doi:10.1136/bmjopen-2015-008964

Hajna, S., Ross, N. A., Joseph, L., Harper, S., & Dasgupta, K. (2016). Neighbourhood Walkability and Daily Steps in Adults with Type 2 Diabetes. *Plos One, 11*(3), e0151544. doi:10.1371/journal.pone.0151544

Hall, C. M., & Ram, Y. (2018). Walk score (R) and its potential contribution to the study of active transport and walkability: A critical and systematic review. *Transportation Research Part D-Transport and Environment, 61*, 310-324. doi:10.1016/j.trd.2017.12.018

Hall, K. S., Hyde, E. T., Bassett, D. R., Carlson, S. A., Carnethon, M. R., Ekelund, U., Evenson, K. R., Galuska, D. A., Kraus, W. E., Lee, I. M., Matthews, C. E., Omura, J. D., Paluch, A. E., Thomas, W. I., & Fulton, J. E. (2020). Systematic review of the prospective association of daily step counts with risk of mortality, cardiovascular disease, and dysglycemia. *International Journal of Behavioral Nutrition and Physical Activity, 17*(1), 78. doi:10.1186/s12966-020-00978-9

Hamano, T., Kawakami, N., Li, X., & Sundquist, K. (2013). Neighbourhood environment and stroke: a follow-up study in Sweden. *Plos One, 8*(2), e56680. doi:10.1371/journal.pone.0056680

Hamidi, S., Ewing, R., Tatalovich, Z., Grace, J. B., & Berrigan, D. (2018). Associations between Urban Sprawl and Life Expectancy in the United States. *International Journal of Environmental Research and Public Health, 15*(5). doi:10.3390/ijerph15050861

Handy, S., Cao, X., & Mokhtarian, P. L. (2006). Self-selection in the relationship between the built environment and walking: Empirical evidence from Northern California. *Journal of the American Planning Association, 72*(1), 55-74. doi:10.1080/01944360608976724

Handy, S. L., Boarnet, M. G., Ewing, R., & Killingsworth, R. E. (2002). How the built environment affects physical activity: views from urban planning. *Am J Prev Med, 23*(2 Suppl), 64-73. doi:10.1016/S0749-3797(02)00475-0

Hankey, S., Marshall, J. D., & Brauer, M. (2012). Health impacts of the built environment: within-urban variability in physical inactivity, air pollution, and ischemic heart disease mortality. *Environmental Health Perspectives, 120*(2), 247-253. doi:10.1289/ehp.1103806

Hankonen, N., Sutton, S., Prevost, A. T., Simmons, R. K., Griffin, S. J., Kinmonth, A. L., & Hardeman, W. (2014). Which Behavior Change Techniques are Associated with Changes in Physical Activity, Diet and Body Mass Index in People with Recently Diagnosed Diabetes? *Annals of Behavioral Medicine, 49*(1), 7-17. doi:10.1007/s12160-014-9624-9

Hardy, R., Lawlor, D. A., & Kuh, D. (2015). A life course approach to cardiovascular aging. *Future Cardiology, 11*(1), 101-113. doi:10.2217/fca.14.67

Haskell, W. L. (2012a). Physical Activity by Self-Report: A Brief History and Future Issues. *Journal of Physical Activity & Health, 9*, S5-S10. doi:10.1123/jpah.9.s1.s5

Haskell, W. L. (2012b). Physical activity by self-report: a brief history and future issues. *Journal of Physical Activity & Health, 9 Suppl 1*, S5-10. doi:10.1123/jpah.9.s1.s5

Haykowsky, M. J., Liang, Y., Pechter, D., Jones, L. W., McAlister, F. A., & Clark, A. M. (2007). A meta-analysis of the effect of exercise training on left ventricular remodeling in heart failure patients: the benefit depends on the type of training performed. *Journal of the American College of Cardiology, 49*(24), 2329-2336. doi:10.1016/j.jacc.2007.02.055

Health Canada. (1994). Strategies for Population Health: Investing in the Health of Canadians / Prepared by the Federal, Provincial and Territorial Advisory Committee on Population Health. *Ottawa*.

Heiss, V., & Petosa, R. (2014). Correlates of Physical Activity Among Adults With Type 2 Diabetes: A Systematic Literature Review. *American Journal of Health Education, 45*(5), 278-287. doi:10.1080/19325037.2014.933139

Henneman, P. L., Garb, J. L., Capraro, G. A., Li, H., Smithline, H. A., & Wait, R. B. (2011). Geography and travel distance impact emergency department visits. *Journal of Emergency Medicine, 40*(3), 333-339. doi:10.1016/j.jemermed.2009.08.058

Herrmann, T., Gleckner, W., Wasfi, R. A., Thierry, B., Kestens, Y., & Ross, N. A. (2019). A pan-Canadian measure of active living environments using open data. *Health Reports, 30*(5), 16-25.

Herzog, T. N., Scheuren, F. J., & Winkler, W. E. (2007). *Data quality and record linkage techniques*: Springer Science & Business Media.

Hippisley-Cox, J., Coupland, C., Robson, J., Sheikh, A., & Brindle, P. (2009). Predicting risk of type 2 diabetes in England and Wales: prospective derivation and validation of QDScore. *BMJ, 338,* b880. doi:10.1136/bmj.b880

Hirsch, J. A., Winters, M., Clarke, P., & McKay, H. (2014). Generating GPS activity spaces that shed light upon the mobility habits of older adults: a descriptive analysis. *International Journal of Health Geographics, 13,* 51. doi:10.1186/1476-072X-13-51

Hochbaum, G. M. (1958). *Public participation in medical screening programs: A socio-psychological study*: US Department of Health, Education, and Welfare, Public Health Service ….

Holman, C. D., Bass, A. J., Rouse, I. L., & Hobbs, M. S. (1999). Population-based linkage of health records in Western Australia: development of a health services research linked database. *Australian and New Zealand Journal of Public Health, 23*(5), 453-459.

Holman, C. D., Bass, J. A., Rosman, D. L., Smith, M. B., Semmens, J. B., Glasson, E. J., Brook, E. L., Trutwein, B., Rouse, I. L., Watson, C. R., de Klerk, N. H., & Stanley, F. J. (2008). A decade of data linkage in Western Australia: strategic design, applications and benefits of the WA data linkage system. *Australian Health Review, 32*(4), 766-777. doi:10.1071/AH080766

Hosler, A. S., Gallant, M. P., Riley-Jacome, M., & Rajulu, D. T. (2014). Relationship between objectively measured walkability and exercise walking among adults with diabetes. *Journal of Environmental and Public Health, 2014*, 542123. doi:10.1155/2014/542123

Howell, N. A., Tu, J. V., Moineddin, R., Chu, A., & Booth, G. L. (2019). Association Between Neighborhood Walkability and Predicted 10-Year Cardiovascular Disease Risk: The CANHEART (Cardiovascular Health in Ambulatory Care Research Team) Cohort. *Journal of the American Heart Association, 8*(21), e013146. doi:10.1161/JAHA.119.013146

Howlett, N., Trivedi, D., Troop, N. A., & Chater, A. M. (2018). Are physical activity interventions for healthy inactive adults effective in promoting behavior change and maintenance, and which behavior change techniques are effective? A systematic review and meta-analysis. *Translational Behavioral Medicine, 9*(1), 147-157. doi:10.1093/tbm/iby010

Hu, G., Eriksson, J., Barengo, N. C., Lakka, T. A., Valle, T. T., Nissinen, A., Jousilahti, P., & Tuomilehto, J. (2004). Occupational, commuting, and leisure-time physical activity in relation to total and cardiovascular mortality among Finnish subjects with type 2 diabetes. *Circulation, 110*(6), 666-673. doi:10.1161/01.CIR.0000138102.23783.94

Huai, P., Xun, H., Reilly, K. H., Wang, Y., Ma, W., & Xi, B. (2013). Physical activity and risk of hypertension: a meta-analysis of prospective cohort studies. *Hypertension, 62*(6), 1021-1026. doi:10.1161/HYPERTENSIONAHA.113.01965

Huang, Y., Cai, X., Mai, W., Li, M., & Hu, Y. (2016). Association between prediabetes and risk of cardiovascular disease and all cause mortality: systematic review and meta-analysis. *BMJ, 355*, i5953. doi:10.1136/bmj.i5953

Huebschmann, A. G., Crane, L. A., Belansky, E. S., Scarbro, S., Marshall, J. A., & Regensteiner, J. G. (2011). Fear of Injury With Physical Activity Is Greater in Adults With Diabetes Than in Adults Without Diabetes. *Diabetes Care, 34*(8), 1717-1722. doi:10.2337/dc10-1801

Inoue, S., Ohya, Y., Odagiri, Y., Takamiya, T., Ishii, K., Kitabayashi, M., Suijo, K., Sallis, J. F., & Shimomitsu, T. (2010). Association between perceived neighborhood environment and walking among adults in 4 cities in Japan. *Journal of Epidemiology, 20*(4), 277-286. doi:10.2188/jea.je20090120

Janssen, I. (2012). Health care costs of physical inactivity in Canadian adults. *Applied Physiology Nutrition and Metabolism-Physiologie Appliquee Nutrition Et Metabolisme, 37*(4), 803-806. doi:10.1139/h2012-061

