A Good Place to Age in Place? Exploring the Relationships Between the Built Environment, Activity Participation and Healthy Aging

By

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Abstract

The concept of aging-in-place has gained growing popularity in public policy. Integrating a planning perspective on this interdisciplinary research topic, this dissertation focuses on the place where people age in place. This dissertation analyzes aging-in-place with a planning perspective, by exploring relationships between the built environment, activity participation and healthy aging in Canada. The first section analyzes spatial patterns and neighborhood contexts of aging-in-place with census data. It categorizes neighborhoods by their age structures, and compares the built environment and housing characteristics between neighborhoods with distinct age-structure types. The second section takes a closer look at aging in a car dependent built environment. By pooling multiple time-use cycles from the General Social Survey, it examines the changing travel behaviors by gender and cohorts, and the differentiated activity participation between car-users and non-car-users over the life course. Results suggest that a large percentage of neighborhoods in Canada are at the mature-stage (characterized by a high percentage of

residents in the baby boomer cohorts). These neighborhoods tend to age steadily and have highly car-dependent built environments. Automobility remains important over the life course for each generations of Canadians, yet older females are more likely to travel by active modes and by transit than are their male counterparts in each cohort. Increased participation gaps (in shopping and obtaining services, active sports, socializing and social participation) are found between car users and non-car-users in older age. Shopping and obtaining services stands out as the most car-dependent activity for older Canadians.

Examining the existing neighbourhood contexts of aging-in-place and the current patterns of activity participation among the aging populations is important for developing practical planning visions of a good place for aging-in-place. This dissertation is a preliminary exploration on this interdisciplinary research topic. With extensive analysis of survey data across Canada, this study integrates a planning perceptive and provides original insights on the academic discussion of aging-in-place.

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Chapter 1 Introduction

1.1 Background

The unprecedented growth of the aging population has far-reaching influences on almost every aspect of society. With a substantial increase of the aging populations who show strong preference for aging-in-place, the role of built environment becomes increasingly important for older people's health and wellbeing (Frank, Kerr, Rosenberg, & King, 2010; Wiles, Leibing, Guberman, Reeve, & Allen, 2012). Scholars argue that built-environment features are particularly important for older adults, since they tend to have more difficulties in mobility and higher risk of exclusion, especially when they face driving cessation due to declined physical and cognitive functioning (Clarke & Nieuwenhuijsen, 2009).

Aging is a ubiquitous phenomenon. With a broad definition, people age in place (remain in their own homes or communities as they age) in almost every kind of rural and urban context. This dissertation starts with an overview of conceptual links between aging, health and place, and conducts a scoping review of empirical studies on the built environment's impact on healthy aging. As both aging populations and places where people age are highly diverse, this dissertation addressed the need to obtain a representative sample to illustrate where people age in place and what are good places to age in place. Therefore, instead of taking a case-study approach, it conducts a macro-level analysis with nation-wide population representative data sets at a detailed spatial scale. Empirically, this dissertation focuses on two interrelated topics - the different type of places where people age in place, and the differentiated mobility behaviours and activity participation among different groups of the aging population over the life course.

Scholars observe that aging-in-place has been used as 'a guiding principle for managing aging population' and there is a worldwide adoption of policies to support aging-in-place (Davies & James, 2011, p.112). In public policy, the concept of aging-in-place is often used to refer to older people's preference for remaining in their own homes or the same neighbourhoods as they age (Lehning, 2012; Oswald, Jopp, Rott, & Wahl, 2011;

Singelenberg, Stolarz, & Mccall, 2014; Thomas & Blanchard, 2009). The concept of aging-in-place has evolved over time. Historically, the aging-in-place idea is connected to the trend of 'deinstitutionalization'- the support for older people to remain in their own homes instead of moving to institutions (Chapin & Dobbs-Kepper, 2001). More recent studies, however, tend to adopt a much broader definition and conceptualize aging-in-place as the free choice of older people to remain in a familiar environment or supportive community as they age (Cutchin, 2003). Similarly, the concept 'aging in community' is proposed to emphasize the supportive environment in older people's communities or neighbourhoods, including mutual support between community-members and community services or care provided by non-for-profit organizations (Thomas & Blanchard, 2009).

The concept of aging-in-place is interrelated with healthy aging. On the one hand, aging-in-place, as a policy objective, is associated with the idea that older people can maintain their identity and supportive networks, and further achieve independence and control over their surrounding environment if they age in place. On the other hand, maintaining good health and certain levels of independence in the aging process enables older adults to age in place. To promote healthy aging, the World Health Organization (WHO) proposed the concept of active aging – "the process of optimizing opportunities for health, participation and security in order to enhance quality of life as people age" (WHO, 2002, p. 12). Further, it developed policy framework for "age-friendly cities" or "age-friendly communities" to create "enabling" social and physical environment for active aging (WHO, 2007).

Supporters for age-friendly communities argue that an environment that is accessible, safe and comfortable for older adults, who experience a decline in physical capacities, can meet the needs of people in all age groups (WHO, 2002; 2007). The main characteristics of age-friendly communities are identified as 'physical accessibility, proximity, security, affordability, and inclusiveness' in all locations (Plouffe & Kalache, 2010, p.737). Local planning authorities have used the concept in initiating policies, programs and infrastructure-improvements to accommodate older people's needs in the identified key domains: neighbourhood design, housing, transportation, health and supportive services, and community engagement (Lehning, 2013). The age-friendly concept has also been

connected to walkable neighbourhoods, incentives for home modification, universal accessibility features in new development projects and existing transit infrastructure, supplement transportation services, senior centres, and social planning that promotes inclusiveness and civic engagement for the elderly (Lehning, 2013; Menec, Means, Keating, Parkhurst, & Eales, 2011; Steels, 2015).

Informed by planning concepts of good urban form, a growing body of literature has linked features of compact development with higher levels of physical activity, lower risks of obesity, and increased chance of social interaction (Frank et al., 2006; Handy, Boarnet, Ewing, & Killingsworth, 2002; Yen, Michael, & Perdue, 2009). In the planning literature, a compact built form at the neighbourhood scale is often characterized by walkable neighbourhoods with relatively high density, well-connected local streets, and good access to a variety of services (such as retail and transit) (Clifton, Ewing, Knaap, & Song, 2008; Congress for the New Urbanism, 2001). In addition, positive associations are identified between features of walkable neighbourhoods and residents' social connections, social trust, and social and political engagement (Leyden, 2003), and active social participation or community engagement is beneficial for older adults' physical and mental health (Peel, Bartlett, & McClure, 2004; Resnick, Gwyther, & Roberto, 2011). Therefore, planning interventions to create age-friendly places are important for facilitating aging-in-place and healthy aging.

The research topic of aging-in-place is multidisciplinary in nature. Disciplines such as demography, gerontology, and public health have provided theories and methods to analyze aging and healthy aging at both individual and population levels. However, these theoretical and methodological frameworks generally do not consider the spatial and built environment contexts of aging and/or aging well. At the same time, disciplines such as planning and geography, which have a strong focus on place, often have limited discussions on aging. Particularly, because conventional planning models ignore environmental needs for different life-stages, aging-in-place has been largely under-explored in the planning literature. This dissertation, therefore, intends to deepen the contextual knowledge of aging-in-place, by exploring the heterogeneous spatial contexts of aging-in-place and the diverse populations who are aging-in-place. Such contextual knowledge is essential for

building interdisciplinary conversations and advancing the knowledge of planning for aging-in-place.

1.2 Knowledge gaps

Although there is a clear ‘spatial nature’ of the aging-in-place concept (Davies & James, 2011, p.8), limited studies have examined the spatial context of aging-in-place, such as where people are aging-in-place, what types of neighbourhoods are expected to host a high percentage of older residents, and what are the built environment characteristics of the aging neighbourhoods. Rather, the aging-in-place literature often emphasizes non-spatial aspects of the emerging community initiatives that support aging-in-place. For example, there are growing studies on the models of consumer-empowerment, the 'naturally occurring' communities, cohousing schemes, and cooperative 'village' models (Bookman, 2008a; Mcdonough & Davitt, 2011; Scharlach, Graham, & Lehning, 2012). These initiatives often build on existing social networks and emphasize members’ autonomy over the planning and design of their shared neighbourhood.

However, because of the heterogeneity in the places where people age in place and the diversity of the aging populations, understanding the spatial patterns of aging and the neighbourhood context is key to evidence-based policy. For example, based on evidential links between walkable neighbourhoods and healthy aging, Frank and colleagues (2010, p.88) suggest that 'policies are needed to bring destinations such as shops and services closer to where elderly live, and to encourage elderly to be located in areas where shops and services are concentrated' based on their empirical analysis. Such policy suggestions may not be feasible given that older adults may not choose to or able to relocate for better neighbourhood walkability. In the context of a car-dependent built environment, especially, to improve the walkability of existing built environment requires long-term planning efforts, while for the aging populations, their participation in social activities and even physical activities, may still largely rely on automobility.

Existing studies on aging-in-place and active aging, in gerontology, public health, geography and planning, tend to take different perspectives, and sometimes provide potentially conflicting policy suggestions. Research that aims at providing policy

suggestions for aging-in-place often emphasizes the older adults' preference of not-moving and the importance of local services (Thomas & Blanchard, 2009), while studies on elderly migration, including seasonal migration, underscores the high level of mobility among older adults and their preferences for certain types of places (McHugh & Mings, 1996). With regards to healthy aging, research in public health and planning has identified positive impacts of a walkable built environment on active aging and/or healthy aging, and supports compact development that prioritize transit-use and active transportation. However, a growing number of studies in gerontology highlights the critical role of car-travel, particularly the ability to continue driving, for older adults' health and well-being (Choi & Mezuk, 2013).

Methodologically, research on policy frameworks of aging-in-place and age-friendly communities are often limited to an exploratory qualitative approach, with relatively small sample size. For instance, the Global Age-friendly Cities Project by WHO only adopted focus groups and interviews to analyze older participants' demands for living environments and the perceived important environmental factors affecting their well-being. At the population level, empirical studies on active aging and healthy aging usually rely on discretionary thresholds of old age, such as age 60 or 65, and arbitrary spatial units of the neighbourhood contexts of aging. As a result, the diversity in aging populations and the variations in their living environments remain under-discussed.

1.3 Research objectives

Addressing these research gaps, this dissertation explores two areas of the interdisciplinary research topic. The first major section of the dissertation (chapter 3 and chapter 4) intends to integrate a planning perspective on the aging-in-place literature by developing a deeper understanding of the places where people age in place. It examines different demographic trends that shape the spatial pattern of aging, methods to analyze patterns of population aging at both the municipal scale and the neighbourhood scale, and whether neighbourhoods with different age structures have distinct characteristics.

Given that the built environment of Canada is primarily car-dependent and older adults' automobility has an important role in both aging-in-place policies and healthy aging

debates, the second major section of this dissertation examines the differentiated automobility among the aging populations, and the extent to which older adults can remain active without cars. This part (chapter 5 and chapter 6) analyzes how mobility gaps between gender and cohort groups varies over time, whether the participation in activities becomes more polarized between car users and non-car-users in older age, and what types of activities are more car dependent for older adults. Highlighting the diversity within the aging populations, this part of discussion adopts a life-course perspective and analyzes the relationships between automobility and gender, socioeconomic status and health status of the aging populations. With a multilevel age-period-cohort analysis, it examines how participation in various activities between car-users and non-car-users differentiate over the life course.

1.4 Conceptual and theoretical framework

1.4.1 Conceptual links between aging, health and place

The conceptual links between aging and health have long been discussed in gerontology. Particularly, older adults' activity participation has gained growing popularity in both academic research and public policy of healthy aging. The conceptual connections between activity and healthy aging include the idea that physical activities benefit one's overall health status and physical functioning in the aging process, as well as the assumption that active participation in society contributes to older people's perceived quality of life and prevents social marginalization of economically disadvantaged seniors (Peel et al., 2004).

The aging-in-place literature has built conceptual links between aging and place. A widely held idea is that older people tend to have strong attachment to familiar surroundings, including places where they lived before retirement and places where they have established social networks (Davis & James, 2011). In addition, involuntary relocation often leads to immense stress for the elderly (Chui, 2008). Nonetheless, a relational approach to conceptualize the relationships between aging and place looks less at the mechanisms or structural reasons for the socio-spatial variation of aging experiences. Rather, it views the aging process as a dynamic path that changes with every life event

(Hopkins & Pain, 2007). Also, place can be regarded not as a specific location but as "actively constituted by mobility" (Cresswell, 2014, p.8), as a person's mobility shapes the place he or she experiences. With this conceptualization of place, physical and social environments are constantly changing and traditional measures of mobility and accessibility can be extended to capture the geographically and temporally dynamic relations between aging, health and place.

The conceptual links between health and place are widely discussed in academic fields such as public health, health geography, environmental health, and increasingly in planning as well. Research on the association between health and place starts with acknowledging that structural conditions of environment influence health related behaviours and outcomes, instead of assuming that individual choices (of lifestyles) are primary determinants of health variations (Macintyre, Ellaway, & Cummins, 2002). However, the "place effects on health" often appears as a "residual category" since some variations of health cannot be explained without contextual factors, but the casual pathways of how place affects health are often unclear (Cummins, Curtis, Diez-Roux, & Macintyre, 2007; Diez Roux et al., 2010). Recent studies have analyzed conceptual problems inherited in the dualism of *contextual* factors versus *compositional* factors, and argue for more comprehensive frameworks to conceptualize causal pathways of the built environment's influence on health (Cummins et al., 2007).

In the literature of planning and design that focuses on the built environment, car-dependent built form is often criticized for its association with unsustainable development and the loss of vibrant and diverse public spaces, and negative health outcomes (Ewing, 1997; Frank et al., 2006). In response, planning ideas, such as new urbanism, have promoted compact development that is characterized by relatively high density, well-connected streets, good access to transit, and walkable neighbourhoods with integrated corner-stores and open spaces (Congress for the New Urbanism, 2001). Moreover, recent interdisciplinary studies have emphasized the health benefits of a compact built environment (such as walkable neighbourhoods), as these environments associate with higher levels of physical activities, social participation and better health outcomes (e.g. Frumkin, 2003; Frank et al., 2006).

To promote public health through planning interventions, researchers have attempted to identify the key features of the built environment that significantly associate with health related behaviours and outcomes. Most of the evidence linking aging, health and place is based on the idea that a supportive environment can help older people to stay in the same neighbourhood as they age, maintain their existing social networks, and engage in everyday physical and social activities (Clarke & Nieuwenhuijsen, 2009; Cunningham & Michael, 2004; Kerr, Rosenberg, & Frank, 2012).