Jaro, M. A. (1995). Probabilistic linkage of large public health data files. *Statistics in Medicine, 14*(5-7), 491-498. doi:10.1002/sim.4780140510

Jeon, C. Y., Lokken, R. P., Hu, F. B., & van Dam, R. M. (2007). Physical activity of moderate intensity and risk of type 2 diabetes: a systematic review. *Diabetes Care, 30*(3), 744-752. doi:10.2337/dc06-1842

Jia, P., Cheng, X., Xue, H., & Wang, Y. (2017). Applications of geographic information systems (GIS) data and methods in obesity-related research. *Obes Rev, 18*(4), 400-411. doi:10.1111/obr.12495

Jia, X., Yu, Y., Xia, W., Masri, S., Sami, M., Hu, Z., Yu, Z., & Wu, J. (2018). Cardiovascular diseases in middle aged and older adults in China: the joint effects and mediation of different types of physical exercise and neighborhood greenness and walkability. *Environ Res, 167*, 175-183. doi:10.1016/j.envres.2018.07.003

Joseph, P., Leong, D., McKee, M., Anand, S. S., Schwalm, J. D., Teo, K., Mente, A., & Yusuf, S. (2017). Reducing the Global Burden of Cardiovascular Disease, Part 1: The Epidemiology and Risk Factors. *Circ Res, 121*(6), 677-694. doi:10.1161/CIRCRESAHA.117.308903

Jutte, D. P., Roos, L. L., & Brownell, M. D. (2011). Administrative record linkage as a tool for public health research. *Annual Review of Public Health, 32*, 91-108. doi:10.1146/annurev-publhealth-031210-100700

Kahneman, D. (2011). *Thinking, Fast and Slow*. New York: Farrar, Straus and Giroux.

Kampstra, P. (2008). Beanplot: A boxplot alternative for visual comparison of distributions. *Journal of statistical software, 28*(1), 1-9.

Karmeniemi, M., Lankila, T., Ikaheimo, T., Koivumaa-Honkanen, H., & Korpelainen, R. (2018). The Built Environment as a Determinant of Physical Activity: A Systematic Review of Longitudinal Studies and Natural Experiments. *Annals of Behavioral Medicine, 52*(3), 239-251. doi:10.1093/abm/kax043

Kartschmit, N., Sutcliffe, R., Sheldon, M. P., Moebus, S., Greiser, K. H., Hartwig, S., Thurkow, D., Stentzel, U., van den Berg, N., Wolf, K., Maier, W., Peters, A., Ahmed, S., Kohnke, C., Mikolajczyk, R., Wienke, A., Kluttig, A., & Rudge, G. (2020). Walkability and its association with prevalent and incident diabetes among adults in different regions of Germany: results of pooled data from five German cohorts. *BMC Endocr Disord, 20*(1), 7. doi:10.1186/s12902-019-0485-x

Katzmarzyk, P. T., Gledhill, N., & Shephard, R. J. (2000). The economic burden of physical inactivity in Canada. *Canadian Medical Association Journal, 163*(11), 1435-1440.

Kautzky-Willer, A., Harreiter, J., & Pacini, G. (2016). Sex and Gender Differences in Risk, Pathophysiology and Complications of Type 2 Diabetes Mellitus. *Endocr Rev, 37*(3), 278-316. doi:10.1210/er.2015-1137

Kearns, R., & Moon, G. (2002). From medical to health geography: novelty, place and theory after a decade of change. *Progress in Human Geography, 26*(5), 605-625. doi:10.1191/0309132502ph389oa

Kearns, R. A., & Joseph, A. E. (1993). Space in its place: developing the link in medical geography. *Soc Sci Med, 37*(6), 711-717. doi:10.1016/0277-9536(93)90364-A

Kennerly, A.-M., & Kirk, A. (2018). Physical activity and sedentary behaviour of adults with type 2 diabetes: a systematic review. *Practical Diabetes, 35*(3), 86-89g. doi:10.1002/pdi.2169

Kim, A. S., & Johnston, S. C. (2011). Global variation in the relative burden of stroke and ischemic heart disease. *Circulation, 124*(3), 314-323. doi:10.1161/CIRCULATIONAHA.111.018820

Kim, E. J., Kim, J., & Kim, H. (2020). Neighborhood Walkability and Active Transportation: A Correlation Study in Leisure and Shopping Purposes. *International Journal of Environmental Research and Public Health, 17*(7). doi:10.3390/ijerph17072178

King, A. C., Stokols, D., Talen, E., Brassington, G. S., & Killingsworth, R. (2002). Theoretical approaches to the promotion of physical activity: forging a transdisciplinary paradigm. *Am J Prev Med, 23*(2 Suppl), 15-25. doi:10.1016/s0749-3797(02)00470-1

King, K. E., & Clarke, P. J. (2015). A disadvantaged advantage in walkability: findings from socioeconomic and geographical analysis of national built environment data in the United States. *American Journal of Epidemiology, 181*(1), 17-25. doi:10.1093/aje/kwu310

King, T. L., Bentley, R. J., Thornton, L. E., & Kavanagh, A. M. (2015). Does the presence and mix of destinations influence walking and physical activity? *International Journal of Behavioral Nutrition and Physical Activity, 12*, 115. doi:10.1186/s12966-015-0279-0

Kirby, R. S., Delmelle, E., & Eberth, J. M. (2017). Advances in spatial epidemiology and geographic information systems. *Ann Epidemiol, 27*(1), 1-9. doi:10.1016/j.annepidem.2016.12.001

Kirst, M., Chaiton, M., & O'Campo, P. (2019). Tobacco outlet density, neighbourhood stressors and smoking prevalence in Toronto, Canada. *Health & Place, 58*. doi:10.1016/j.healthplace.2019.102171

Knol, M. J., & VanderWeele, T. J. (2012). Recommendations for presenting analyses of effect modification and interaction. *International Journal of Epidemiology, 41*(2), 514-520. doi:10.1093/ije/dyr218

Knowler, W. C., Barrett-Connor, E., Fowler, S. E., Hamman, R. F., Lachin, J. M., Walker, E. A., Nathan, D. M., & Diabetes Prevention Program Research, G. (2002). Reduction in the incidence of type 2 diabetes with lifestyle intervention or metformin. *New England Journal of Medicine, 346*(6), 393-403. doi:10.1056/NEJMoa012512

Kodama, S., Tanaka, S., Heianza, Y., Fujihara, K., Horikawa, C., Shimano, H., Saito, K., Yamada, N., Ohashi, Y., & Sone, H. (2013). Association between physical activity and risk of all-cause mortality and cardiovascular disease in patients with diabetes: a meta-analysis. *Diabetes Care, 36*(2), 471-479. doi:10.2337/dc12-0783

Kohl, H. W., 3rd, Craig, C. L., Lambert, E. V., Inoue, S., Alkandari, J. R., Leetongin, G., Kahlmeier, S., & Lancet Physical Activity Series Working, G. (2012). The pandemic of physical inactivity: global action for public health. *The Lancet, 380*(9838), 294-305. doi:10.1016/S0140-6736(12)60898-8

Kolb, H., & Martin, S. (2017). Environmental/lifestyle factors in the pathogenesis and prevention of type 2 diabetes. *BMC Medicine, 15*(1), 131. doi:10.1186/s12916-017-0901-x

Korkiakangas, E. E., Alahuhta, M. A., & Laitinen, J. H. (2009). Barriers to regular exercise among adults at high risk or diagnosed with type 2 diabetes: a systematic review. *Health Promotion International, 24*(4), 416-427. doi:10.1093/heapro/dap031

Kuh, D., & Shlomo, Y. B. (2004). *A life course approach to chronic disease epidemiology*. Oxford, UK: Oxford University Press.

Kwan, M.-P. (2012). The Uncertain Geographic Context Problem. *Annals of the Association of American Geographers, 102*(5), 958-968. doi:10.1080/00045608.2012.687349

Kyu, H. H., Bachman, V. F., Alexander, L. T., Mumford, J. E., Afshin, A., Estep, K., Veerman, J. L., Delwiche, K., Iannarone, M. L., Moyer, M. L., Cercy, K., Vos, T., Murray, C. J., & Forouzanfar, M. H. (2016). Physical activity and risk of breast cancer, colon cancer, diabetes, ischemic heart disease, and ischemic stroke events: systematic review and dose-response meta-analysis for the Global Burden of Disease Study 2013. *BMJ, 354*, i3857. doi:10.1136/bmj.i3857

Laatikainen, T., Dunbar, J. A., Chapman, A., Kilkkinen, A., Vartiainen, E., Heistaro, S., Philpot, B., Absetz, P., Bunker, S., O'Neil, A., Reddy, P., Best, J. D., & Janus, E. D. (2007). Prevention of type 2 diabetes by lifestyle intervention in an Australian primary health care setting: Greater Green Triangle (GGT) Diabetes Prevention Project. *Bmc Public Health, 7*, 249. doi:10.1186/1471-2458-7-249

Lally, P., & Gardner, B. (2013). Promoting habit formation. *Health Psychology Review, 7*(sup1), S137-S158. doi:10.1080/17437199.2011.603640

Law, M. R., Morris, J. K., & Wald, N. J. (2009). Use of blood pressure lowering drugs in the prevention of cardiovascular disease: meta-analysis of 147 randomised trials in the context of expectations from prospective epidemiological studies. *BMJ, 338*, b1665. doi:10.1136/bmj.b1665

Leccese, M., & McCormick, K. (2000). *Charter of the new urbanism*: McGraw-Hill Professional.