With a strong preference among older adults aging in their own homes or neighbourhoods, local resources in the existing built environment are important for the everyday life of older adults, especially for the oldest old who tend to have shrinking activity space. However, in Canada, as well as other developed countries with extensive post-war urban expansion, the prevalence of car-dependent built form has particularly strong impacts on older adults. As older people lose the ability to drive, they may face challenges both in terms of a sudden and significant decrease of mobility and accessibility in their everyday life; and in terms of an emotional distress for the perceived loss of independence (e.g. Adler & Rottunda, 2006; Davey, 2007).

1.4.2 The life-course perspective on healthy aging

The concept of age is used as both a biological indicator (which is associated with a general trend of changing physical or psychological conditions) and a social marker of one's expected role in society (Hodge, 2008; Harper, 2005). In social science, age or age-cohort is commonly used as a descriptive variable that helps to identify an individual's cohort-membership and life-experiences that are shared by the same generation (Harper, 2005, p.3). Moreover, chronological age is associated with life-stages that are deeply influenced by social institutions. Through age-eligibility thresholds, chronological age functions as "a social clock" for life events and transitions (Harper, 2005, p.69-71). Further, as the life-course perspective suggests, age-related social expectations provide norms for the social timing of life transitions, and such expectations are interrelated with physical and psychological development (Elder, 1998). However, with increasing longevity and a

common delay of life-transitions, life trajectories have become increasingly diverse (Harper, 2005, p.80-81).

In contrast, aging emphasizes the process of getting older, in terms of both chronological age and the age-related physical and psychological changes. Influenced by the life-course perspective, aging research in gerontology often refers to 'human development over time' (Kunkel, 2003, p.130). More often than not, studies on age and aging are not interested in the concepts themselves, but rather use age or aging to capture some general patterns such as biological/psychological changes in the aging process, common characteristics of certain age-groups, and social trends that are associated with the increased share of aging population in a society.

Traditionally, the biomedical model views aging as a biological process and uses physical (and cognitive) functioning as the most important determinant for healthy aging. However, as discussed by theorists in gerontology, an overemphasis on the biomedical factors leads to the danger of constructing "aging as problem" given that the biomedical model views the (inevitable) trend of physical decline as problematic and the aging or declining body as an object to be fixed (Powell, 2005, p.31). Also, as the new generations of aging populations are expected to live longer without significant disabilities (Christensen, Doblhammer, Rau, & Vaupel, 2009), non-biomedical factors become more important for understanding the great variation of aging experiences.

In gerontology, many concepts have been proposed to identify key factors or determinants of aging well, such as "successful aging" (Rowe & Kahn, 1997), "positive aging" (Bowling, 1993), and "productive aging" (Kerschner & Pegues, 1998). Based on the World Health Organization (WHO)'s definition of health, the concept of 'active aging' or 'healthy aging' emphasizes physical, mental and social aspects of wellbeing for the aging populations (WHO 2002). This concept also connects with policies that promote health related activities (such as social participation and physical activities) in older adults, as well as social and environmental factors that help older adults adapt to changes in the aging process (Bartlett and Peel, 2004).

As noted by Kunkel (2003) and Chapman (2005), theories and concepts of healthy aging have moved beyond the paradigms of "aging as problem" and "aging as normal" and started to focus on the open-ended process of adaptation over the life-course, the social institutions and living environments that enable this process, and the diversity of experiences within this process.

1.4.3 Aging-in-place, place and mobility

The aging-in-place literature often indicates that most people prefer to remain in familiar environments where social networks have been well established and local resources are easily accessible as they age (Katz, 2005; Wiles et al., 2005). Surveys across developed countries report that older adults have strong preference for familiar environments, especially their own homes. For example, in 2000, the American Association of Retired Persons (AARP) reported that about 92% of surveyed older American (over 65) wanted to stay in their own homes as they age and 82% indicated the preference for staying in their homes even when they need aged care (Thomas & Blanchard, 2009).

The concept of "place" in aging-in-place is connected with home or home-like environment, as 'home' is sometimes used as a metaphor for "place" (Cresswell, 2014, p.24). For an individual, the meaning of "home" can be a place of personal identity, sense of security, privacy and familiarity (Means et al., 2008, p.155). A similar idea is the "attachment to place", as Tuan (1977) pointed out, there is a people-place bond, a natural attachment between people and place, as people perceive and experience the world through places (Tuan, 1977). With a phenomenological perspective, scholars such Tuan (1977) and Relph (1976), explained that people develop 'attachment to place' because they create meanings and form their identities through places. They further argued that the concept of place is not necessarily associated with a fixed location or a spatial boundary. Rather, place is a "pre-scientific fact of life", which is based on human experience, and at the same time shapes people's consciousness and experiences (Cresswell, 2004, p.23).

Historically, the literature on place often sees high levels of mobility as a threat to "place" and views modernist mass-production resulting in the "erosion of place" (Relph,

1976). Following Relph's argument on the erosion of place, scholars argue that the increasing speed of travel (or increasing mobility) makes non-places such as freeways and airports (Relph, 1976). Scholars argued that the non-places are associated with a "superficial sense of place" as people often pass through these places without actually experiencing them (Cresswell, 2014, p.48). The concepts of "placelessness" and non-place blame the environmental features (such as high-speed circulation and the lack of diversity) created by modernist development for the fact that they undermine people's attachment to place and the development of social bonds. However, recent research on mobility and place has increasingly linked the two concepts together. Massey (1993) argued that place is "produced through connections" and "actively constituted by mobility" (as cited by Cresswell, 2014, p.8). More recently, studies on new forms of mobility conceptualized places as "a set of spaces where ranges of relational networks and flows coalesce, interconnect and fragment" (Urry, 2000, p.140).

This broader definition of place is in line with gerontologists who suggest that research on aging-in-place needs to focus on whether older people are able to engage in place-making or place-integration in a locality and develop meanings and personal identities from new localities (McHugh and Mings, 1996; Cutchin, 2003). Moreover, as high levels of mobility, automobility particularly, has been an essential part of modern lifestyle; the mobility of the aging population may be an important and largely neglected aspect of aging-in-place. As explained by McHugh and Mings (1996), the idea of home is 'geographically elastic' and the 'attachment to place' is based on a lifelong accumulation of experiences in multiple communities.

Therefore, instead of assuming planning for aging-in-place is to help older adults stay in the same neighbourhood as they age, this study explores the spatial patterns of aging and population change, the differentiated automobility among the aging populations, and discusses the ability to stay or gain access to environments that support healthy aging.

1.5 Methods and key findings

This dissertation starts with a scoping study of the built environment's impact on healthy aging. It identifies the need to understand the contextual differences among places

where people age, and the variations in mobility and activity participation among older adults and in their aging process. Therefore, the empirical part of this dissertation conducts macro-level analyses to understand population aging in relation to place and mobility, with population representative data sets at a detailed spatial scale in Canada.

Focusing on aging populations across Canada, this dissertation uses multiple cycles of nation-wide surveys to investigate diverse spatial contexts where people age in place and the differentiated activity participation among subgroups of the aging populations. Given the interdisciplinary nature of this topic, this research adopts methods from various disciplines, including spatial analysis based on geographical information system (GIS), age-period-cohort analysis in demography, and objective urban form measures from planning research.

The first major section of the dissertation addresses the research need for an evidence-based conceptualization of the spatial context of aging-in-place, it examines the spatial pattern of aging at a local scale, and analyzes aging-in-place in relation to population growth/decline and moving/non-moving. The result highlights the importance of understanding the spatial patterns of aging with multiple indicators that can capture changes in both population size and population age structure. Also, the empirical data in Canada shows that there are only weak correlations between population aging and population decline, yet the weak association is strongly influenced by a few outliers that either have substantially higher growth rates or have experienced sporadic population change during a short period.

Further, it characterizes the aging neighbourhoods by conducting a cluster analysis of the age-profiles of all neighbourhoods – with dissemination area (DA) as proxies. The results show four types of neighbourhoods that have distinct age structures. These neighbourhood clusters are: the young neighbourhood (with high percentages of residents in mid-20s); the middle-stage neighbourhood (with high percentages of residents around 30s-40s and 10 years old); the mature-stage neighbourhood (with high percentages of residents around 40s-50s and 15-19 years old); and the aged neighbourhood (with high percentages of residents above age 65). To understand the unique aging-in-place challenges for each type of neighbourhood, the housing characteristics and local built environment are

compared among the four types of neighbourhoods. Compared with other types of neighbourhoods, the mature-stage neighbourhoods are most stable, with relatively high income, high home-ownership rate and low living cost. However, these neighbourhoods also tend to have the characteristics of a car-dependent built environment - low density, limited street connectivity, and very few retail and service locations within a walkable distance.

Taking a closer look at aging in a car dependent built environment, the second major section of the dissertation examines the changing travel behaviours and activity participations in the aging process. By pooling multiple cross-sectional surveys, this study attempts to understand the differentiated trajectories of automobility between different subgroups of the population, and the relationships between car-travel and activity participation over the life course. This study takes two approaches to analyze changes over the life course. First, cohort analysis is conducted to compare the change of travel behaviours over time, for each cohort and gender group. The results show that automobility remains important over the life course for each cohort. Within each cohort, older females are more likely to travel by active modes and by transit than their male counterparts are. However, in recent periods, older females tend to travel less with alternative modes, especially among females turning toward advanced old age. A smaller gender gap in automobility can be expected among the baby boomer cohorts, yet gender differences in driving and car-travel frequency remain significant, particularly in advanced old age,

Second, a multilevel age-period-cohort analysis is used to illustrate the age effect of car-travel and activity participation. By estimating the probabilities of car-travel and activity participation by age group, this study explores the differentiated automobility among different social groups, and the variation in activity participation between car users and non-car-users over the life course. The results indicate that the participation gap between car users and non-car-users is even larger in older age, for social participation and the participation in shopping and obtaining services, active sports and socializing. Particularly, shopping and obtaining services show the highest level of car-dependency.

1.6 Organization of the dissertation

To obtain a systematic analysis of the existing empirical evidence on the associations between built environment and healthy aging, Chapter 2 conducts a systematic literature search and a quantitative content analysis of the empirical findings from the selected existing empirical studies. Chapter 3 and Chapter 4 consist of the first major section of the dissertation. They analyze population aging in relation to place by examining the spatial pattern of aging and neighbourhood contexts of aging-in-place across Canada with census data at detailed geographical scales. With a focus on analyzing population aging in relation to transportation mobility, Chapter 5 and Chapter 6 compose the second major section of the dissertation. Both chapters use the General Social Survey time-use cycles. Chapter 5 adopts a cohort analysis to show the mobility gap between gender and cohort groups. Chapter 6 uses a multilevel age-period-cohort analysis to explore the relationships between automobility and activity participation over the life course. Summarizing the main empirical findings, Chapter 7 discusses this dissertation's original contributions to both the empirical knowledge and conceptual framework of healthy aging-in-place.

Chapter 2 Built environment's impact on healthy aging: a quantitative analysis of the literature

2.1 Introduction

The impact of the built environment (the BE) on residents' health-related behaviours and health outcomes has received growing research interest since the 2000s. The concept of the BE often includes urban design features, land-use patterns, transportation systems, and human activities embedded in the environment (Handy et al., 2002). Understanding the numerous ways the BE can impact older adults' activities and health is particularly important, because older adults tend to experience more barriers in the built environment, which adversely affects their mobility, social participation and health (Cunningham & Michael, 2004).

Informed by accumulating research and evidence, policy frameworks have been proposed to promote "active aging" and to create "age-friendly communities" (WHO 2002; WHO 2007). According to the definition by the World Health Organization [WHO] (2002), the objective of active aging is "optimizing opportunities for health, participation and security in order to enhance quality of life as people age", and the concept of being active includes participation in a variety of physical, social, employment, economic, cultural, spiritual and civic activities (p.12). With this broadly defined agenda, the guidelines proposed for "age-friendly communities" have included a comprehensive checklist of environmental features that can potentially encourage and enable active aging (WHO, 2007). From the perspective of planning practice, however, it is important to identify domains that are amenable to interventions and to determine priorities that can balance the trade-offs in planning interventions and make efficient use of limited recourses (Campbell, 2016).

Although the built environment has long been a key research focus in urban planning and urban design, multidisciplinary knowledge is essential for planners and designers to gain a deeper understanding of the pathways through which BE can influence activity patterns of the aging population and contribute to their health and wellbeing. Addressing

the need to review the existing empirical evidence of the BE's impact on the activities and health of the aging population across disciplines, and to highlight the policy implications of existing research evidence, this chapter takes a novel approach by combining the techniques of a quantitative content analysis with a scoping review.

A growing body of literature has discussed the impact of the BE on active aging and healthy aging in various disciplines. As the concepts of the BE, activity participation, and the health and well-being of the aging population, can be broadly interpreted, it is challenging to summarise the empirical results systematically. In addition to this, researchers' understanding of BE features has often been limited by the tools of describing or measuring them, particularly because it is the different combinations of BE features as a multi-dimensional construct, rather than understanding how separate aspects of them affect people's experience (Clarke & Nieuwenhuijsen 2009). Likewise, there are complicated interactions between physical functioning of bodies, mental health, activities, lifestyles and environmental factors, and these can change over time as one ages (Clarke & Nieuwenhuijsen 2009).

Because of the complexity of these interactions and the diversity in the research designs of relevant studies, systematic reviews on this topic usually attempt to identify a specific area of focus. For example, Cerin and colleagues (2017) analyzed the strength of evidence for associations between BE features and older adults' active travel, with a meta-analysis of quantitative studies. Moran and colleagues (2014) overviewed the qualitative research on the relationships between BE features and physical activity in older adults, and Annear and colleagues (2014) reviewed gerontological research on the impacts of various environmental factors on healthy aging. Despite the availability of a large and growing number of empirical studies on the relationships between the BE and healthy aging, relatively few studies have focused on reviewing the recommendations generated from empirical studies that help to inform planning interventions with a systematic approach.

In health research, the BE has often been regarded as a contextual factor that influences population health in numerous, and often indirect, ways. In gerontology, the activity theory has long emphasized the importance of staying active in preventing illness

and physical decline, and had enduring impacts on aging studies, health-promotion programs and the health related professional discourse (Katz, 2000). Also, the theory of "environmental press" provides a conceptual framework to understand the interactions between the BE and the aging person (Lawton 1983). In planning research, comprehensive methods have been developed to measure a variety of detailed aspects of the BE, assess the compactness, walkability or design quality of the BE, and evaluate the impact of BE features on travel behaviours and activities (Ewing & Cervero, 2010; Handy et al., 2002). These methods have been widely applied in the studies of the associations between the BE, physical activity, and health.

Highlighting the interdisciplinary nature of this research topic, this chapter aims to provide a systematic analysis of empirical evidence that offers insights on the interrelations between the BE, older adults' participation in activities, and their health and wellbeing. More specifically, this chapter focuses on the health aspect of active aging and examining the intersection of health (including the general ideas of well-being and quality of life), aging or old age, and the BE. In this review of the interdisciplinary studies that can inform planning interventions on the BE, the following questions are explored: (1) what aspects of the BE were identified as associated with older adults' activity participation and their health and wellbeing in the literature? (2) What types of activities were studied in relation to BE features and the health and wellbeing of older adults? (3) Where are the main agreements and disagreements in the identified associations between the BE features and the activities that contribute to healthy aging?

2.2 Method

2.2.1 Methodological framework

In order to include empirical studies conducted with different theoretical frameworks and research designs, this chapter adopts a scoping review framework (Figure 2.1). According to Arksey and O'Malley (2005), scoping reviews have been commonly used as a technique to "map relevant literature" (p.20) and to summarize its "volume, nature and characteristics" (p.30), on a broad research topic that is complex and heterogeneous in nature. There are clear differences between a systematic review and a scoping review. A

systematic review seeks to summarize high-quality empirical evidence on a well-defined research question, often with appropriate study designs predefined for the review. It requires an unbiased selection and assessment of primary studies and a synthesis of evidence from the assessed studies (Higgins & Green, 2011). In contrast, scoping review aims to provide an overview of a broad research topic that encompasses a wide range of theoretical frameworks, study designs, and methodologies (Pham et al., 2014). As a relatively rapid way to collect and summarize a large volume of information, a scoping review helps to examine the extent and nature of existing studies, identify research gaps, inform the question-forming of systematic reviews, and engage a broad audience including policy makers and practitioners (Arksey & O'Malley, 2005). Nevertheless, because various types of studies are included, scoping review often does not assess the quality of studies or synthesize the empirical findings with statistical methods (Pham et al., 2014).

Given that a scoping review aims to overview a large and diverse body of literature, the methodological focus of scoping review shifts away from expert knowledge of a specific field towards skills to retrieve, manage and summarize a large quantity of data (Arksey & O'Malley, 2005). As such, structured approaches are important for the identification and analyses of relevant studies. Similar to systematic reviews, scoping reviews often include a systematic search of the literature, and quite a few have adopted the PRISMA guideline, which was developed for systematic reviews (Levasseur et al., 2015; Pham et al., 2014). However, the strategy to summarize the diverse body of literature remains a key challenge in scoping reviews. Although Levac and colleagues (2010) recommended the use of thematic analyses or qualitative content analyses in a scoping review (Levac, Colquhoun, & O'Brien, 2010), Pham and colleagues (2014) identified that 344 out of 365 selected scoping reviews were limited to providing narrative summaries without formal qualitative analysis.

Drawing on the need for structured and efficient ways to analyze large quantities of literature in scoping review, this chapter integrates a quantitative content analysis to the methodological framework developed by Arksey and O'Malley (2005). Different from the qualitative content analysis that focuses on the meanings of texts, the quantitative content analysis focuses on identifying categories and indicators to represent the construct of

interest, and therefore has a strong emphasis on developing guidelines for managing, scoring, and interpreting the coding schemes of the data (Rourke & Anderson, 2004). To the authors' knowledge, the method of quantitative content analysis has not been used in the context of scoping reviews. However, the techniques of quantitative content analysis can provide opportunities to advance the methodology of scoping reviews. On the one hand, quantitative content analysis provides a promising tool to assist the charting and analysis of textual data assembled in a scoping review. For example, based on frequency counts of coded data, a variety of descriptive or inferential statistical techniques and computational modeling can be applied with the qualitative content analysis (Rourke & Anderson, 2004). On the other hand, literature reviews can direct a quantitative content analysis, as it helps to determine the strategy to categorize information and code the textual data (Barringer, Jones, & Neubaum, 2005).

Stage 1. Identifying the research question
To overview empirical studies on the interrelations between the BE, older adults' activity participation, and their health and wellbeing.
Stage 2. Identifying relevant studies
Adopted PRISMA guideline for a systematic search of literature.
Stage 3. Study selection
An iterative process including searching the literature, refining the search strategy, independent selection of studies, consensus on the inclusion/exclusion of studies.
Stage 4. Data charting
Developed a literature map (Figure 2.3) to identify key concepts and the relationships between these concepts; Extracted key information from the full-text of selected articles.
Stage 5. Quantitative content analysis
An iterative process including: develop a guideline to categorize and interpret the data, preliminary tryouts of coding schemes, refine coding schemes, and refine the guideline.

Figure 2.1 Methodological framework

2.2.2 Literature search strategy

The literature search aims to obtain the empirical evidence on the interrelations between the BE, older adults' participation in activities, and their health and well-being, and to target (1) primary research that has older adults (or the aging population) as research participants, and (2) review articles in different research fields that summarized (part of the) relevant empirical studies. Different combinations of search terms, including "activity", "health", "aging", "built environment", and their synonyms were tested in three databases: Scopus, PubMed, and Web of Science. These comprehensive databases are well suited for the review of interdisciplinary research, as they include academic journals in Medline, EMBASE, and Compendex, in addition to other peer-reviewed publications from a wide range of research fields (e.g. the social sciences). Search terms were refined to obtain the most relevant results. For example, the keyword "age-friendly" was not included in the search terms because the additional articles it identified focused on the development of policies, program, community initiatives, or methods to evaluate the age-friendliness of environments. In addition, because a large portion of the targeted research used walkability as a key measure of the BE, the keywords "walkability" and "walkable" were added as alternative terms of "built environment".

All types of studies were included in the initial search, including articles and articles in press, reviews, conference paper and conference reviews, books and book chapters, short surveys, research notes, letters, newspaper articles and so on. In later steps of inclusion/exclusion, only peer-reviewed primary-research articles and review papers were included. Because this review focuses on empirical evidence and a large part of the grey literature tend to show descriptions of research projects that have results published in peer-reviewed articles, and refining the selection to peer-reviewed articles compensates for the lack of quality-assessment in this scoping review. Nevertheless, bibliography and citations of the selected articles were screened to identify additional items. The process of literature search followed the PRISMA-guidelines (Moher et al., 2015), and the search results included articles from the earliest dates available in these databases until October 20th, 2016 (Figure 2.2).

2.2.3 Inclusion/exclusion criteria

The following inclusion criteria were developed as follows: (1) English peer-reviewed articles that are either primary research (including qualitative, quantitative and mixed methods research) or literature reviews, (2) Studies that discussed the relationships between various aspects of the BE, participation in physical, social, economic, cultural or political activities, and health and well-being of the aging population. Further, studies were excluded if they met one of the following criteria. (1) The article did not clearly state the methodology of assessing/ measuring BE features or activity-participation. (2) The article focused on social environment, natural environment, or a single aspect of the BE. (3) The article did not explicitly focus on older adults, subgroups of older adults, or the aging population in the research objective. (4) The article focused on the perspectives of policy-makers, managers, professionals, or the development of methods, policies or intervention programs. (5) The article was exploratory in nature and only investigated older people's preferences or perceived barriers of the BE without examining the impact of these BE features. In addition, three articles were excluded because another more relevant article based on the same research project and used the same measures was already included in the selection. Because the selection included studies with different research designs, the inclusion/exclusion criteria did not adopt rigid thresholds for age or sample-size.

Available information of all the searched items, including title, authors, publication date, journal title, keywords, and abstract, were obtained from the databases and organized in R 3.3.0. Given the large amount of information from the 1,642 articles, R code was applied to flag the articles that contain any of a set of keywords that indicate a possible satisfaction of the exclusion criteria. These keywords were identified based on screening the titles of the searched items. For example, keywords such as "policy", "stakeholder", "management", "strategy", "evaluation" and "recommendation" were used to flag articles on policy. In addition to this, the author screened the searched items independently and assessed the articles against the inclusion/exclusion criteria. The selections of included articles from both methods were compared, and a final database of papers was established.

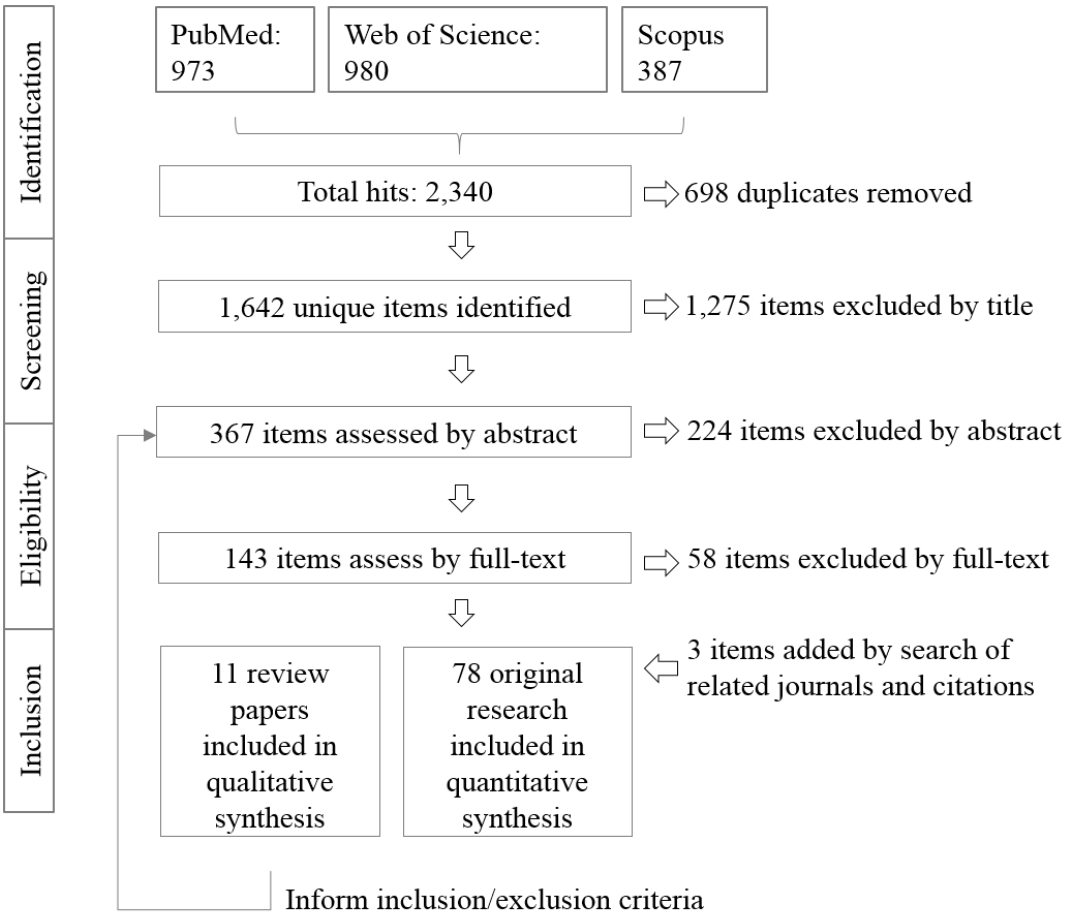


Figure 2.2 Systematic literature search

2.2.4 Literature map and data charting

In total, 89 items were selected for review, including 78 empirical studies and 11 review papers (Appendix A). A literature map was created through summarizing the identified review papers (Appendix B), extracting the key components the BE's and activities in relation to healthy aging, and charting the associations discussed in these papers (Figure 2.3). This literature map further helps to categorize key information of the selected empirical studies. By reading the full-text of identified articles, the following contents were extracted from the empirical studies. Authors, year of publication, study location, study populations (samples and sampling methods if applicable), research objectives, methodology, measures of BE features, measures of activities, aspects of health discussed or included in the analysis, other environmental factors or individual factors (if applicable), important results (and recommendations if applicable).

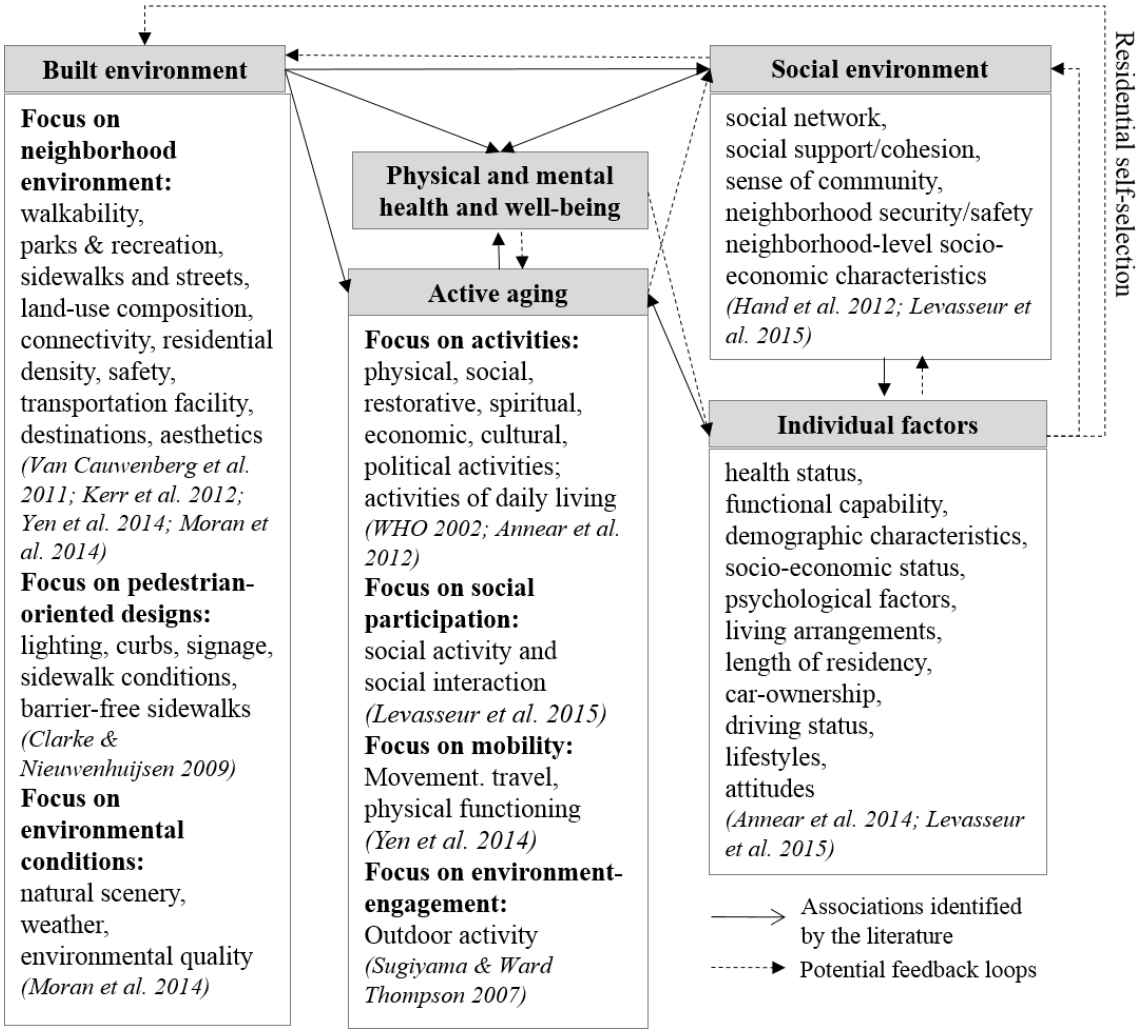


Figure 2.3 Literature map of key concepts and associations between the concepts

2.2.5 Quantitative content analysis

Using the extracted data from the scoping review, a quantitative content analysis is adopted to summarize the BE features, activity types, aspects of health, and key findings emphasized by the authors. A quantitative content analysis typically includes a systematic categorization of qualitative content and identifying the relationships among these categories with statistical analyses (Riffe, Lacy, & Fico, 1997). However, as a variety of relationships between different BE features and activity-types are identified in the literature, the sample was not large enough to conduct statistical analyses (e.g. a chi-square test) effectively. Therefore, this chapter calculated the word-frequency of extracted information and analyzed the relationships between repeated keywords identified in the empirical

studies. The analysis of word-frequency illustrates the intensity of research emphasis on certain BE features and activity types for healthy aging.