Lee, D. S., Chiu, M., Manuel, D. G., Tu, K., Wang, X., Austin, P. C., Mattern, M. Y., Mitiku, T. F., Svenson, L. W., Putnam, W., Flanagan, W. M., Tu, J. V., & Canadian Cardiovascular Outcomes Research, T. (2009). Trends in risk factors for cardiovascular disease in Canada: temporal, socio-demographic and geographic factors. *CMAJ, 181*(3-4), E55-66. doi:10.1503/cmaj.081629

Lee, I. M., Shiroma, E. J., Lobelo, F., Puska, P., Blair, S. N., Katzmarzyk, P. T., & Lancet Physical Activity Series Working, G. (2012). Effect of physical inactivity on major non-communicable diseases worldwide: an analysis of burden of disease and life expectancy. *The Lancet, 380*(9838), 219-229. doi:10.1016/S0140-6736(12)61031-9

Lee, J. E., Sung, J. H., Ward, W. B., Fos, P. J., Lee, W. J., & Kim, J. C. (2007). Utilization of the emergency room: impact of geographic distance. *Geospatial Health, 1*(2), 243-253. doi:10.4081/gh.2007.272

Leon, D. A. (2008). Cities, urbanization and health. *International Journal of Epidemiology, 37*(1), 4-8. doi:10.1093/ije/dym271

Leslie, E., Coffee, N., Frank, L., Owen, N., Bauman, A., & Hugo, G. (2007). Walkability of local communities: using geographic information systems to objectively assess relevant environmental attributes. *Health Place, 13*(1), 111-122. doi:10.1016/j.healthplace.2005.11.001

Li, J., & Siegrist, J. (2012). Physical activity and risk of cardiovascular disease--a meta-analysis of prospective cohort studies. *Int J Environ Res Public Health, 9*(2), 391-407. doi:10.3390/ijerph9020391

Liao, Y., Shibata, A., Ishii, K., Koohsari, M. J., Inoue, S., & Oka, K. (2018). Can neighborhood design support walking? Cross-sectional and prospective findings from Japan. *Journal of Transport & Health, 11*, 73-79. doi:10.1016/j.jth.2018.10.008

Lin, G., Allan, D. E., & Penning, M. J. (2002). Examining distance effects on hospitalizations using GIS: a study of three health regions in British Columbia, Canada. *Environment and Planning a-Economy and Space, 34*(11), 2037-2053. doi:10.1068/a3528

Link, B. G., & Phelan, J. (1995). Social conditions as fundamental causes of disease. *J Health Soc Behav, Spec No*, 80-94. doi:10.2307/2626958

Lira, Y., Elaine, M. O., Younghan, L., Allison, S., & Tanya, R. B. (2017). A Systematic Review of Community-wide Media Physical Activity Campaigns: An Update From 2010. *Journal of Physical Activity and Health, 14*(7), 552-570. doi:10.1123/jpah.2016-0616 10.1123/jpah.2016-0616

Lohr, K. N., & Steinwachs, D. M. (2002). Health services research: an evolving definition of the field. *Health Services Research, 37*(1), 7-9. doi:10.1111/1475-6773.01020

Loo, C. K., Greiver, M., Aliarzadeh, B., & Lewis, D. (2017). Association between neighbourhood walkability and metabolic risk factors influenced by physical activity: a cross-sectional study of adults in Toronto, Canada. *Bmj Open, 7*(4), e013889. doi:10.1136/bmjopen-2016-013889

Lynch, J., & Smith, G. D. (2005). A life course approach to chronic disease epidemiology. *Annual Review of Public Health, 26*, 1-35. doi:10.1146/annurev.publhealth.26.021304.144505

Lyons, R. A., Jones, K. H., John, G., Brooks, C. J., Verplancke, J.-P., Ford, D. V., Brown, G., & Leake, K. (2009). The SAIL databank: linking multiple health and social care datasets. *BMC Medical Informatics and Decision Making, 9*(1), 3. doi:10.1186/1472-6947-9-3

Ma, C., Avenell, A., Bolland, M., Hudson, J., Stewart, F., Robertson, C., Sharma, P., Fraser, C., & MacLennan, G. (2017). Effects of weight loss interventions for adults who are obese on mortality, cardiovascular disease, and cancer: systematic review and meta-analysis. *BMJ, 359*, j4849. doi:10.1136/bmj.j4849

Mackenbach, J. D., Rutter, H., Compernolle, S., Glonti, K., Oppert, J. M., Charreire, H., De Bourdeaudhuij, I., Brug, J., Nijpels, G., & Lakerveld, J. (2014). Obesogenic environments: a systematic review of the association between the physical environment and adult weight status, the SPOTLIGHT project. *Bmc Public Health, 14*, 233. doi:10.1186/1471-2458-14-233

Magliano, D. J., Barr, E. L. M., Zimmet, P. Z., Cameron, A. J., Dunstan, D. W., Colagiuri, S., Jolley, D., Owen, N., Phillips, P., Tapp, R. J., Welborn, T. A., & Shaw, J. E. (2008). Glucose Indices, Health Behaviors, and Incidence of Diabetes in Australia. *The Australian Diabetes, Obesity and Lifestyle Study, 31*(2), 267-272. doi:10.2337/dc07-0912

Mah, S. M., Sanmartin, C., Riva, M., Dasgupta, K., & Ross, N. A. (2020). Active living environments, physical activity and premature cardiometabolic mortality in Canada: a nationwide cohort study. *Bmj Open*, *10*(11), e035942. doi:10.1136/bmjopen-2019-035942

Manuel, D., Rosella, L., Tuna, M., & Bennett, C. (2010). How many Canadians will be diagnosed with diabetes between 2007 and 2017. *Assessing population risk. ICES Investigative Report. Toronto (Ont.): ICES*.

Manuel, D. G., Perez, R., Sanmartin, C., Taljaard, M., Hennessy, D., Wilson, K., Tanuseputro, P., Manson, H., Bennett, C., & Tuna, M. (2016). Measuring burden of unhealthy behaviours using a multivariable predictive approach: life expectancy lost in Canada attributable to smoking, alcohol, physical inactivity, and diet. *Plos Medicine*, *13*(8), e1002082. doi:10.1371/journal.pmed.1002082

Marcus, B., Owen, N., Forsyth, L., Cavill, N., & Fridinger, F. (1998). Physical activity interventions using mass media, print media, and information technology. *Am J Prev Med, 15*(4), 362-378. doi:10.1016/S0749-3797(98)00079-8

Markevych, I., Schoierer, J., Hartig, T., Chudnovsky, A., Hystad, P., Dzhambov, A. M., de Vries, S., Triguero-Mas, M., Brauer, M., Nieuwenhuijsen, M. J., Lupp, G., Richardson, E. A., Astell-Burt, T., Dimitrova, D., Feng, X., Sadeh, M., Standl, M., Heinrich, J., & Fuertes, E. (2017). Exploring pathways linking greenspace to health: Theoretical and methodological guidance. *Environ Res, 158*, 301-317. doi:10.1016/j.envres.2017.06.028

Maslow, A. H. (1943). A theory of human motivation. *Psychological review*, *50*(4), 370-396. doi:10.1037/h0054346

Mayer, J. D. (1982). Relations between Two Traditions of Medical Geography: Health Systems Planning and Geographical Epidemiology. *Progress in Human Geography, 6*(2), 216-230. doi:10.1177/030913258200600203

Mazumdar, S., Learnihan, V., Cochrane, T., Phung, H., O'Connor, B., & Davey, R. (2016). Is Walk Score associated with hospital admissions from chronic diseases? Evidence from a cross-sectional study in a high socioeconomic status Australian city-state. *Bmj Open, 6*(12), e012548. doi:10.1136/bmjopen-2016-012548

Mazzali, C., & Duca, P. (2015). Use of administrative data in healthcare research. *Internal and Emergency Medicine, 10*(4), 517-524. doi:10.1007/s11739-015-1213-9

McCormack, G. R. (2017). Neighbourhood built environment characteristics associated with different types of physical activity in Canadian adults. *Health Promotion and Chronic Disease Prevention in Canada-Research Policy and Practice, 37*(6), 175-185. doi:10.24095/hpcdp.37.6.01

McCormack, G. R., Cabaj, J., Orpana, H., Lukic, R., Blackstaffe, A., Goopy, S., Hagel, B., Keough, N., Martinson, R., Chapman, J., Lee, C., Tang, J., & Fabreau, G. (2019). A scoping review on the relations between urban form and health: a focus on Canadian quantitative evidence. *Health Promotion and Chronic Disease Prevention in Canada-Research Policy and Practice, 39*(5), 187-200. doi:10.24095/hpcdp.39.5.03

McCormack, G. R., & Shiell, A. (2011). In search of causality: a systematic review of the relationship between the built environment and physical activity among adults. *International Journal of Behavioral Nutrition and Physical Activity, 8*, 125. doi:10.1186/1479-5868-8-125

McEwen, L. N., Kim, C., Haan, M., Ghosh, D., Lantz, P. M., Mangione, C. M., Safford, M. M., Marrero, D., Thompson, T. J., & Herman, W. H. (2006). Diabetes Reporting as a Cause of Death. *Diabetes Care, 29*(2), 247. doi:10.2337/diacare.29.02.06.dc05-0998

McLeroy, K. R., Bibeau, D., Steckler, A., & Glanz, K. (1988). An Ecological Perspective on Health Promotion Programs. *Health Education Quarterly, 15*(4), 351-377. doi:10.1177/109019818801500401

McMichael, A. J. (1999). Prisoners of the proximate: loosening the constraints on epidemiology in an age of change. *American Journal of Epidemiology, 149*(10), 887-897. doi:10.1093/oxfordjournals.aje.a009732

Meade, M. S., & Emch, M. (2010). Medical geography. In: Wiley Online Library.