The selection of representative samples and the construction of categories, which were identified as the most challenging steps in quantitative content analysis (Riffe et al., 1997), are relatively straightforward in this study. The scoping review process helps to obtain text-samples systematically and develop rules to categorize information, especially given that many key research themes were summarized in previous review papers (Appendix B). With the key information categorization and text frequency counts established, the quantitative content analysis is performed, using the statistical software R 3.3.0, to better understand the relationships between key BE features and health-related activities of older adults. The findings from this analysis are summarized in the next section.

2.3 Results

2.3.1 Characteristics of reviewed studies

Compared with results from previous reviews, the articles selected for this chapter show that many previously identified research gaps have been addressed in recent studies (Table 2.1). More studies based on longitudinal surveys or intervention-based, multi-stage surveys were published in recent years. Also, the diversity in the geographic regions of study has increased significantly: the percentage of studies conducted outside of North America has increased from less than 10% to 58.2% after 2010. More than half of the examined studies have sample sizes between 100 and 1000, with the range of sample sizes varying from 58 to 50,685. About 82.1% of the studies investigated older people with mean age below 75 and very few papers focused on the oldest older adults. About 80.5% of the studies included both genders, regardless of the participants' ethnicity. Though minority groups tend to be under-represented, about 20.2% of the studies explicitly explained purposeful sampling methods to obtain representative samples.

Similar to the findings of Haselwandter et al. (2015), older adults living in institutional settings, retirement communities and assisted living environments were under-represented in the selected studies. Though several exploratory studies investigated

retirement communities and assisted living environments, they were excluded for the lack of comprehensive assessments of both the BE and older adults' activity participation. Thus, the findings of this chapter mainly apply to the living environments of community-dwelling older adults.

Table 2.1 Characteristics of reviewed studies

Publish-Date	N	Subject Area	N	Geographic Region	N
2015-2016	**25**	**Health & Medicine**	**44**	**North America**	**39**
2013-2014	15	Gerontology/Aging	9	Europe	15
2011-2012	16	Planning & Design	7	Asia	13
2009-2010	9	Physical Activity	11	Australia	5
2007-2008	9	Transportation	3	South America	4
2002-2006	5	Others	4	Others	2
Sample Size	N	Mean Age	N	Research Design	N
<100	9	55-65	12	**Cross sectional survey**	**59**
100-500	**22**	66-70	17	Multi-stage cross-sectional surveys	6
500-1000	18	**71-75**	**35**		
1000-2000	17	76-80	9	Longitudinal survey	9
2000-5000	3	80+	2	Controlled Trial	3
>5000	9	Unknown	3	Case study	1

Note: Mean age is estimated for studies that only reported number of people in different age groups.

2.3.2 The built-environment features and activity participation older adults

BE features and measures

By listing word-frequency of the studied BE features and identifying synonyms based on how these features were measured, key BE features analyzed in the literature were identified (Table 2.2). Notably, BE features were measured with a great variety of detail, many of the key features were interrelated, and different measures were overlapping. For example, a higher degree of land-use mix often means closer proximity and better accessibility to a variety of destinations. More often than not, the actual measures used in the studies were not directly comparable and the relationships between BE features were not discussed. Acknowledging this limitation, this analysis focuses on the authors' emphases on certain aspects or indicators of the BE and reveals which BE features were considered important in relation to activity-participation for healthy aging.

Main themes of BE features can be summarized as: (1) urban form and neighbourhood-design features, including measures of land-use patterns, street-network design, proximity to services and destinations and overall scores for walkability and accessibility. (2) Transportation systems and street-facilities, including infrastructure or facilities for walking, cycling and transit, as well as design elements and conditions of streets. (3) Different types of services within a walkable distance. (4) Related social and natural aspects. It is noteworthy that some BE features, such as accessibility to services or destinations, are often not measured consistently across studies. In cases where measures of distance to destinations are used, these BE measures are categorized as measures of proximity rather than accessibility, for this review.

Table 2.2 Frequency of built environment features measured in selected articles

Urban form and neighbourhood-design measures	**N**	**Transportation systems and street-facilities**	**N**
green-space coverage (parks)	32	infrastructure for walking/cycling	19
land-use mix (diversity of land-use)	30	transit stations (bus stops)	19
connectivity (intersection density)	29	sidewalk conditions	13
residential density/ level of urbanization	28	paths/trials/walkway	11
walkability/ walk score	33	slope	2
aesthetics	18	lighting/streetlight	4
proximity to services	15	curbs	3
accessibility score	8	crossings	2
perceived physical barriers	4	benches/sitting space	3
accessible building design	3		
Types of services/destinations	**N**	**Related social and natural aspects**	**N**
shops (grocery/mall/retail)	20	perceived safety	20
recreational facilities	14	traffic (high volume/unsafe)	8
community centres	7	crime rate	4
restaurants	6	social support (social cohesion)	6
fast-food outlet	2	air quality/pollution	6
healthcare units (clinics/pharmacy)	4	noise	4
place of worship	4	natural features	4
businesses/employment	3	(trees/vegetation/rivers)	

Note: N= number of studies measured this BE feature. Synonyms were combined, general terms that were used with other specific BE features, such as "access (to)" and "availability (of)", were not included. Less-frequently measured BE features (N<2) were not included in the table.

Although the studied BE features showed an emphasis on man-made landscapes and particularly the physical environment of urban residential neighbourhoods, quite a few

studies included natural and social aspects of the neighbourhood environment, especially in terms of perceived safety and overall environmental quality. This indicates a growing consensus that it is important to consider not only the presence of certain BE features, but also the safety and environmental quality embedded in the BE, especially for older adults (Yen et al. 2014; Moran et al. 2014).

Both Geographic Information System (GIS)-based assessment tools such as the walkability index (Frank et al., 2010), and survey instruments such as Neighbourhood Environment Walkability Scale (NEWS) and the International Physical Activity Questionnaire-Environmental module (IPAQ-E) are widely adopted. As such, most of the studied BE features were measured both objectively (based on GIS or environment-audit) and subjectively (based on surveys or interviews). In the reviewed studies, 46.2% used objective GIS-based measures, 35.9% used subjective survey-based measures, and 17.9% combined both. Fisher's Exact Test was applied to examine whether articles that adopted objectively measured BE features were more likely to report insignificant results than articles that only used subjective measures of perceived BE features. No significant difference was found between the objectively measured BE and subjectively measured ones in reporting a significant or insignificant result (two-sided exact significance = 0.434).

Types and measures of activities in older adults

Though this chapter intends to capture a broad range of activities for older adults, the results showed that most of the measures of activities in the selected studies capture different aspects of physical activity (Table 2.3). Total levels of walking and physical activities (PA) were most commonly analyzed. Studies also examined PA with various levels of detail, including different motivations for walking (transportation or recreational), subgroups of physical activities (leisure time physical activity [LTPA] or moderate-to-vigorous physical activity [MVPA]), whether the activity levels fulfilled the recommendation of 150 minutes per week of MVPA, and the time and frequency being active or inactive outdoors. Beyond this, a few studies examined social activities, including social participation or civic engagement, social interaction and social support, in relation to the BE and healthy aging (Clarke et al 2011, Cerin et al. 2013, Mowen et al. 2007).

However, other types of economic, cultural, and spiritual activities were not discussed in the selected articles.

Meanwhile, 78.2% of the studies measured multiple health conditions of the older adults and these measures were often used as covariates. Obesity, physical functioning, and psychological factors, such as self-efficacy for walking, were commonly investigated in relation to the BE and activity participation in older adults. There are 86.2% of the studies used questionnaires to obtain self-reported or self-rated activities, 7.4% used objective measures (for example, using an accelerometer) and 6.4% combined both objective and subjective self-reported variables. Many research projects used specially designed questionnaires, while a few adopted International Physical Activity Questionnaire (IPAQ), and others obtained data from transportation surveys.

Table 2.3 Frequency of activities studied in selected articles

Activity types	**N**	**Health-measures**	**N**
walking (total)	26	obesity (BMI/waist circumference)	29
walking for transportation	17	multiple chronic conditions	11
walking for recreation	14	functional limitations of daily living	19
physical activities (PA) (total)	20	mobility levels (measured)	4
leisure-time physical activities (LTPA)	10	use of assistive devices	5
moderate-to-vigorous physical activities (MVPA)	14	psychological factors (self-efficacy/ fear of fall)	12
meeting recommendations	16	self-rated health/ satisfaction of health	13
homebound (mobility going outdoors)	10	general health status (measured)	8
inactive (sedentary time/ TV viewing)	7	quality of life (perceived)	4
cycling	4	cognitive status (cognitive impairment)	7
active use of facilities (parks/transit)	2	depression (depressive symptoms)	4
social participation (social interaction)	3	healthy lifestyle (smoking/alcohol-use)	12

Note: N= number of studies measured this type of activity. This table did not distinguish overall walking and within neighbourhood walking, but the difference was noted in the flowing sections on the identified relations and the variation of results.

2.3.3 Relationships between the built environment and activity participation

Previous studies highlight the mix of empirical evidence, the modest statistical associations, and underexplored nonlinear relationships between the BE and older adults' activities and health (e.g. Van Cauwenberg et al. 2011; Yen, Michael, and Perdue 2009). Therefore, instead of attempting to generalize specific empirical results or summarize

results of all statistical models, this chapter maps the important links identified in the reviewed articles by investigating the authors' interpretations of important findings (Figure 2.3). It is important to note that because many BE features are interrelated and BE measures tend to have high correlations with each other, most empirical studies adopted techniques to group different measures of the BE. Some used factor analysis or principal component analysis to generate a new set of variables to represent distinct aspects of the BE; some combined all the measures into a single index to represent overall walkability; some divided the neighbourhood BE into categories such as highly walkable, walkable or non-walkable. As a result, walkability, as an integrated measure, was most intensively analyzed in relation to activity participation for healthy aging.

Generally, strong associations between walkability and the total levels of walking and MVPA are found. Related to this, the availability of pedestrian infrastructure, sidewalk conditions, and street-connectivity generally showed a positive impact on older adults' walking activities. However, results showed that BE features that are positively associated with older adults' higher levels of activity may have limited effect on changing the behaviour patterns of older adults who stayed inactive (Nagel, Carlson, Bosworth and Michael 2008; Ribeiro, Mitchell, Carvalho, and de Pina, 2013). Also, results of intervention-based studies showed that walkability had no significant effect on the change of walking behaviour among older adults over time, and self-efficacy for walking was identified as a more important mediator of the intervention to promote walking among sedentary older adults than neighbourhood walkability (Michael and Carlson, 2009). Similarly, Curl, Ward Thompson, and Aspinall (2015) reported that the change of street design did not result in more time and frequency outdoors for older people. Nonetheless, other studies showed that lower levels of land-use mix (less availability of a variety of destinations) are associated with higher chances of older people being inactive or homebound (Barnett et al., 2015; Murayama et al., 2012; Rosso et al., 2013). Also, heavy traffic in the neighbourhood is related to a higher chance of inactivity (Shibata et al., 2015; Hsueh et al., 2016).

Table 2.4 Associations between BE features and activity participation

BE features	Walking (total)	Walking for transport	Walking for recreation	PA (total)	LTPA	MVPA	Meeting recommenda-tions	Active use of facilities	Less likely to be inactive	Less likely to be home-bound	Cycling	Social participation
green spaces (parks) 12(+)	3 (+)		1 (+)	3 (+)	2 (+)		2 (+)	1 (+)				
land-use mix (10+,1-, 1NS)		4 (+)	1 NS	1 (+)		1(+)1(-)		1 (+)		2 (+)	1 (+)	
Connectivity (intersection) (8+, 2-)	2 (+)	3 (+)		2 (+)			1(+) 1 (-)	1 (-)				
(residential) density (6+, 1-, 1NS)	2 (+)	2 (+)	1NS				1 (+)				1(+), 1(-)	
Walkability (20+, 6NS)	6(+);2NS	3 (+)	1 (+)	1 (+)	2 (+)	5 (+)	1NS	1 (+)	1(+); 2NS		1NS	
Aesthetics (6+)	2 (+)	2 (+)	1 (+)			1 (+)						
proximity (to services) (11+)	1 (+)	3 (+)		1 (+)	2 (+)	1 (+)		1 (+)			1 (+)	1 (+)
Accessibility (2+, 1NS)	1 (+)	1 (+)					1NS					
Absence of physical barriers (3+, 1NS)		1 (+)	1 (+)						1 NS	1(+)		
commercial (grocery/mall/retail) (6+, 1NS)	3(+),1NS	1 (+)	1 (+)						1 (+)			
recreational facilities (7+, 1NS)	3 (+)	1 (+)	1 (+)		1 (+)		1NS		1 (+)			
community centers/ resources (5+)	1 (+)	1 (+)		1 (+)	1 (+)				1 (+)			
healthcare (clinics/pharmacy) (2+, 1-)	2 (+)						1 (-)					
(walking/cycling) infrastructure (9+, 2NS)	1 (+)	2 (+)	2 (+)	1 (+)	2 (+)		1NS	1NS			1 (+)	
transit stations (bus stops) (5+, 1-)	3(+);1(-)						1(+)				1 (+)	
sidewalk conditions (7+, 1NS)	1 (+)	1 (+)	1 (+)		2 (+)		1(+)	1NS				1 (+)
traffic (high volume) (4-)	1 (-)								2 (-)			1 (-)
perceived safety (8+)	2 (+)	1 (+)	1 (+)			1 (+)			2 (+)		1 (+)	
crime rate (objective) (1-, 2NS)	1NS				1NS	1 (-)						
social support (cohesion) 5(+)				1 (+)	2 (+)	1 (+)			1(+)			

Note: All selected articles are included. 1 (+) = significant positive relations emphasized by 1 article; 1 (-) = significant negative relations emphasized by 1 article; 1NS = association proved to be insignificant and emphasized by 1 article; this table only included BE features that were identified significant in more than 1 article.