Mensah, G. A., Wei, G. S., Sorlie, P. D., Fine, L. J., Rosenberg, Y., Kaufmann, P. G., Mussolino, M. E., Hsu, L. L., Addou, E., Engelgau, M. M., & Gordon, D. (2017). Decline in Cardiovascular Mortality: Possible Causes and Implications. *Circ Res, 120*(2), 366-380. doi:10.1161/CIRCRESAHA.116.309115

Millward, H., Spinney, J., & Scott, D. (2013). Active-transport walking behavior: destinations, durations, distances. *Journal of Transport Geography, 28*, 101-110. doi:10.1016/j.jtrangeo.2012.11.012

Mizen, A., Song, J., Fry, R., Akbari, A., Berridge, D., Parker, S. C., Johnson, R., Lovell, R., Lyons, R. A., Nieuwenhuijsen, M., Stratton, G., Wheeler, B. W., White, J., White, M., & Rodgers, S. E. (2019). Longitudinal access and exposure to green-blue spaces and individual-level mental health and well-being: protocol for a longitudinal, population-wide record-linked natural experiment. *Bmj Open, 9*(4), e027289. doi:10.1136/bmjopen-2018-027289

Moore, S. C., Patel, A. V., Matthews, C. E., Berrington de Gonzalez, A., Park, Y., Katki, H. A., Linet, M. S., Weiderpass, E., Visvanathan, K., Helzlsouer, K. J., Thun, M., Gapstur, S. M., Hartge, P., & Lee, I. M. (2012). Leisure time physical activity of moderate to vigorous intensity and mortality: a large pooled cohort analysis. *Plos Medicine, 9*(11), e1001335. doi:10.1371/journal.pmed.1001335

Morris, J. N., & Hardman, A. E. (1997). Walking to health. *Sports Medicine, 23*(5), 306-332.

Morris, T., Manley, D., & Sabel, C. E. (2018). Residential mobility: Towards progress in mobility health research. *Progress in Human Geography, 42*(1), 112-133. doi:10.1177/0309132516649454

Moudon, A. V., Lee, C., Cheadle, A. D., Garvin, C., Johnson, D., Schmid, T. L., Weathers, R. D., & Lin, L. (2006). Operational Definitions of Walkable Neighborhood: Theoretical and Empirical Insights. *Journal of Physical Activity and Health, 3*(s1), S99-S117. doi:10.1123/jpah.3.s1.s99

Muller-Riemenschneider, F., Pereira, G., Villanueva, K., Christian, H., Knuiman, M., Giles-Corti, B., & Bull, F. C. (2013). Neighborhood walkability and cardiometabolic risk factors in Australian adults: an observational study. *Bmc Public Health, 13*, 755. doi:10.1186/1471-2458-13-755

Murtagh, E. M., Nichols, L., Mohammed, M. A., Holder, R., Nevill, A. M., & Murphy, M. H. (2015). The effect of walking on risk factors for cardiovascular disease: An updated systematic review and meta-analysis of randomised control trials. *Preventive Medicine, 72*, 34-43. doi:10.1016/j.ypmed.2014.12.041

Nathan, A., Villanueva, K., Rozek, J., Davern, M., Gunn, L., Trapp, G., Boulange, C., & Christian, H. (2018). The Role of the Built Environment on Health Across the Life Course: A Call for CollaborACTION. *American Journal of Health Promotion, 32*(6), 1460-1468. doi:10.1177/0890117118779463a

National Assembly for Wales Finance Committee. (2018). *The Cost of Caring for an Ageing Population*. Retrieved from https://senedd.wales/laid%20documents/cr-ld11773/cr-ld11773-e.pdf

Nayor, M., & Vasan, R. S. (2015). Preventing heart failure: the role of physical activity. *Current opinion in cardiology, 30*(5), 543-550. doi:10.1097/HCO.0000000000000206

NCD Risk Factor Collaboration. Worldwide trends in diabetes since 1980: a pooled analysis of 751 population-based studies with 4·4 million participants. *The Lancet, 387*(10027), 1513-1530. doi:10.1016/S0140-6736(16)00618-8

Newcombe, H. B., Kennedy, J. M., Axford, S. J., & James, A. P. (1959). Automatic Linkage of Vital Records. *Science, 130*(3381), 954-959. doi:10.1126/science.130.3381.954

Ng, E., Dasgupta, K., & Johnson, J. A. (2008). An algorithm to differentiate diabetic respondents in the Canadian Community Health Survey. *Health Reports, 19*(1), 71-79.

Ng, S. W., & Popkin, B. M. (2012). Time use and physical activity: a shift away from movement across the globe. *Obesity Reviews, 13*(8), 659-680. doi:10.1111/j.1467-789X.2011.00982.x

Nieuwenhuijsen, M. J. (2018). Influence of urban and transport planning and the city environment on cardiovascular disease. *Nature Reviews Cardiology*. doi:10.1038/s41569-018-0003-2

Nolan, C. J., Damm, P., & Prentki, M. (2011). Type 2 diabetes across generations: from pathophysiology to prevention and management. *The Lancet, 378*(9786), 169-181. doi:10.1016/S0140-6736(11)60614-4

O'Donnell, M. J., Chin, S. L., Rangarajan, S., Xavier, D., Liu, L., Zhang, H., Rao-Melacini, P., Zhang, X., Pais, P., Agapay, S., Lopez-Jaramillo, P., Damasceno, A., Langhorne, P., McQueen, M. J., Rosengren, A., Dehghan, M., Hankey, G. J., Dans, A. L., Elsayed, A., Avezum, A., Mondo, C., Diener, H. C., Ryglewicz, D., Czlonkowska, A., Pogosova, N., Weimar, C., Iqbal, R., Diaz, R., Yusoff, K., Yusufali, A., Oguz, A., Wang, X., Penaherrera, E., Lanas, F., Ogah, O. S., Ogunniyi, A., Iversen, H. K., Malaga, G., Rumboldt, Z., Oveisgharan, S., Al Hussain, F., Magazi, D., Nilanont, Y., Ferguson, J., Pare, G., Yusuf, S., & investigators, I. (2016). Global and regional effects of potentially modifiable risk factors associated with acute stroke in 32 countries (INTERSTROKE): a case-control study. *Lancet, 388*(10046), 761-775. doi:10.1016/S0140-6736(16)30506-2

Ogilvie, D., Foster, C. E., Rothnie, H., Cavill, N., Hamilton, V., Fitzsimons, C. F., & Mutrie, N. (2007). Interventions to promote walking: systematic review. *BMJ, 334*(7605), 1204. doi:10.1136/bmj.39198.722720.BE

Olshansky, S. J., Passaro, D. J., Hershow, R. C., Layden, J., Carnes, B. A., Brody, J., Hayflick, L., Butler, R. N., Allison, D. B., & Ludwig, D. S. (2005). A potential decline in life expectancy in the United States in the 21st century. *New England Journal of Medicine, 352*(11), 1138-1145. doi:10.1056/NEJMsr043743

Ontario Community Health Profiles Partnership. (2021). Population Health Status Indicator (PHSI) Dashboard: Adult Chronic Disease. Retrieved from http://www.ontariohealthprofiles.ca/torontohealthstatus/2_AdultChronicDisease.php

OpenStreetMap Contributors. (2017). OpenStreetMap Base Data. Retrieved from https://www.OpenStreetMap.org

OpenStreetMap Contributors. (2018). OpenStreetMap Base Data. Retrieved from https://www.OpenStreetMap.org

Orr, J., Smith, M., Burchill, C., Katz, A., & Fransoo, R. (2016). Outcomes of an investment in administrative data infrastructure: An example of capacity building at the Manitoba Centre for Health Policy. *Canadian Journal of Public Health, 107*(4-5), e480-e481. doi:10.17269/cjph.107.5659