An interesting contrast between the results of transportation-related and recreational activities can be observed: urban-form characteristics such as land-use mix and proximity to services showed stronger associations with walking for transportation than recreational

walking (e.g. Hirsch et al. 2014). In comparison, recreational activities such as recreational walking and LTPA were more likely to associate with the availability of amenities, such as basic infrastructure and better sidewalk conditions. Despite the fact that psychosocial factors were found to have an insignificant impact on walking for transportation or MVPA, a positive association was observed between walkability and recreational walking in older adults with high self-efficacy for walking (Van Holle et al., 2015). Similarly, the importance of social support and social cohesion for LTPA was noted by Giehl et al. (2012) and Gao et al. (2015).

Moreover, a few studies examined the interactions between the BE and socioeconomic or psychosocial factors and their impact on older people's activity participation. Results indicated that though a walkable BE is positively associated with PA for older people regardless of income levels (Winters et al., 2015), older people who scored higher in psychological factors tended to benefit more from an activity-supportive BE (Carlson et al., 2012). Further, psychological factors, such as self-efficacy for walking, were identified as significantly mediating the association between neighbourhood walkability and recreational walking, but not between neighbourhood walkability and walking for transportation or MVPA (Van Holle et al., 2015).

There was a general lack of studies examining the relationship between the BE and bicycle use by older adults. Nonetheless, studies in Asian and European contexts highlighted the positive impacts of a compact urban form (in terms of relatively high density and diversity of land use) and the infrastructure on active transportation (Van Cauwenberg et al., 2012; Zhang, Yang, Li, Liu, & Li, 2014). While no significant association was identified in relatively low-density contexts in the U.S. (Gell et al. 2015; Takahashi et al. 2012). In the Netherlands, however, Kemperman and Timmerman (2009) reported that older adults in lower-density urban areas tend to bike more and the number of bike riders is positively associated with higher education and income levels.

Although the health benefits of staying active for older adults are well-documented and the impacts of the BE on older people's physical activity and health outcomes are widely examined (Kerr, Rosenberg, and Frank 2012), few studies holistically explain the

synergies and interrelations between the BE, older adults' activities, and health outcomes. This is partly because of the complexity of interactions between related factors (Carlson et al., 2012). Nonetheless, a few longitudinal studies have examined the long-term benefit of walkable BEs on cognitive decline, functional loss, the incidence of diabetes, change of blood-pressure, and Body Mass Index in the aging process (Clarke et al. 2015; Balfour and Kaplan 2002; Christine et al. 2015; Li, Harmer, Cardinal, and Vongjaturapat 2009; Li, Harmer, Cardinal, Bosworth, et al. 2009).

In addition, a growing body of literature in recent years has investigated the mediating or moderating effects of various aspects of the BE, PA, health outcomes, psychological factors and socio-economic status. Recent studies reported that walking, especially walking for transportation, and MVPA mediate the association between neighbourhood walkability and obesity, and a stronger mediating effect was found in lower-income neighbourhoods (e.g. Carlson et al., 2016; Van Cauwenberg et al., 2016). Interestingly, car-ownership and driving status were also identified as potential moderators of the BE and activity participation, as stronger associations were observed between neighbourhood BE features and the participation of physical activities and leisure walking among older adults who drive, controlling for demographic characteristics, health status and physical performance (Cerin et al. 2016; Ding et al. 2014)

2.4 Discussion

2.4.1 Variation of findings

Contextual differences

The selected studies shared a general assumption that a walkable BE with a relatively high density, variety of accessible services and amenities, good quality of design, and infrastructure to support active transportation can promote healthy aging. Yet, there were findings that challenged the conventional assumptions of an age-friendly environment. For example, land-use mix was negatively correlated with leisure-time MVPA in a South African context (Kolbe-Alexander, Pacheco, Tomaz, Karpul, & Lambert, 2015). Access to public transit was negatively associated with walking-levels in a rural Japanese context

(Tsunoda et al., 2012). High connectivity was associated with lower rates of adequate walking and active park use in the Latin American context (Gómez et al., 2010; Parra, Gomez, Fleischer, & David Pinzon, 2010).

Given the fact that the importance of different aspects of the interrelated BE features varies across contexts, it is important to investigate reasons for the variation rather than assuming a linear relationship between BE measures and activity levels. For instance, high connectivity and land-use mix in overcrowded cities may be associated with high volumes of traffic and low levels of pedestrian safety, which may in turn strongly discourage older people's outdoor activities. In addition, walkability measures were not significantly associated with higher levels of activities in a context where there is a general lack of access to services within walkable distance (Takahashi et al. 2012). Whereas strong associations were identified between walkability measures and activity levels in compact Asian cities, such as Hong Kong, where older people reported many more walking activities in their everyday lives (Cerin et al. 2013).

Recent empirical studies showed that more significant impacts of the BE can be observed when comparing neighbourhoods with distinct BE profiles (ones that are dense, walkable and have good access to transit and recreational facilities at the same time versus ones that non-walkable and have limited access to services for example). Also, a combination of favorable BE features and related social environment features, rather than separated BE measures, can capture the important role of the BE in the promotion of healthy aging (Troped et al. 2014; Todd et al. 2016; Van Holle et al. 2016). However, despite the fact that the analysis of neighbourhood BE profiles tends to generate more significant results in statistical analysis, such results may be even more difficult to compare and to use to inform planning interventions.

The effect of spatial scale

Defining the boundaries of neighbourhoods remained a challenge in effectively analyzing and comparing empirical results. Various spatial scales of neighbourhoods were used: survey-tools often defined a neighbourhood as the participants' surrounding environments, e.g. within 15 to 20 minutes' walk. GIS-based measures often used buffers

or network buffers from participants' home addresses to define their neighbourhood, with the radii of buffers ranging from 100 meters to 1500 meters (with 400 meters and 800 meters used most frequently). Studies that considered the effect of spatial scale emphasized the importance of the immediate neighbourhood environment, as a large portion of older adults' physical activities were at home, immediately close to home, or within their neighbourhood (Cerin et al. 2013; Chaudhury et al. 2015). Also, high levels of social participation were associated with greater perceived proximity to services (Levasseur et al., 2011) and the incentives the BE provided for walking diminished when favorable BE features were perceived to be further away (Van Cauwenberg et al., 2013).

Notably, the importance of different BE features varies with spatial scale. It was reported that the availability of services within 400 meters and the pedestrian infrastructure within 800 meters were significantly associated with walking (Nathan et al. 2012). Furthermore, the effect of spatial scale varies with different types of activities. For example, social activities (e.g. in-person social interactions) and receiving health care had stronger associations with BE features at the fine-grained block-group level for older adults with disability, while voting was associated with BE features at the larger census-tract level (Clarke et al. 2011). Nonetheless, some BE features such as walkability were reported to be associated with more walking for exercise across spatial scales (Berke et al. 2007b).

Objective versus subjective measures of BE features

Studies that analyzed both perceived and objective BE features reported very limited agreement between the two types of measures (Michael et al. 2006; Mowen et al. 2007). Therefore, it is problematic to generalize research findings without examining the measuring details. For example, two recent studies analyzed objective data on crime rates and found that crime was not an important factor affecting older adults' outdoor activities (Gell et al., 2015; Ribeiro, Pires, Carvalho, & Pina, 2015). However, other studies identified crime as a significant factor by analyzing crime signage and perceived safety from crime (Barnett et al., 2015; Strath et al., 2012). The seemingly inconsistent findings may not be contradictory, as individuals' perceptions of safety from crime may differ from the actual crime rate of the neighbourhood. Therefore, a deeper understanding of what each

BE measure actually captures is necessary for interpreting and comparing results. It is also important to note that the safety factors may not be emphasized by the authors when safety is not an obvious concern in the built environment. However, it is reported that safety moderates the association between BE features and older adults' participation of outdoor activities, as it is likely to be a precondition for older adults to use public spaces (Yen, Flood, Thompson, Anderson, & Wong, 2014). Yet, the perception of safety, as well as many other socio-psychological factors, is difficult to measure and compare among individuals and across neighbourhoods.

In general, objective BE measures can better capture planned urban form features and subjective BE measures can reflect participants' own perspectives of the BE, thereby highlighting the barriers and motivators of activities for older adults. Increasingly, studies have used non-overlapping subjective and objective measures to assess different aspects of BE features (Nyunt et al., 2015). Yet, the existing variation of both objective and subjective BE measures used in different studies make it difficult to compare results.

Variation in the aging population and changes in the aging process

Gender difference was noted multiple times in the selected articles. For example, Berke, Gottlieb and colleagues (2007a) identified walkability is associated with depressive symptoms in older men but not in older women. Further, cultural differences can have a strong impact on older people's perception of the BE and attitudes towards healthy aging (e.g. Bird et al. 2009). These cultural differences may relate to BE characteristics in different geographic contexts and the lifestyle one develops in these contexts over the life-course. Moreover, the perceived barriers of older people change during the aging process and the identified important BE features may not be significant for the same population in later years (Ståhl, Horstmann, & Iwarsson, 2013). It is important to remember that the aging population is highly diverse. Though socio-economic factors and covariates of health conditions can be statistically controlled with adequate sample size, the variations of BE features' impact on activity participation in different subgroups of older adults, and how the impact changes in the aging process, remain under-explored.

2.4.2 Knowledge gaps

Through the quantitative content analysis, it was possible to sift through a variety of studies to identify the BE features that were intensively emphasized as important factors for healthy aging, such as the availability of green spaces and parks, proximity to services, infrastructure for active transportation, and overall walkability. The research findings also showed that frequently used BE measures showed much stronger associations with transportation related activities than other types of activities for older adults.

There are clear knowledge gaps in the interdisciplinary research of the BE's impact on activity-participation for healthy aging. Despite an increase of studies in various geographical regions, a large proportion of the empirical studies were conducted in the U.S. and focused on urban or suburban settings, it is questionable whether the existing empirical findings can be effectively compared across geographical contexts, especially among places with drastically different densities and accessible amenities. In addition, more than 96% of selected studies focused on outdoor BEs, with an emphasis on the neighbourhood scale. There is limited work examining activity spaces and indoor activities. This is partly because the conceptualization of BE (e.g. Handy et al. 2002) has focused on public spaces where planning interventions can be developed. Also, most studies focused on outdoor physical activities such as walking and exercising and very few examined other types of activities, such as socializing and volunteering.

However, the reviewed studies show that a set of urban-form features, including the coverage of green spaces, walkability, density and proximity, has been commonly identified as important for healthy aging, and the objective measures of these urban-form features have been well established. Standardized perceived measures have also been widely applied, especially the survey instrument NEWS and its context-specific variations. In contrast, relatively few studies measured micro-scale BE features or compared macro-level contextual differences of the BE. Particularly, the measure of design quality or perceived safety has often restricted to a very general rating of the overall aesthetics or safety from crime/traffic, but limited evidence is available to guide urban design interventions and improve the design quality and the sense of safety for older adults.

At the same time, though most studies identified statistical associations between BE measures and levels of physical activity, limited details can be drawn from the empirical findings to inform planning interventions. Because the statistical methods have often been restricted to testing the significance of associations between a type of neighbourhood environment (such as walkable versus non-walkable) and the activity participation in older adults, without identifying the effect of changes in a specific BE measure on activity-participation. This can be attributed to the fact that many BE measures are strongly correlated and there is limited understanding on the interactions between BE features.

The well-established urban-form measures can potentially provide comprehensive indicators of the BE and capture contextual differences effectively, however, inconsistent results were found in studies examining the effects of urban-form features, especially land-use mix and connectivity, on activity participation (Figure 2.3). One possible explanation is that the relationships between BE features and older people's activity-levels are nonlinear and there may be tipping points at which increased land-use mix and connectivity create overcrowding and reduce the likelihood for older people to be active outdoors. Therefore, to test the hypothesized nonlinear relationships and generalize empirical findings, it is necessary to explore the interactions between different BE features, and to establish a systematic comparison of the neighbourhood BE profiles across geographical regions. Moreover, the statistical results need to be linked back to the actual BE measures, in order to provide insights on how much change in a specific BE feature can significantly affect the associations between the BE and activity participation in a given context.

Despite an increase of longitudinal studies, there is a lack of empirical evidence on how the relationships between the BE and activity participation change in the aging process. As older people's mobility levels change in older age, their life-spaces and experiences in a neighbourhood or in a residence also change. A few studies adopted ecological models and socioecological models to conceptualize the influences of physical and social environment on people's behaviours (e.g. Van Cauwenberg et al. 2013). Yet limited studies examined how the meaning of healthy aging changes over the life course and how the impact of different BE features at different scales or in different settings (such as aging in community or in assisted living residence or in institutional settings) on activity

participation changes accordingly. As a result, it is difficult to explain why walkability did not show a significant effect in encouraging more older adults to walk in intervention-based studies (Michael and Carlson 2009), even though it was commonly identified as a significant BE feature influencing older adults' total levels of walking in cross-sectional studies. Nonetheless, theoretical models in gerontology, such as the ecological theory of adaptation, provide conceptual frameworks to understand interactions between the environment and the aging person and older people's adaptation to the environment in the aging process (e.g. Nahemow et al. 2016). In addition, many studies measured BE features with arbitrary distance thresholds (such as a 400-meter buffer), while detailed measures of older adults' activity space and the BE features they interact with, are particularly important for analyzing the BE's impact on activity participation and healthy aging.

2.4.3 A planning perspective

Empirical evidence in the literature raised two distinct questions that need to be addressed by planning policies: how to encourage inactive older adults to participate in outdoor activities, and how to increase activity participation among active older adults through planning interventions on the BE. Existing studies showed that lower traffic volume, perceived safety of the BE (which is also related to individual psychological factors), and social support can reduce the chance of being inactive. The characteristics of a compact urban form including higher density, better connectivity and closer proximity to services, can effectively facilitate walking for transportation and hence increase the total amount of walking and physical activities. The availability of transportation infrastructure for walking and biking and better sidewalk conditions encourage recreational walking and leisure-time physical activities. Despite all of this, BE features have limited impact on older adults' ability to meet recommended levels of physical activity. In addition, results of the literature showed that some BE features may be competing against each other. For example, higher street-connectivity may be associated with overcrowding and therefore reduce the effect from an increase in perceived safety from traffic (e.g. Gómez et al. 2010). Driving may be associated with less use of transit-use or walking for transportation, but increased recreational walking or leisure-time physical activities (e.g. Ding et al., 2014). Ultimately, closer examination of the interactions between BE features (including safety and design

quality) is necessary to analyze and quantify the trade-offs in planning for an age-friendly environment.