Owen, N., Cerin, E., Leslie, E., duToit, L., Coffee, N., Frank, L. D., Bauman, A. E., Hugo, G., Saelens, B. E., & Sallis, J. F. (2007). Neighborhood walkability and the walking behavior of Australian adults. *Am J Prev Med, 33*(5), 387-395. doi:10.1016/j.amepre.2007.07.025

Owen, N., Humpel, N., Leslie, E., Bauman, A., & Sallis, J. F. (2004). Understanding environmental influences on walking; Review and research agenda. *Am J Prev Med, 27*(1), 67-76. doi:10.1016/j.amepre.2004.03.006

Pan, X. R., Li, G. W., Hu, Y. H., Wang, J. X., Yang, W. Y., An, Z. X., Hu, Z. X., Lin, J., Xiao, J. Z., Cao, H. B., Liu, P. A., Jiang, X. G., Jiang, Y. Y., Wang, J. P., Zheng, H., Zhang, H., Bennett, P. H., & Howard, B. V. (1997). Effects of diet and exercise in preventing NIDDM in people with impaired glucose tolerance. The Da Qing IGT and Diabetes Study. *Diabetes Care, 20*(4), 537-544. doi:10.2337/diacare.20.4.537

Pandey, A., Garg, S., Khunger, M., Darden, D., Ayers, C., Kumbhani, D. J., Mayo, H. G., de Lemos, J. A., & Berry, J. D. (2015). Dose-Response Relationship Between Physical Activity and Risk of Heart Failure: A Meta-Analysis. *Circulation, 132*(19), 1786-1794. doi:10.1161/CIRCULATIONAHA.115.015853

Patel, A. V., Hildebrand, J. S., Leach, C. R., Campbell, P. T., Doyle, C., Shuval, K., Wang, Y., & Gapstur, S. M. (2018). Walking in Relation to Mortality in a Large Prospective Cohort of Older U.S. Adults. *Am J Prev Med, 54*(1), 10-19. doi:10.1016/j.amepre.2017.08.019

Patterson, R., Webb, E., Hone, T., Millett, C., & Laverty, A. A. (2019). Associations of Public Transportation Use With Cardiometabolic Health: A Systematic Review and Meta-Analysis. *American Journal of Epidemiology, 188*(4), 785-795. doi:10.1093/aje/kwz012

Paul, B. K. (1985). Approaches to medical geography: An historical perspective. *Soc Sci Med, 20*(4), 399-404. doi:https://doi.org/10.1016/0277-9536(85)90015-2

Pearce, J., Barnett, R., & Moon, G. (2012). Sociospatial inequalities in health-related behaviours: Pathways linking place and smoking. *Progress in Human Geography, 36*(1), 3-24. doi:10.1177/0309132511402710

Pilote, L., Dasgupta, K., Guru, V., Humphries, K. H., McGrath, J., Norris, C., Rabi, D., Tremblay, J., Alamian, A., Barnett, T., Cox, J., Ghali, W. A., Grace, S., Hamet, P., Ho, T., Kirkland, S., Lambert, M., Libersan, D., O'Loughlin, J., Paradis, G., Petrovich, M., & Tagalakis, V. (2007). A comprehensive view of sex-specific issues related to cardiovascular disease. *Canadian Medical Association Journal, 176*(6), S1-44. doi:10.1503/cmaj.051455

Pollard, T. M., & Wagnild, J. M. (2017). Gender differences in walking (for leisure, transport and in total) across adult life: a systematic review. *Bmc Public Health, 17*(1), 341. doi:10.1186/s12889-017-4253-4

Pouliou, T., & Elliott, S. J. (2010). Individual and socio-environmental determinants of overweight and obesity in Urban Canada. *Health Place, 16*(2), 389-398. doi:10.1016/j.healthplace.2009.11.011

Prince, S. A., Adamo, K. B., Hamel, M. E., Hardt, J., Connor Gorber, S., & Tremblay, M. (2008). A comparison of direct versus self-report measures for assessing physical activity in adults: a systematic review. *International Journal of Behavioral Nutrition and Physical Activity, 5*, 56. doi:10.1186/1479-5868-5-56

Prince, S. A., Melvin, A., Roberts, K. C., Butler, G. P., & Thompson, W. (2020). Sedentary behaviour surveillance in Canada: trends, challenges and lessons learned. *International Journal of Behavioral Nutrition and Physical Activity, 17*(1), 34. doi:10.1186/s12966-020-00925-8

Prince, S. A., Roberts, K. C., Reed, J. L., Biswas, A., Colley, R. C., & Thompson, W. (2020). Daily physical activity and sedentary behaviour across occupational classifications in Canadian adults. *Health Reports, 31*(9), 13-26. doi:10.25318/82-003-x202000900002-eng

Prochaska, J. O., & DiClemente, C. C. (1992). Stages of change in the modification of problem behaviors. *Progress in behavior modification, 28*, 183-218.

Public Health Agency of Canada. (2014). *Supportive environments for physical activity: how the built environment affects our health*. Retrieved from Ottawa, ON: https://www.canada.ca/en/public-health/services/health-promotion/healthy-living/supportive-environments-physical-activity-built-environment-affects-health.html

Public Health Agency of Canada. (2020). Public Health Infobase: Canadian chronic disease surveillance system. Retrieved 2 Feb 2021 https://health-infobase.canada.ca/ccdss/data-tool

Public Health Wales Observatory (Producer). (2019, 26 June 2020). Obesity in Wales.

Punthakee, Z., Goldenberg, R., & Katz, P. (2018). Definition, classification and diagnosis of diabetes, prediabetes and metabolic syndrome. *Canadian Journal of Diabetes, 42*, S10-S15.

Ramachandran, A., Snehalatha, C., Mary, S., Mukesh, B., Bhaskar, A. D., Vijay, V., & Indian Diabetes Prevention, P. (2006). The Indian Diabetes Prevention Programme shows that lifestyle modification and metformin prevent type 2 diabetes in Asian Indian subjects with impaired glucose tolerance (IDPP-1). *Diabetologia*, *49*(2), 289-297. doi:10.1007/s00125-005-0097-z

Ramlo-Halsted, B. A., & Edelman, S. V. (1999). The natural history of type 2 diabetes: Implications for clinical practice. *Primary Care: Clinics in Office Practice, 26*(4), 771-789. doi:10.1016/s0095-4543(05)70130-5

Rana, J. S., Li, T. Y., Manson, J. E., & Hu, F. B. (2007). Adiposity Compared With Physical Inactivity and Risk of Type 2 Diabetes in Women. *Diabetes Care, 30*(1), 53-58. doi:10.2337/dc06-1456

Rees, R., & Roberts, C. (2018). *Discontinuities in Results for Health-Related Lifestyle and General Health between the Welsh Health Survey and National Survey for Wales*. Retrieved from https://gov.wales/sites/default/files/statistics-and-research/2019-02/discontinuities-results-health-related-lifestyle-general-health-between-welsh-health-survey-national-survey-wales-2018.pdf

Rhodes, R. E., McEwan, D., & Rebar, A. L. (2019). Theories of physical activity behaviour change: A history and synthesis of approaches. *Psychology of Sport and Exercise, 42*, 100-109. doi:10.1016/j.psychsport.2018.11.010

Richter, B., Hemmingsen, B., Metzendorf, M. I., & Takwoingi, Y. (2018). Development of type 2 diabetes mellitus in people with intermediate hyperglycaemia. *Cochrane Database Syst Rev, 10*, CD012661. doi:10.1002/14651858.CD012661.pub2

Riley, G. F. (2009). Administrative and Claims Records as Sources of Health Care Cost Data. *Med Care, 47*(7_Supplement_1), S51-S55. doi:10.1097/MLR.0b013e31819c95aa

Roche, M. M., & Wang, P. P. (2013). Sex differences in all-cause and cardiovascular mortality, hospitalization for individuals with and without diabetes, and patients with diabetes diagnosed early and late. *Diabetes Care, 36*(9), 2582-2590. doi:10.2337/dc12-1272

Rodriguez-Gutierrez, R., & Montori, V. M. (2016). Glycemic Control for Patients With Type 2 Diabetes Mellitus: Our Evolving Faith in the Face of Evidence. *Circulation: Cardiovascular Quality and Outcomes*. doi:10.1161/CIRCOUTCOMES.116.002901

Roos, L. L., Menec, V., & Currie, R. J. (2004). Policy analysis in an information-rich environment. *Soc Sci Med, 58*(11), 2231-2241. doi:10.1016/j.socscimed.2003.08.008

Rose, G. (1985). Sick individuals and sick populations. *International Journal of Epidemiology, 14*(1), 32-38. doi:10.1093/ije/30.3.427

Rosella, L. C., Manuel, D. G., Burchill, C., Stukel, T. A., & team, P.-D. (2011). A population-based risk algorithm for the development of diabetes: development and validation of the Diabetes Population Risk Tool (DPoRT). *Journal of Epidemiology and Community Health, 65*(7), 613-620. doi:10.1136/jech.2009.102244

Rosenstock, I. M. (1974). The health belief model and preventive health behavior. *Health education monographs, 2*(4), 354-386. doi:10.1177/109019817400200405

Ross, N. A., Gilmour, H., & Dasgupta, K. (2010). 14-year diabetes incidence: the role of socio-economic status. *Health Reports, 21*(3), 19-28.