Furthermore, incremental changes of the BE can have long-term impacts on older people's health outcomes for both active and inactive older adults (e.g. Christine et al. 2015; Clarke et al. 2015). Admittedly, the change of the BE through planning policies may not have direct influence on behaviour change, but in the long term, it can increase the options for the aging population to adopt a more active lifestyle.

2.4.4 Limitation of study

Although the relationship between the BE and the activity participation for healthy aging has been intensively discussed, most of the existing reviews of the relevant empirical evidence has been conducted in the research fields of health and gerontology. This chapter aims to integrate a planning perspective and examine the BE features studied in relation to activity participation and healthy aging, and the framework of a scoping review is adopted because it provides the flexibility to include interdisciplinary research on a complex topic. Nonetheless, because of limited resources, this study did not conduct a detailed quality appraisal of the identified literature. In addition, this study did not include an extensive consultation exercise with key stakeholder groups, which is proposed as an optional stage of conducting scoping reviews by Arksey and O'Malley (2005).

2.5 Conclusion

This chapter analyzed the research scope and key findings of studies on the broad topic of the BE's impact on activity participation and healthy aging. It identified three main research gaps: 1) the lack of close examination of the interactions between different BE features, 2) the lack of detailed thresholds to guide planning interventions on BE features, and 3) the lack of understanding how the impact of the BE on older adults' activity patterns changes through the life course.

Further, with a structured overview of the empirical evidence, this chapter showed that it is important to understand how different aspects of BE features influences the activity-participation between different groups of older adults. Instead of assuming

planners can achieve a universally age-friendly built environment, researchers and practitioners need to develop a more nuanced understanding of the interactions between BE features and the thresholds for optimal changes to the existing built environments. The empirical evidence showed that compact built environments tend to have stronger impacts on transportation related activities than on recreational activities as well as stronger impacts for active older adults than for inactive ones.

Recognizing variations of the BE's impact on activity participation and healthy aging, this chapter highlights the need to understand the different types of built environments or neighbourhood contexts within which people age in place. Given the nonlinear relationships between urban form measures and older adults' activity participation and healthy aging, more informative evidence-based discussions can be generated by analyzing a variety of neighbourhood environments and developing thresholds of key BE features (such as of density, connectivity, and diversity) for different types of built environments that have distinct impacts on healthy aging.

This scoping study identifies the research need to compare across geographical regions based on a deeper understanding of contextual differences. The empirical part of this dissertation, therefore, starts with a macro-level analysis on the spatial pattern of aging in Canada at both the municipal scale and the neighbourhood scale. With census data at a fine-grained spatial scale, this dissertation provides a big-picture understanding of the different type of places where people age.

Moreover, addressing the need to examine variations in the aging population and in the aging process, this dissertation investigates two important aspects of these variations. First, it examines gender differences in mobility patterns over the life course. Second, it analyzes the differentiated activity participation between car-users and non-car-users over the life course. With the General Social Survey time-use cycle, a great variety of activities are considered in the analysis.

Chapter 3 Where do people age in place? Mapping spatial patterns of aging and population change in Canada

3.1 Introduction

The population of Canada has been steadily aging for decades. From 1971 to 2011, the median age of Canadians increased from 26.2 to 40.6, and the percentage of population aged 65 and over increased from 8.1% to 14.8% (Statistics Canada, 2011a). Similar to other developed countries, the increasing longevity combined with decreasing birth rates substantially increased the percentage of older adults in the total population in Canada. Yet at the same time, the Canadian population has been growing steadily because of high immigration rates (Beaujot and Kerr, 2004). Although the demographic statistics show concurrent trends of population growth and population aging at the national level, limited studies have examined the spatial heterogeneity of these demographic trends. Moreover, as suggested by the aging-in-place literature, older adults have strong preferences for remaining in the same community as they age (Wiles et al., 2012), and to avoid involuntary relocation can contribute to older adults' health and quality of life (Chui, 2008). To facilitate older adults' choice of aging-in-place and to plan for supportive environments for healthy aging, it is important to understand the spatial pattern of aging at a local scale. Because policies for aging-in-place are place specific, and the financing of housing, transportation, service and care largely depends on the local government.

It is widely acknowledged that population aging is spatially differentiated. Yet existing studies on the spatial pattern of aging often focus on different aspects of population aging and sometimes arrive at contradicting conclusions. Demographic studies pointed out that places with a high percentage of older people are often not where older population increases most, rather, they tend to be places where younger people continuously move out and relatively immobile seniors are left behind (e.g. Frey, 2011). Studies on elder migration suggest that older adults are highly mobile and many of them move, even multiple times, for amenity or assistance, such as to relocate in neighbourhoods where they have established social networks (e.g. Litwak, & Longino, 1987). While the aging-in-place literature emphasizes that a majority of older people prefer to remain in their own homes

as they age (e.g. Thomas & Blanchard, 2009), and therefore the spatial trend of aging-in-place is characterized by a majority of older residents aging in their own communities without moving.

It can be argued that all these demographic trends shape the spatial patterns of aging simultaneously, and that places that show a trend of demographic aging are very different. Places can be aging because of a substantial outflow of younger people, or a substantial inflow of older adults, or a high percentage of older residents remaining in the same neighbourhood as they age. To understand these different types of places that are aging, it is important to consider the change of age structure (such as the change of median age) and the change of population (such as the growth, decline, and moving of population) at the same time. Although various indicators, such as the percentage of people aged 65 and older, are commonly adopted to describe the aging trend of a place, few studies have analyzed this trend in relation to population growth/decline and moving. Hence, the different types of places that are aging (or different types of aging-in-place) are under-examined and under-theorized. This research gap further prevents a critical examination on the extent to which simplified indicators of aged or aging can represent the uneven geographies of aging and illustrate the relationships between aging and population change.

Therefore, this chapter analyzes the spatial pattern of aging in relation to population change at a local scale, and critically examined the different methods that are used to analyze the geography of aging. This helps to understand two foundational questions that have not been well understood in the aging-in-place literature – where do people age in place? How different are these places? Empirically, this chapter analyzes relationships between demographic trends of aging, moving, and population growth/decline across Canada, and further explores the spatial pattern of aging and population change by combining two distinct approaches. First, based on the aging-in-place literature, this study analyzes spatial patterns of median-age change, population growth/decline, and moving/non-moving at both the municipal scale and the neighbourhood scale. Second, it develops a spatial typology of aging based on the method of population aging matrix, which distinguishes four types of aging by intersecting the indicator of numeric aging (increase

of population aged 65 and over) and structural aging (increase in the percentage of population aged 65 and over) (Atkins & Tonts, 2016).

3.2 Methods to understand the geography of aging

3.2.1 Review of existing methods

Population aging is commonly defined as the increase of the proportion of older adults (often defined as people aged 65 and over) in the population of a given area (Moore, Rosenberg, and McGuinness, 1997). Complex and dynamic socioeconomic factors, such as birth rate and mortality rate, residential mobility, and the growth and decline of economy, influence the age structure of population at different scales and create highly uneven geographies of aging (Hodge, 2008; Davies & James, 2011). To control for the complex spatial heterogeneity, studies on demographic aging often conduct analyses at national, provincial or regional scale, with spatially aggregated data. Classic demographic models, such as life-tables, are developed mostly to capture the age-structure of population in a nation or a region, without examining the spatial aspect of aging (Preston, Heuveline, & Guillot, 2001).

Because of the under-developed methodology, many studies use simple indicators of age to measure and compare the level of population aging across geographical regions. Some commonly used indicators include median age, the percentage of people aged 65 and over, and the ratio of older adults to young adults or to working-age adults (e.g. Rogerson 1996; Moore and Pacey 2004; UNDESA 2013). As a single indicator alone can hardly capture the population structure of a geographical region, a growing number of studies interpret spatial patterns of aging by combining multiple indictors. Hence, they can obtain a balanced view of both the numeric aging – an increase of older population, and the structural aging – an increase in the percentage of older adults (Moore, Rosenberg, and McGuinness 1997; Walford and Kurek 2008; Atkins & Tonts, 2016).

At the same time, the aging-in-place literature often focuses on aging at the neighbourhood scale. The concept of naturally occurring retirement community (NORC) is widely used in aging-in-place policies to describe the spatial concentration of older adults (e.g. Bookman, 2008b; Scharlach, Graham, & Lehning, 2012). A neighbourhood is defined

as a NORC if more than 50% of its residents are aged 55 and over (Hunt & Gunter-Hunt, 1986). However, as the definition of NORC shows, the method to identify where people age in place relies on arbitrary thresholds and is not necessarily generalizable across urban and rural areas. With a broad definition, people age in place almost everywhere, yet the concept of aging-in-place has two main indictors: a high percentage of residents are aging, and they do not move to other neighbourhoods in the aging process. However, most existing studies on aging-in-place focus on qualitative discussions on residents' perceptions of aging-in-place (e.g. Chapin & Dobbs-Kepper, 2001; Cutchin, 2003; Wiles, Leibing, Guberman, Reeve, & Allen, 2012), and there is a lack of established method to quantify or measure aging-in-place.

3.2.2 A mixed approach

Focusing on the different types of aging-in-place at the local scale, this study explores the spatial pattern of aging across Canada with two distinct approaches to integrate multiple measures of population change and aging. First, this chapter maps a set of indicators of aging-in-place. The concept of aging-in-place includes two key components: aging and (not) moving (Davies & James, 2011). This study retrieves three sets of variables from census data: median age and the change of median age, percentage of non-movers, and percentage change of population. With these indicators, this study maps the spatial patterns of aging and population change across the country at municipal scale and analyzes the relationships between these indictors.

Second, drawing on the conventional definition of population aging (change in the proportion of population aged 65 and over), this study adopts the conceptual model of population aging matrix to map the spatial typology of aging (Atkins & Tonts, 2016). This method intersects two measures of aging – change in population aged 65 and over (numeric change), and change in the percentage of population aged 65 and over (structural increase), and develops four types of aging scenario. (1) A numeric increase and a structural decrease of older adults, indicating an inflow of younger population. (2) A numeric increase and a structural increase of older adults, showing a trend of steady aging-in-place. (3) A numeric decrease and a structural increase of older adults, indicating an aging trend driven by the

outflow of younger population. (4) A numeric decrease and a structural decrease of older adults, showing an aging trend led by stagnation or population decline.

Focusing on one metropolitan area, the method of population aging matrix proposed by Atkins and Tonts (2016) uses the absolute increase or decrease in the number or percentage of older adults as thresholds for the classification scheme. This study extends this method to examine aging across Canada by classifying each municipality based on the z scores of its changes in the population and the percentage of older adults. As such, for each municipality, the increase or decrease in each measure is relative to the national average. This method is more accurate for national wide comparison, as the total population and the absolute number of people aged 65 and over are growing each census year.

Furthermore, to understand the spatial pattern of aging-in-place at the neighbourhood scale beyond identifying individual NORCs, the spatial pattern of aging is explored with two variables (median-age change and percentage of non-movers) at the dissemination area (DA) level. The DA is the most fine-grained geographic unit, at which census data is available. It often includes a few street blocks, with a population range from 400 to 700 (Statistics Canada, 2011b). Although a DA is smaller than a census tract, which is a spatial unit similar to a conventional planning concept of neighbourhood, it is a spatial unit that enables comparison across the country, while census tracts only cover metropolitan areas. The local Moran's I, which measures the significant spatial clustering of similar or different values around a given location (Anselin, 1995), is used to explore the spatial clustering of aging neighbourhoods and stable neighbourhoods.

By combining two distinct approaches and exploring the spatial pattern of aging at different geographical scales, this chapter synthesizes the empirical findings on the spatial pattern of aging in Canada, discusses the advantages and limitations of each approach, and proposes research directions to improve the methods of analyzing the spatial pattern of aging.

3.3 Aging and population change at the municipal scale

3.3.1 Relationships between aging, moving and population decline

The Maritime Provinces (Nova Scotia, New Brunswick, and Prince Edward Island) and Newfoundland and Labrador along the east coast of Canada have highest levels of median age and highest percentages of population aged 65 and over. Yet the total population 65 and over in these four provinces is only about 54% of that in the Toronto metropolitan area (Table 3.1). The northern part of Canada is sparsely populated. Because of the small population size, the composition of local population in these areas can change sporadically. In addition, northern communities in the territories tend to have suppressed census data or missing data. Given the large variation in population distribution, analyzing population aging across the country is particularly challenging.

Table 3.1 Indicators of population aging in Canada

Geographical region	Median age	Population 65 and over	Population 65 and over %	Population change% (2006-2011)
Canada	40.6	4945055	14.8%	5.9%
Provinces				
Ontario	40.4	1878325	14.6%	5.7%
Quebec	41.9	1257685	15.9%	4.7%
British Columbia	41.9	688725	15.7%	7.0%
Alberta	36.5	405725	11.1%	10.8%
Manitoba	38.4	172450	14.3%	5.2%
Saskatchewan	38.2	153705	14.9%	6.7%
Nova Scotia	43.7	153375	16.6%	0.9%
New Brunswick	43.7	123630	16.5%	2.9%
Newfoundland and Labrador	44.0	82105	16.0%	1.8%
Prince Edward Island	42.8	22780	16.2%	3.2%
Yukon Territory	39.1	3095	9.1%	11.6%
Northwest Territories	32.3	2390	5.8%	0.0%
Nunavut	24.1	1060	3.3%	8.3%
Three largest metropolitan areas				
Toronto	38.6	706660	12.7%	9.2%
Montréal	39.7	559840	14.6%	5.2%
Vancouver	40.2	312900	13.5%	9.3%

At the municipal scale, the spatial pattern of age is fairly mixed within each province (Figure 3.1). Overall, municipalities along the west coast and east coast tend to be more aged. Although rural areas tend to be more aged than urban areas, there is no clear pattern indicating that remote areas are aged areas. Instead, both the densely populated metropolitan areas and the sparsely populated northern regions tend to have relatively low median age.

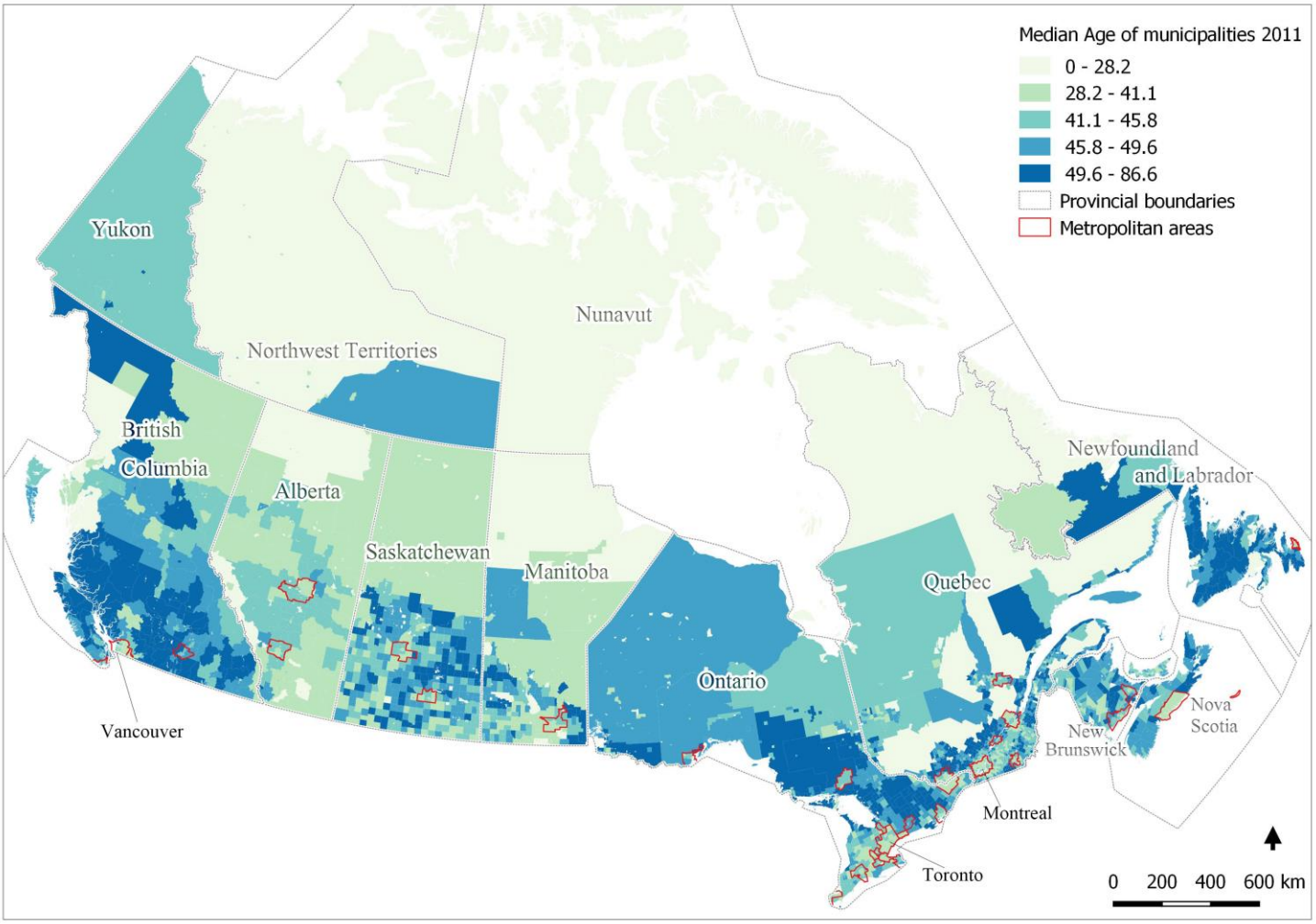


Figure 3.1 Median age of Canadian municipalities

Moreover, the population growth of the country is highly concentrated in the most populated metropolitan areas. According to the latest census data, Canadian population grew by 1,863,791 between 2006 and 2011, of which, only 5.3% is in rural areas, while 72.7% is in the 10 largest metropolitan areas. Particularly, 45.9% of the population growth is in the three largest metropolitan areas- Toronto, Montreal and Vancouver, and the

Toronto metropolitan area alone saw 25.2% of nation's total population growth. At the same time, among the 151 metropolitan and urban-agglomeration areas, 29 have shown decreases of population. Within the context of highly uneven population growth and decline, it is important to understand the spatial pattern of aging in relation to population change.

Data from census periods (2006-2011) is used to analyze the relationships between median-age increase, population growth/decline, and the moving of residents. It is often assumed that population decline is associated with the trend of younger population moving out and a high percentage of older residents staying and aging in place (Frey, 2011). Among Canadian municipalities, the correlation between median-age increase and the decrease in population is very weak (the correlation coefficient is 0.06). As the distribution of population growth is highly skewed towards a few fast-growing municipalities with large population sizes, such as Toronto, the percentage of population change is used in the analysis to control for strong variations in population size among municipalities. As shown in Figure 3.2, an increase in median age has weak negative correlation with the percentage of population growth (-0.292) and weak positive correlation with higher percentage of non-movers (0.250). Yet as some municipalities with small population experiences sporadic change, a few outliers shift the distributions of population change and median-age change substantially. After removing outliers (with values below or above 1.5 times of the interquartile range), the correlation between median-age increase and population decline becomes moderate (0.447), and the correlation between median-age increase and the higher percentage of non-movers remains weak (0.288). However, because of the large variation among municipalities, the number of outliers in the percentage of population change, median-age change, and the percentage of non-movers is 564, 264, and 41 respectively.

In addition, correlations between median-age change, the percentage of population change, and the percentage of non-movers at the neighbourhood scale are even weaker. Among all DAs in Canada, the correlation between median-age increase and the percentage of population growth is -0.15, and only -0.23 after removing all outliers. Also, the percentage of non-movers shows weak correlations with median-age increase (0.091) and

with the percentage of population growth (-0.10) at the neighbourhood scale, and these coefficients only change slightly after removing outliers.

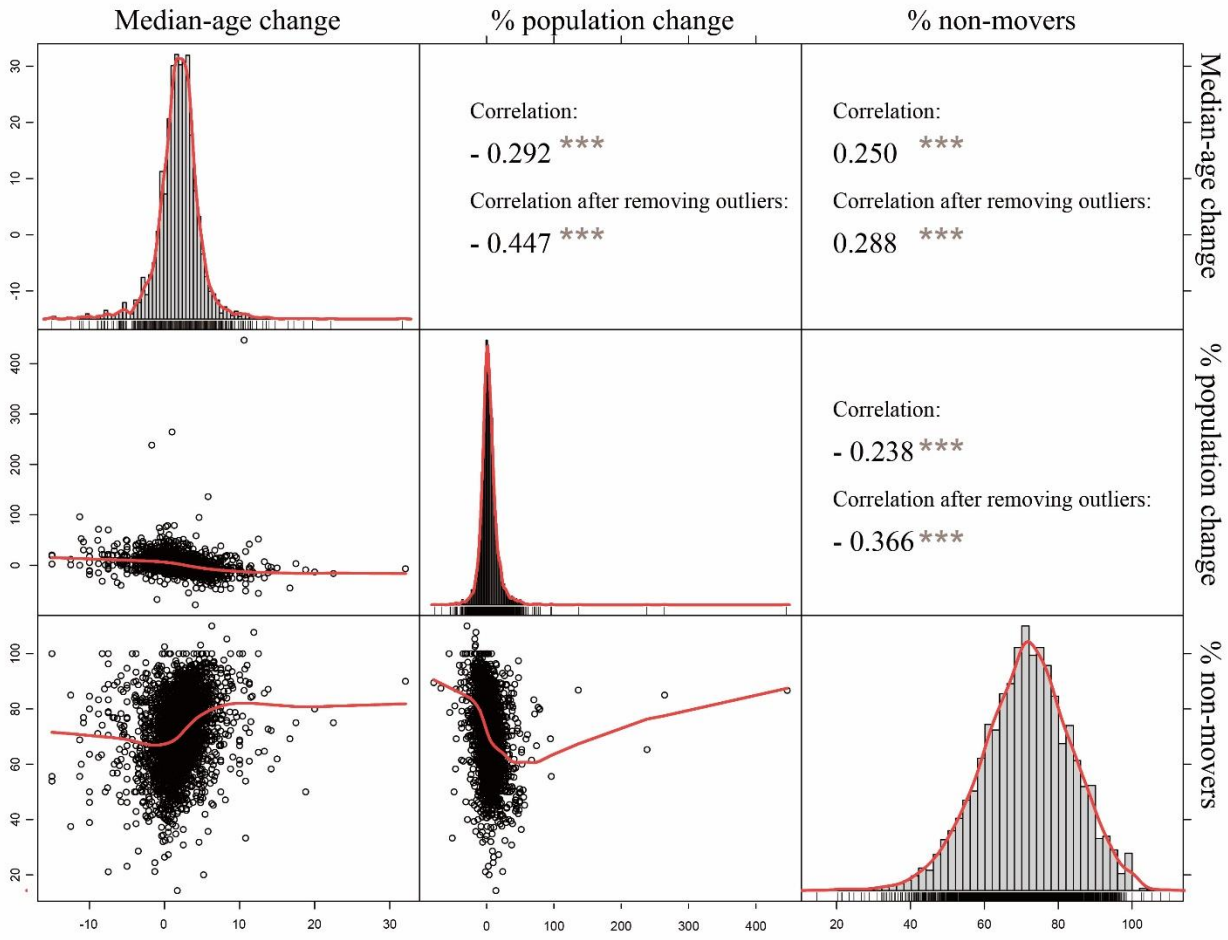


Figure 3.2 Relationships between aging and population change at the municipal scale

Because the analysis of demographic trends is sensitive to small municipalities with sporadic change of population, trends of median-age increase, population change, and percentage of non-movers in each municipality are examined over a longer period (from 2001 to 2011). Municipalities with continued population decline, continued high median-age increase (above national average), and continued high percentage of non-movers (above national average) are identified, and the geographical distribution of these municipalities is analyzed in Table 3.2.

Table 3.2 Percentage of municipalities with continued aging, non-moving and population decline

Percentage of municipalities by geographical area	% with continued high median-age increase			% with continued high percentage of non-movers			% with continued population decline		
	Metro (100%)	Town (100%)	Rural (100%)	Metro (100%)	Town (100%)	Rural (100%)	Metro (100%)	Town (100%)	Rural (100%)
Canada	9.2	21.3	24.9	9.8	13.7	24.0	5.3	15.0	27.7
By Province (cell percentage)									
Ontario	8.7	**25.0**	**29.1**	8.7	10.7	17.1	3.3	8.9	22.3
Quebec	7.0	**23.5**	**27.4**	8.9	**17.3**	**31.6**	4.5	**17.3**	25.4
British Columbia	**10.8**	17.5	20.1	5.4	3.6	8.5	4.1	10.9	14.8
Alberta	2.3	2.3	10.1	**11.4**	4.5	16.4	2.3	6.8	14.7
Manitoba	0.0	0.0	12.0	**50.0**	12.5	**26.6**	**8.3**	12.5	24.7
Saskatchewan	**12.2**	4.0	13.3	4.9	4.0	19.3	**7.3**	8.0	**31.7**
Nova Scotia	0.0	**38.9**	**50.0**	0.0	**27.8**	**32.9**	0.0	**38.9**	**51.3**
New Brunswick	**29.0**	**46.7**	**51.8**	**16.1**	**44.4**	**34.0**	**19.4**	**35.6**	**40.1**
Newfoundland and Labrador	7.7	**40.0**	**56.3**	**15.4**	**46.7**	**47.1**	**7.7**	13.3	**58.6**
Prince Edward Island		17.4	**34.4**		8.7	**33.3**		**17.4**	**35.6**
Yukon		14.3	13.3		0.0	0.0		0.0	10.0
Northwest Territories			2.5			0.0			0.0
Nunavut			0.0			6.5			6.5

Note: All values are calculated as cell percentage. For example, 8.7% of municipalities in Ontario metropolitan areas showed continued median-age increase. Values above overall percentages in Canada are highlighted. Continued high median-age increase means above 3 and above 2.3 in periods of 2001-2006 and 2006-2011 respectively, and continued high percentage of non-movers means above 71.5% and above 71.7% in 2001-2006 and 2006-2011 respectively.

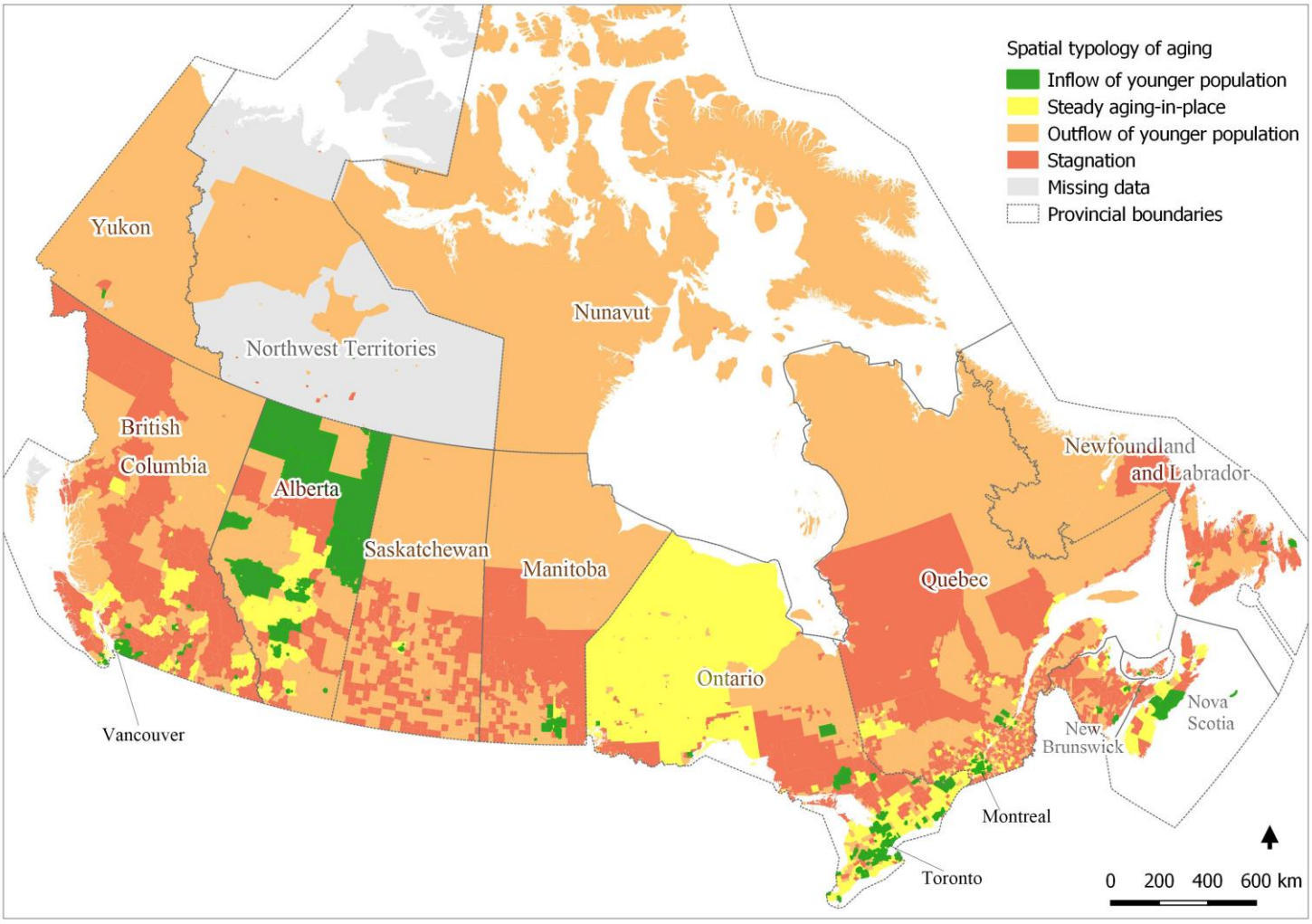
Across Canada, only 5.5% of municipalities experience continued trends of aging, population decline, and high percentages of non-movers simultaneously, yet 92.7% of these municipalities are in rural areas. Although only 9.2% of municipalities in metropolitan areas have continued high median-age increase, many municipalities close to metropolitan areas show trends of continued aging and population growth, especially in the southeast part of Ontario (close to Toronto) and the southwest part of British Columbia (close to Vancouver and Victoria). About 30% of these municipalities locate in Newfoundland and Labrador, and 27.8% of them locate in Quebec. In terms of land area, however, rural areas in northern Ontario stand out as places of steady aging and population decline.