Ross, N. A., Tremblay, S., Khan, S., Crouse, D., Tremblay, M., & Berthelot, J. M. (2007). Body mass index in urban Canada: neighborhood and metropolitan area effects. *American Journal of Public Health, 97*(3), 500-508. doi:10.2105/AJPH.2004.060954

Ross, N. A., Tremblay, S. S., & Graham, K. (2004). Neighbourhood influences on health in Montreal, Canada. *Social Science and Medicine, 59*(7), 1485-1494. doi:10.1016/j.socscimed.2004.01.016

Rudge, G. M., Mohammed, M. A., Fillingham, S. C., Girling, A., Sidhu, K., & Stevens, A. J. (2013). The combined influence of distance and neighbourhood deprivation on Emergency Department attendance in a large English population: a retrospective database study. *Plos One, 8*(7), e67943. doi:10.1371/journal.pone.0067943

Sadarangani, K. P., Hamer, M., Mindell, J. S., Coombs, N. A., & Stamatakis, E. (2014). Physical Activity and Risk of All-Cause and Cardiovascular Disease Mortality in Diabetic Adults From Great Britain: Pooled Analysis of 10 Population-Based Cohorts. *Diabetes Care, 37*(4), 1016-1023. doi:10.2337/dc13-1816

Saelens, B. E., & Handy, S. L. (2008). Built environment correlates of walking: a review. *Medicine & science in sports & exercise, 40*(7 Suppl), S550-566. doi:10.1249/MSS.0b013e31817c67a4

Sallis, J. F. (2009). Measuring physical activity environments: a brief history. *Am J Prev Med, 36*(4 Suppl), S86-92. doi:10.1016/j.amepre.2009.01.002

Sallis, J. F., Cerin, E., Conway, T. L., Adams, M. A., Frank, L. D., Pratt, M., Salvo, D., Schipperijn, J., Smith, G., Cain, K. L., Davey, R., Kerr, J., Lai, P. C., Mitas, J., Reis, R., Sarmiento, O. L., Schofield, G., Troelsen, J., Van Dyck, D., De Bourdeaudhuij, I., & Owen, N. (2016). Physical activity in relation to urban environments in 14 cities worldwide: a cross-sectional study. *The Lancet, 387*(10034), 2207-2217. doi:10.1016/S0140-6736(15)01284-2

Sallis, J. F., Cerin, E., Kerr, J., Adams, M. A., Sugiyama, T., Christiansen, L. B., Schipperijn, J., Davey, R., Salvo, D., Frank, L. D., De Bourdeaudhuij, I., & Owen, N. (2020). Built Environment, Physical Activity, and Obesity: Findings from the International Physical Activity and Environment Network (IPEN) Adult Study. *Annual Review of Public Health, 41*, 119-139. doi:10.1146/annurev-publhealth-040218-043657

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

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

Sallis, J. F., Linton, L., & Kraft, M. K. (2005). The first Active Living Research Conference: growth of a transdisciplinary field. *Am J Prev Med, 28*(2 Suppl 2), 93-95. doi:10.1016/j.amepre.2004.10.032

Sallis, J. F., & Owen, N. (2015). Ecological models of health behavior. In K. Glanz, B. K. R. Rimer, & K. Viswanath (Eds.), *Health behavior: Theory, research, and practice* (Vol. 5). San Fransisco, CA: Jossey-Bass (Wiley).

Sallis, J. F., & Saelens, B. E. (2000). Assessment of physical activity by self-report: status, limitations, and future directions. *Research Quarterly for Exercise and Sport, 71*(2 Suppl), S1-14. doi:10.1080/02701367.2000.11082780

Sallis, J. F., Saelens, B. E., Frank, L. D., Conway, T. L., Slymen, D. J., Cain, K. L., Chapman, J. E., & Kerr, J. (2009). Neighborhood built environment and income: examining multiple health outcomes. *Social Science and Medicine, 68*(7), 1285-1293. doi:10.1016/j.socscimed.2009.01.017

Sanmartin, C., Decady, Y., Trudeau, R., Dasylva, A., Tjepkema, M., Fines, P., Burnett, R., Ross, N., & Manuel, D. G. (2016). Linking the Canadian Community Health Survey and the Canadian Mortality Database: An enhanced data source for the study of mortality. *Health Reports, 27*(12), 10-18.

Sayers, A., Ben-Shlomo, Y., Blom, A. W., & Steele, F. (2016). Probabilistic record linkage. *International Journal of Epidemiology, 45*(3), 954-964. doi:10.1093/ije/dyv322

Schellenberg, E. S., Dryden, D. M., Vandermeer, B., Ha, C., & Korownyk, C. (2013). Lifestyle interventions for patients with and at risk for type 2 diabetes: a systematic review and meta-analysis. *Ann Intern Med, 159*(8), 543-551. doi:10.7326/0003-4819-159-8-201310150-00007

Schootman, M., Andresen, E. M., Wolinsky, F. D., Miller, J. P., Yan, Y., & Miller, D. K. (2010). Neighborhood conditions, diabetes, and risk of lower-body functional limitations among middle-aged African Americans: A cohort study. *Bmc Public Health, 10*(1), 283. doi:10.1186/1471-2458-10-283

Shortt, N. K., Tisch, C., Pearce, J., Mitchell, R., Richardson, E. A., Hill, S., & Collin, J. (2015). A cross-sectional analysis of the relationship between tobacco and alcohol outlet density and neighbourhood deprivation. *Bmc Public Health, 15*. doi:10.1186/s12889-015-2321-1

Sibley, L. M., & Weiner, J. P. (2011). An evaluation of access to health care services along the rural-urban continuum in Canada. *Bmc Health Services Research, 11*, 20. doi:10.1186/1472-6963-11-20

Sigal, R. J., Armstrong, M. J., Bacon, S. L., Boulé, N. G., Dasgupta, K., Kenny, G. P., Riddell, M. C., & Committee, D. C. C. P. G. E. (2018). Physical Activity and Diabetes. *Canadian Journal of Diabetes, 42,* S54-S63. doi:10.1016/j.jcjd.2017.10.008

Sinclair, A. J., & Rodriguez-Manas, L. (2016). Diabetes and Frailty: Two Converging Conditions? *Canadian Journal of Diabetes, 40*(1), 77-83. doi:10.1016/j.jcjd.2015.09.004

Sluik, D., Buijsse, B., Muckelbauer, R., Kaaks, R., Teucher, B., Johnsen, N. F., Tjonneland, A., Overvad, K., Ostergaard, J. N., Amiano, P., Ardanaz, E., Bendinelli, B., Pala, V., Tumino, R., Ricceri, F., Mattiello, A., Spijkerman, A. M., Monninkhof, E. M., May, A. M., Franks, P. W., Nilsson, P. M., Wennberg, P., Rolandsson, O., Fagherazzi, G., Boutron-Ruault, M. C., Clavel-Chapelon, F., Castano, J. M., Gallo, V., Boeing, H., & Nothlings, U. (2012). Physical Activity and Mortality in Individuals With Diabetes Mellitus: A Prospective Study and Meta-analysis. *Arch Intern Med, 172*(17), 1285-1295. doi:10.1001/archinternmed.2012.3130

Smalls, B. L., Gregory, C. M., Zoller, J. S., & Egede, L. E. (2015). Direct and indirect effects of neighborhood factors and self-care on glycemic control in adults with type 2 diabetes. *Journal of Diabetes and its Complications, 29*(2), 186-191. doi:10.1016/j.jdiacomp.2014.10.008

Smith, A. D., Crippa, A., Woodcock, J., & Brage, S. (2016). Physical activity and incident type 2 diabetes mellitus: a systematic review and dose–response meta-analysis of prospective cohort studies. *Diabetologia, 59*(12), 2527-2545. doi:10.1007/s00125-016-4079-0

Smith, T. C., Wingard, D. L., Smith, B., Kritz-Silverstein, D., & Barrett-Connor, E. (2007). Walking decreased risk of cardiovascular disease mortality in older adults with diabetes. *Journal of Clinical Epidemiology, 60*(3), 309-317. doi:10.1016/j.jclinepi.2006.06.013

Sorensen, H. T., Sabroe, S., & Olsen, J. (1996). A Framework for Evaluation of Secondary Data Sources for Epidemiological Research. *International Journal of Epidemiology, 25*(2), 435-442. doi:10.1093/ije/25.2.435

Stafford, M., Cummins, S., Macintyre, S., Ellaway, A., & Marmot, M. (2005). Gender differences in the associations between health and neighbourhood environment. *Soc Sci Med, 60*(8), 1681-1692. doi:10.1016/j.socscimed.2004.08.028

Statistics Canada. (2011a). *Canadian Community Health Survey (CCHS) Annual Component, 2009-2010 Common Content: Derived Variable (DV) Specifications*. Retrieved from Ottawa:

Statistics Canada. (2011b). Canadian Community Health Survey—Annual Component. User Guide 2010 and 2009/2010 Microdata Files. Retrieved from http://www23.statcan.gc.ca/imdb-bmdi/document/3226_D7_T9_V8-eng.pdf

Statistics Canada. (2016). *Population size and growth in Canada: Key results from the 2016 Census*. Retrieved from http://www.statcan.gc.ca/daily-quotidien/170208/dq170208a-eng.pdf

Statistics Canada. (2017a). *Canada [Country] and Canada [Country] (table). Census Profile.* Retrieved from Ottawa: https://www12.statcan.gc.ca/census-recensement/2016/dp-pd/prof/index.cfm?Lang=E

Statistics Canada. (2017b). Evaluation of the Health Statistics Program 2015. Retrieved from https://statcan.gc.ca/eng/about/er/hspfr

Statistics Canada. (2018). Diabetes, 2017. *Health Fact Sheets.* Retrieved from https://www150.statcan.gc.ca/n1/pub/82-625-x/2018001/article/54982-eng.htm

Statistics Canada. (2019). Overweight and obese adults, 2018. *Health Fact Sheets.* Retrieved from https://www150.statcan.gc.ca/n1/pub/82-625-x/2019001/article/00005-eng.pdf

Statistics Canada. (2020a). Table 13-10-0337-01 (formerly CANSIM 117-0019) – Distribution of the household population meeting/not meeting the Canadian physical activity guidelines. (Publication no. 10.25318/1310033701-eng). Retrieved April 23, 2020

Statistics Canada. (2020b). Table 13-10-0096-01 Health characteristics, annual estimates. doi:10.25318/1310009601-eng

Statistics Canada. (2020c). Table 13-10-0451-01 - Health indicators, annual estimates, 2003 - 2014 (Publication no. 10.25318/1310045101-eng). Retrieved April 23, 2020

StatsWales. (2016). Illnesses by gender and year. Retrieved from https://statswales.gov.wales/Catalogue/Health-and-Social-Care/Welsh-Health-Survey/illnesses-by-gender-year

Sternfeld, B., & Goldman-Rosas, L. (2012). A systematic approach to selecting an appropriate measure of self-reported physical activity or sedentary behavior. *Journal of Physical Activity and Health, 9 Suppl 1*, S19-28. doi:10.1123/jpah.9.s1.s19

Stokols, D. (1992). Establishing and maintaining healthy environments: toward a social ecology of health promotion. *American psychologist, 47*(1), 6. doi:10.1037//0003-066x.47.1.6

Strack, F., & Deutsch, R. (2004). Reflective and Impulsive Determinants of Social Behavior. *Personality and Social Psychology Review, 8*(3), 220-247. doi:10.1207/s15327957pspr0803_1

Sugiyama, T., Giles-Corti, B., Summers, J., du Toit, L., Leslie, E., & Owen, N. (2013). Initiating and maintaining recreational walking: a longitudinal study on the influence of neighborhood green space. *Preventive Medicine, 57*(3), 178-182. doi:10.1016/j.ypmed.2013.05.015

Sugiyama, T., Neuhaus, M., Cole, R., Giles-Corti, B., & Owen, N. (2012). Destination and route attributes associated with adults' walking: a review. *Medicine & science in sports & exercise, 44*(7), 1275-1286. doi:10.1249/MSS.0b013e318247d286

Sundquist, K., Eriksson, U., Mezuk, B., & Ohlsson, H. (2015). Neighborhood walkability, deprivation and incidence of type 2 diabetes: a population-based study on 512,061 Swedish adults. *Health Place, 31*, 24-30. doi:10.1016/j.healthplace.2014.10.011

Susser, M., & Susser, E. (1996a). Choosing a future for epidemiology: I. Eras and paradigms. *Am J Public Health, 86*(5), 668-673. doi:10.2105/AJPH.86.5.668

Susser, M., & Susser, E. (1996b). Choosing a future for epidemiology: II. From black box to Chinese boxes and eco-epidemiology. *American Journal of Public Health, 86*(5), 674-677. doi:10.2105/ajph.86.5.674

Swinburn, B. A., Sacks, G., Hall, K. D., McPherson, K., Finegood, D. T., Moodie, M. L., & Gortmaker, S. L. (2011). The global obesity pandemic: shaped by global drivers and local environments. *The Lancet, 378*(9793), 804-814. doi:10.1016/S0140-6736(11)60813-1

Szreter, S. (2003). The population health approach in historical perspective. *American Journal of Public Health, 93*(3), 421-431. doi:10.2105/ajph.93.3.421

Tabaei, B. P., Rundle, A. G., Wu, W. Y., Horowitz, C. R., Mayer, V., Sheehan, D. M., & Chamany, S. (2018). Associations of Residential Socioeconomic, Food, and Built Environments With Glycemic Control in Persons With Diabetes in New York City From 2007-2013. *Am J Epidemiol, 187*(4), 736-745. doi:10.1093/aje/kwx300

Tam, T. (2017). *The Chief Public Health Officer's Report on the State of Public Health in Canada 2017–Designing Healthy Living*. Retrieved from https://www.canada.ca/en/public-health/services/publications/chief-public-health-officer-reports-state-public-health-canada/2017-designing-healthy-living.html

Tanamas, S., Magliano, D., Lynch, B., Sethi, P., Willenberg, L., Polkinghorne, K., Chadban, S., Dunstan, D., & Shaw, J. (2013). *AusDiab 2012: The Australian Diabetes, Obesity and Lifestyle Study*. Retrieved from Melbourne: https://www.bakeridi.edu.au/Assets/Files/Baker%20IDI%20Ausdiab%20Report_interactive_FINAL.pdf

Tarride, J. E., Lim, M., DesMeules, M., Luo, W., Burke, N., O'Reilly, D., Bowen, J., & Goeree, R. (2009). A review of the cost of cardiovascular disease. *Canadian Journal of Cardiology, 25*(6), e195-202. doi:10.1016/s0828-282x(09)70098-4

Taylor, F., Huffman, M. D., Macedo, A. F., Moore, T. H., Burke, M., Davey Smith, G., Ward, K., & Ebrahim, S. (2013). Statins for the primary prevention of cardiovascular disease. *Cochrane Database of Systematic Reviews*(1), CD004816. doi:10.1002/14651858.CD004816.pub5

Taylor, L. M., Leslie, E., Plotnikoff, R. C., Owen, N., & Spence, J. C. (2008). Associations of perceived community environmental attributes with walking in a population-based sample of adults with type 2 diabetes. *Annals of Behavioral Medicine, 35*(2), 170-178. doi:10.1007/s12160-008-9021-3

Thielman, J., Rosella, L., Copes, R., Lebenbaum, M., & Manson, H. (2015). Neighborhood walkability: Differential associations with self-reported transport walking and leisure-time physical activity in Canadian towns and cities of all sizes. *Preventive Medicine, 77*, 174-180. doi:10.1016/j.ypmed.2015.05.011

Toronto Public Health. (2017). Health Surveillance Indicators: Diabetes. Retrieved from https://www.toronto.ca/wp-content/uploads/2017/12/8c72-tph-hsi-diabetes-july18f.pdf

Tran, D. T., Ohinmaa, A., Thanh, N. X., Welsh, R. C., & Kaul, P. (2018). The Healthcare Cost Burden of Acute Myocardial Infarction in Alberta, Canada. *Pharmacoeconomics - Open, 2*(4), 433-442. doi:10.1007/s41669-017-0061-0

Tremblay, M. S., Warburton, D. E. R., Janssen, I., Paterson, D. H., Latimer, A. E., Rhodes, R. E., Kho, M. E., Hicks, A., LeBlanc, A. G., Zehr, L., Murumets, K., & Duggan, M. (2011).

New Canadian Physical Activity Guidelines. *Applied Physiology, Nutrition, and Metabolism, 36*(1), 36-46. doi:10.1139/H11-009

Tu, J. V., Chu, A. N., Donovan, L. R., Ko, D. T., Booth, G. L., Tu, K. R., Maclagan, L. C., Guo, H. L., Austin, P. C., Hogg, W., Kapral, M. K., Wijeysundera, H. C., Atzema, C. L., Gershon, A. S., Alter, D. A., Lee, D. S., Jackevicius, C. A., Bhatia, R. S., Udell, J. A., Rezai, M. R., & Stukel, T. A. (2015). The Cardiovascular Health in Ambulatory Care Research Team (CANHEART) Using Big Data to Measure and Improve Cardiovascular Health and Healthcare Services. *Circulation: Cardiovascular Quality and Outcomes, 8*(2), 204-+. doi:10.1161/Circoutcomes.114.001416

Tudor-Locke, C., Williams, J. E., Reis, J. P., & Pluto, D. (2002). Utility of pedometers for assessing physical activity: convergent validity. *Sports Med, 32*(12), 795-808. doi:10.2165/00007256-200232120-00004

Tuomilehto, J., Lindstrom, J., Eriksson, J. G., Valle, T. T., Hamalainen, H., Ilanne-Parikka, P., Keinanen-Kiukaanniemi, S., Laakso, M., Louheranta, A., Rastas, M., Salminen, V., & Uusitupa, M. (2001). Prevention of type 2 diabetes mellitus by changes in lifestyle among subjects with impaired glucose tolerance. *New England Journal of Medicine, 344*(18), 1343-1350. doi:10.1056/nejm200105033441801

Turcotte, M. (2012). Profile of seniors' transportation habits. *Canadian Social Trends, 93*(2012001), 1-16.

Turin, T. C., Saad, N., Jun, M., Tonelli, M., Ma, Z., Barnabe, C. C., Manns, B., & Hemmelgarn, B. (2016). Lifetime risk of diabetes among First Nations and non-First Nations people. *Canadian Medical Association Journal, 188*(16), 1147-1153. doi:10.1503/cmaj.150787

United Nations, D. o. E. a. S. A., Population Division,. (2018). World Urbanization Prospects: The 2018 Revision (ST/ESA/SER.A/420). In. New York: United Nations.

Valanou, E. M., Bamia, C., & Trichopoulou, A. (2006). Methodology of physical-activity and energy-expenditure assessment: a review. *Journal of Public Health, 14*(2), 58-65. doi:10.1007/s10389-006-0021-0

Van Cauwenberg, J., Nathan, A., Barnett, A., Barnett, D. W., Cerin, E., Council on, E., & Physical Activity -Older Adults Working, G. (2018). Relationships Between Neighbourhood Physical Environmental Attributes and Older Adults' Leisure-Time Physical Activity: A Systematic Review and Meta-Analysis. *Sports Medicine, 48*(7), 1635-1660. doi:10.1007/s40279-018-0917-1

Van Cauwenberg, J., Van Holle, V., De Bourdeaudhuij, I., Van Dyck, D., & Deforche, B. (2016). Neighborhood walkability and health outcomes among older adults: The mediating role of physical activity. *Health Place, 37*, 16-25. doi:10.1016/j.healthplace.2015.11.003

van Dijk, J.-W., Venema, M., van Mechelen, W., Stehouwer, C. D. A., Hartgens, F., & van Loon, L. J. C. (2013). Effect of Moderate-Intensity Exercise Versus Activities of Daily Living on 24-Hour Blood Glucose Homeostasis in Male Patients With Type 2 Diabetes. *Diabetes Care, 36*(11), 3448-3453. doi:10.2337/dc12-2620

Van Holle, V., Deforche, B., Van Cauwenberg, J., Goubert, L., Maes, L., Van de Weghe, N., & De Bourdeaudhuij, I. (2012). Relationship between the physical environment and different domains of physical activity in European adults: a systematic review. *Bmc Public Health, 12*, 807. doi:10.1186/1471-2458-12-807

VanderWeele, T. J. (2014). A unification of mediation and interaction: a 4-way decomposition. *Epidemiology, 25*(5), 749-761. doi:10.1097/EDE.0000000000000121

Villanueva, K., Knuiman, M., Nathan, A., Giles-Corti, B., Christian, H., Foster, S., & Bull, F. (2014). The impact of neighborhood walkability on walking: does it differ across adult life stage and does neighborhood buffer size matter? *Health Place, 25*, 43-46. doi:10.1016/j.healthplace.2013.10.005

Walk Score Methodology. (2020). Retrieved from https://www.walkscore.com/methodology.shtml

Warburton, D. E. R., & Bredin, S. S. D. (2017). Health benefits of physical activity: a systematic review of current systematic reviews. *Current opinion in cardiology, 32*(5), 541-556. doi:10.1097/HCO.0000000000000437

Warburton, D. E. R., Nicol, C. W., & Bredin, S. S. D. (2006). Health benefits of physical activity: the evidence. *Canadian Medical Association Journal, 174*(6), 801-809. doi:10.1503/cmaj.051351

Wasfi, R. A., Dasgupta, K., Eluru, N., & Ross, N. A. (2016). Exposure to walkable neighbourhoods in urban areas increases utilitarian walking: Longitudinal study of Canadians. *Journal of Transport & Health, 3*(4), 440-447. doi:10.1016/j.jth.2015.08.001

Wasfi, R. A., Dasgupta, K., Orpana, H., & Ross, N. A. (2016). Neighborhood Walkability and Body Mass Index Trajectories: Longitudinal Study of Canadians. *American Journal of Public Health, 106*(5), 934-940. doi:10.2105/AJPH.2016.303096

Weinstein, A. R., Sesso, H. D., Lee, I. M., Cook, N. R., Manson, J. E., Buring, J. E., & Gaziano, J. M. (2004). Relationship of physical activity vs body mass index with type 2 diabetes in women. *JAMA, 292*(10), 1188-1194. doi:10.1001/jama.292.10.1188

Wendel-Vos, W., Droomers, M., Kremers, S., Brug, J., & van Lenthe, F. (2007). Potential environmental determinants of physical activity in adults: a systematic review. *Obesity Reviews, 8*(5), 425-440. doi:10.1111/j.1467-789X.2007.00370.x

Wharton, S., Pedersen, S. D., Lau, D. C., Sharma, A. M., & Committee, D. C. C. P. G. E. (2018). Weight Management in Diabetes. *Canadian Journal of Diabetes, 42*, S124-S129. doi:10.1016/j.jcjd.2017.10.015

Wilkins, R., & Peters, P. (2012). *PCCF + Version 5K* User's Guide. Automated geographic coding based on the Statistics Canada Postal Code Conversion Files including Postal Codes through May 2011*. Retrieved from Ottawa, ON, Canada:

Woodcock, J., Franco, O. H., Orsini, N., & Roberts, I. (2011). Non-vigorous physical activity and all-cause mortality: systematic review and meta-analysis of cohort studies. *International Journal of Epidemiology, 40*(1), 121-138. doi:10.1093/ije/dyq104

Woolcott, J. C., Ashe, M. C., Miller, W. C., Shi, P., Marra, C. A., & Team, P. R. (2010). Does physical activity reduce seniors' need for healthcare?: a study of 24 281 Canadians. *British Journal of Sports Medicine*, *44*(12), 902-904. doi:10.1136/bjsm.2008.057216

World Health Organization. (2010). *Global recommendations on physical activity for health*: World Health Organization.

World Health Organization. (2018). *World health statistics 2018: monitoring health for the SDGs sustainable development goals*. Retrieved from Geneva: https://apps.who.int/iris/bitstream/handle/10665/272596/9789241565585-eng.pdf?ua=1

World Health Organization. (2019). *Global action plan on physical activity 2018-2030: more active people for a healthier world*: World Health Organization.

World Health Organization. (2020). *World health statistics 2020: monitoring health for the SDGs, sustainable development goals.* Retrieved from Geneva: https://apps.who.int/iris/handle/10665/332070

Wu, J., Grannis, S. J., Xu, H., & Finnell, J. T. (2016). A practical method for predicting frequent use of emergency department care using routinely available electronic registration data. *BMC Emergency Medicine*, *16*, 12. doi:10.1186/s12873-016-0076-3

Wu, Y. T., Prina, A. M., Jones, A., Barnes, L. E., Matthews, F. E., Brayne, C., & Mrc, C. (2016). Land use mix and five-year mortality in later life: Results from the Cognitive Function and Ageing Study. *Health Place*, *38*, 54-60. doi:10.1016/j.healthplace.2015.12.002

Xue, Q. L., Fried, L. P., Glass, T. A., Laffan, A., & Chaves, P. H. M. (2008). Life-space constriction, development of frailty, and the competing risk of mortality. *American Journal of Epidemiology, 167*(2), 240-248. doi:10.1093/aje/kwm270

Yang, Y., & Diez-Roux, A. V. (2012). Walking Distance by Trip Purpose and Population Subgroups. *Am J Prev Med, 43*(1), 11-19. doi:10.1016/j.amepre.2012.03.015

Yaropud, T., Gilmore, J., & LaRochelle-Côté, S. (2019). *Results from the 2016 Census: Long commutes to work by car*: Statistics Canada= Statistique Canada.

Yu, Y., Davey, R., Cochrane, T., Learnihan, V., Hanigan, I. C., & Bagheri, N. (2017). Neighborhood walkability and hospital treatment costs: A first assessment. *Preventive Medicine, 99*, 134-139. doi:10.1016/j.ypmed.2017.02.008

Yusuf, S., Hawken, S., Ounpuu, S., Dans, T., Avezum, A., Lanas, F., McQueen, M., Budaj, A., Pais, P., Varigos, J., Lisheng, L., & Investigators, I. S. (2004). Effect of potentially modifiable risk factors associated with myocardial infarction in 52 countries (the INTERHEART study): case-control study. *Lancet, 364*(9438), 937-952. doi:10.1016/S0140-6736(04)17018-9

Zapata-Diomedi, B., & Veerman, J. L. (2016). The association between built environment features and physical activity in the Australian context: a synthesis of the literature. *Bmc Public Health, 16*(1), 484. doi:10.1186/s12889-016-3154-2

Zheng, H., Orsini, N., Amin, J., Wolk, A., Nguyen, V. T., & Ehrlich, F. (2009). Quantifying the dose-response of walking in reducing coronary heart disease risk: meta-analysis. *European Journal of Epidemiology, 24*(4), 181-192. doi:10.1007/s10654-009-9328-9

Zimmet, P. Z. (2017). Diabetes and its drivers: the largest epidemic in human history? *Clinical Diabetes and Endocrinology, 3*, 1. doi:10.1186/s40842-016-0039-3