High percentages of municipalities in the Maritime Provinces and Newfoundland and Labrador show trends of aging, non-moving and population decline, yet only New Brunswick has relatively high percentages of aging and declining municipalities in metropolitan areas. In the Prairie Provinces (Alberta, Saskatchewan and Manitoba), however, very low percentages of municipalities in rural areas and middle cities/small towns show continued aging. Among the three most populous provinces, middle and small size cities and rural areas in Ontario and Quebec tend to have high median age increase. In comparison, metropolitan areas in British Columbia show a much stronger trend of aging.

3.3.2 A spatial typology of aging

Given the difficulty in understanding the relationships between aging and population change and the need to conceptualize aging beyond a single indicator of age, this study maps the spatial typology of aging based on the conceptual model of population aging matrix (Figure 3.3). Further, it compares the characteristics of the different types of aging places, in terms of their geographical distribution, median-age change, percentages of non-movers and population change.

The spatial typology of aging provides a synthesis of complex interactions between population aging and population change (growth, decline and moving). Although this method only adopts two simple measures – the change in population aged 65 and over and the change in the percentage of population aged 65 and over, the results capture places with distinct characteristics in the change of median age, the change of population, and the level of residential mobility (Table 3.3).



Note: The missing data is because of no population aged 65 and over is shown in census data, which may be a result of suppressed data in municipalities with small population size.

Figure 3.3 A spatial typology of aging

This classification scheme helps to visualize how the different demographic trends shape the spatial pattern of aging. It also provides insights on the primary demographic trend in a specific municipality. In particular, this method distinguishes steady aging-in-place and stagnation. Both types of aging have high increase of median age, yet places showing stagnation (such as municipalities along the east coast) shows simultaneous trends of aging and population decline (relative to the national growth). Places characterized by steady aging-in-place have population growth and high median age increase at the same time. Interestingly, places characterized by outflow of younger population do not show

high increase of median age. This can be partly explained by the fact that many of these places have high birth rates, which can result in low median age increase even when working age young adults are moving out.

Table 3.3 Descriptive statistics of municipalities by the type of aging

Municipalities by type of aging and by population-size	Geographical distribution		Change in median age (2006-2011)		Percentage of non-movers (2006-2011)		Population change (2006-2011)	
	Count	%	Mean	S.D.	Mean	S.D.	Mean	S.D.
Type 1. Inflow of younger population	**197**	**100%**	**0.86**	**1.08**	**58.98**	**8.75**	**5735**	**12704**
Metropolitan areas	115	58%	0.77	1.04	58.88	7.79	8675	15888
Town	37	19%	1.08	0.93	55.10	8.46	2554	3222
Rural	45	23%	0.93	1.29	62.52	10.02	834	847
Type 2. Steady aging-in-place	**479**	**100%**	**2.55**	**1.11**	**67.33**	**7.51**	**899**	**3480**
Metropolitan areas	133	28%	1.96	0.97	67.53	6.10	2583	6167
Town	114	24%	2.49	1.03	64.18	8.16	436	1345
Rural	232	48%	2.93	1.07	68.91	7.46	160	405
Type 3. Outflow of younger population	**2532**	**100%**	**0.82**	**3.52**	**69.86**	**13.25**	**48**	**275**
Metropolitan areas	124	5%	0.38	3.02	64.94	12.55	204	793
Town	181	7%	0.68	2.75	65.65	11.47	169	484
Rural	2227	88%	0.86	3.60	70.53	13.32	29	171
Type 4. Stagnation	**2017**	**100%**	**3.33**	**2.91**	**75.22**	**12.10**	**-18**	**113**
Metropolitan areas	97	5%	2.84	2.35	71.02	10.41	32	120
Town	126	6%	3.00	1.85	74.08	9.49	3	120
Rural	1794	89%	3.38	3.00	75.59	12.34	-22	111
Canada			**2.10**	**3.23**	**71.08**	**12.66**	**313**	**3599**

Despite overall consistency, this result highlights some spatial patterns of aging that are missing from or different from the above findings. For example, the northern parts of Alberta (the regional municipality of Wood Buffalo and surrounding areas, which host vast oil sand deposits) stands out as places with inflow of younger population. Though these places are sparsely populated, the mining industry is likely to attract working age adults and hence show a demographic trend characterized by inflow of younger population. Also, this analysis shows northern parts of Ontario as steady aging-in-place instead of stagnation, while continued population decline is observed in this area. Given that this analysis uses age 65 as a single age threshold, a decline in total population counts is not necessarily characterized by a trend of stagnation, if there is increase in older population.

With only two simple measures, this method is effective in synthesizing complex demographic trends that shape the spatial pattern of aging simultaneously. It also helps to identify the main demographic trends that shape population aging for each municipality, and to underscore geographical differences that need to be considered in local policies for aging-in-place. However, this method can be inaccurate when analyzing population aging at a neighbourhood scale across highly diverse geographical regions. The population composition of neighbourhoods often does not resemble the population pyramid of a city or region, instead, it directly relates to the household structures in the neighbourhood. Hence, the use of age 65 as a threshold can be problematic. For example, this method does not distinguish neighbourhoods with an increase of pre-retirement residents in their late 50s and early 60s from neighbourhoods with growing concentrations of young adults in their 20s. Moreover, neighbourhood-scale population composition can change significantly with new urban development, and this method cannot separate structural aging trends from sporadic changes led by new development.

3.4 Spatial patterns of aging at the neighbourhood scale

Because aging-in-place policies target at local neighbourhoods, it is important to understand aging at both the municipal scale and the neighbourhood scale. However, there is no established theory or method to effectively compare demographic trends at a neighbourhood scale across geographical regions. Based on the working definition of NORC, neighbourhoods that have 50% of residents aged 55 and over for 10 years are identified across Canada. Only 13% of these neighbourhoods are in rural areas and about 73% of them cluster in metropolitan areas, where population aging is not a prominent demographic trend at the municipal scale. As the population of older adults in metropolitan areas is substantially larger than that in small cities and rural areas, many neighbourhoods within these metropolitan areas are aging steadily, despite of the fact that most metropolitan areas have low median age and low increase of median age.

As the above analysis shows, the interpretation of where people age can vary significantly by the indicator of age or aging and by the scale of analysis. Hence, this study conducts a neighbourhood scale analysis based on the same set of variables and compares the results. As shown in Figure 3.4, the map of median age at the neighbourhood scale

provides a relatively accurate representation of aging in densely versus sparsely populated places. Overall, metropolitan areas appear to be centres of younger population, and the remote northern regions tend to have scattered communities with low median age. Places along the southeast coast and the southwest coast stand out as aged neighbourhoods. Zooming in to the metropolitan areas, the neighbourhood scale map provides a more nuanced understanding of the age pattern within densely populated areas. In the three largest metropolitan areas, both downtown centres and the outer fringes of the metropolitan areas tend to have low median age. These places also tend to be locations where substantial new developments happened. In contrast, the suburban areas and communities scattered around the metropolitan area often show high median age. Many of the aged suburbs are built during the post-war urban expansion.

Moreover, to understand where people age in place at the neighbourhood scale, this chapter uses local Moran's I to analyze and map the spatial cluster of aging neighbourhoods and stable neighbourhoods across Canada (Figure 3.5, Figure 3.6). A spatial cluster of aging neighbourhoods is identified when a neighbourhood with high median-age increase is surrounded by neighbourhoods with high median-age increase; similarly, a spatial cluster of stable neighbourhoods is found when a neighbourhood with high percentage of non-movers is surrounded by neighbourhoods with high percentage of non-movers. The distance threshold of surrounding neighbourhoods is defined as the closest eight neighbourhoods, instead of using a fixed distance bandwidth. Given that a fixed distance can generate incomparable results in urban and rural areas and the threshold of the closest eight neighbourhoods can approximately include the surrounding neighbourhoods in all directions and capture detailed local variations. This method also controls for variations in neighbourhood-size, because for each neighbourhood, the median-age change and percentages of non-movers are compared against its surrounding neighbourhoods, regardless of the geographic size of neighbourhood.

As shown in Figure 3.5 and Figure 3.6, large metropolitan areas show high concentrations of neighbourhoods that are getting younger. Although the downtown centres and parts of the inner city and/or inner suburbs are both clusters of neighbourhoods with low median-age increase, the inner city and/or inner suburbs tend to be clusters of

stable neighbourhoods with low percentages of people moving in. In comparison, with low median age increase and low percentage of non-movers, the urban centres stand out as spatial clusters where younger populations move in. The outer suburbs tend to age steadily, with high median-age increase and high percentage of non-movers.

Similar to findings from the municipal scale analysis, the coastal areas of the Maritime Provinces and Newfoundland and Labrador show high concentrations of neighbourhoods with high median-age increase and high proportions of non-movers, which indicate a trend of steadily aging-in-place. While in the Prairie Provinces, there are quite a few clusters of neighbourhoods with low median age increase in the rural areas and small towns. Notably, a few places are clusters of both aging neighbourhoods and neighbourhoods with low percentage of non-movers, such as some outer-suburbs north of the Toronto metropolitan area and some settlements along the east coast of Vancouver Island. These locations are likely to be receiving areas of amenity-searching older adults.

Nonetheless, the correlation between the Moran's I measures (the z scores) of the median-age increase and the percentages of non-movers for all the neighbourhoods is moderate (with a correlation coefficient of 0.2465). This indicates that spatial clusters of aging neighbourhoods are not necessarily stable neighbourhoods with residents steadily aging-in-place. Rather, as shown in above analysis, there is no clear linear relationship between aging, moving and population decline.

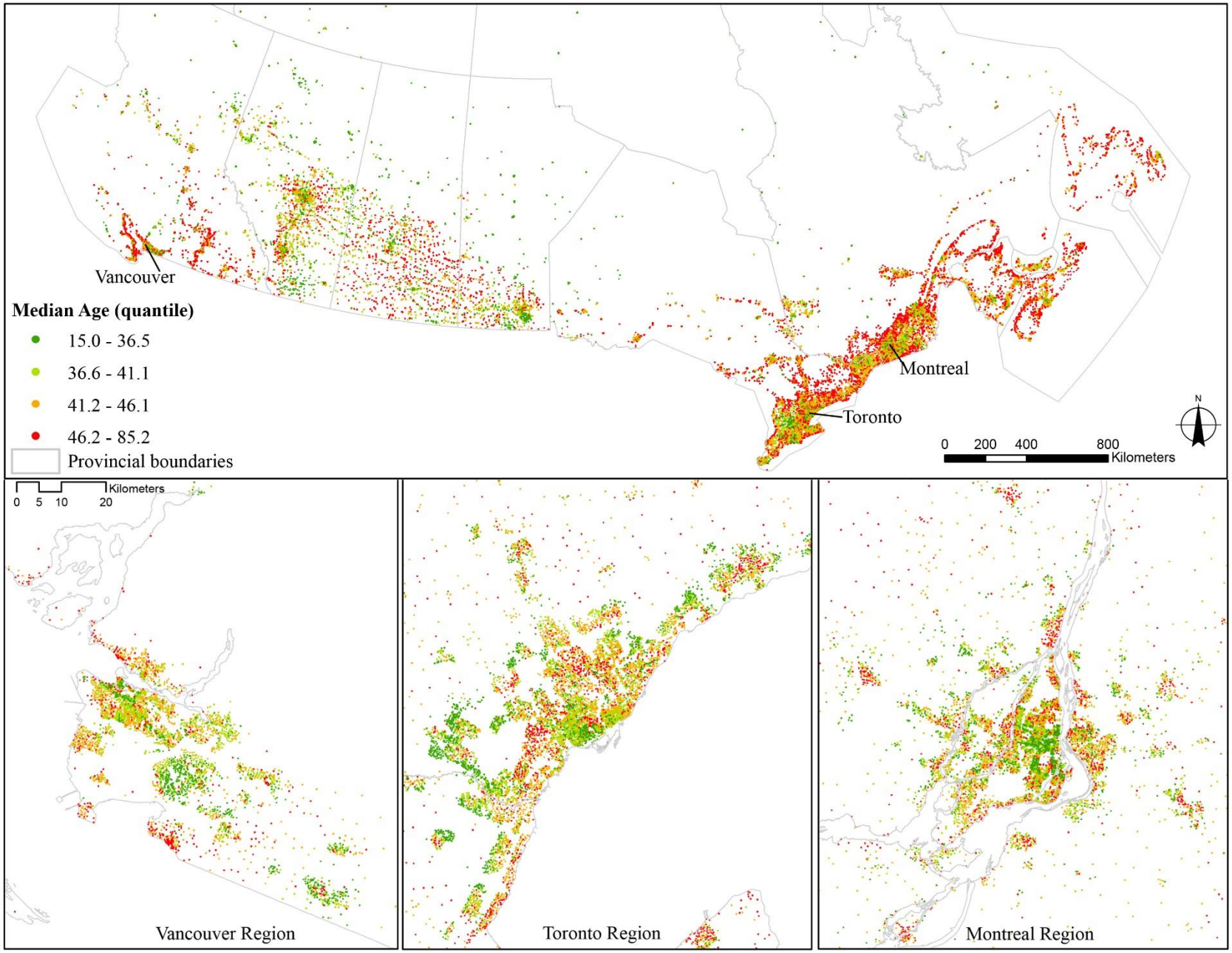


Figure 3.4 Median age of neighbourhoods

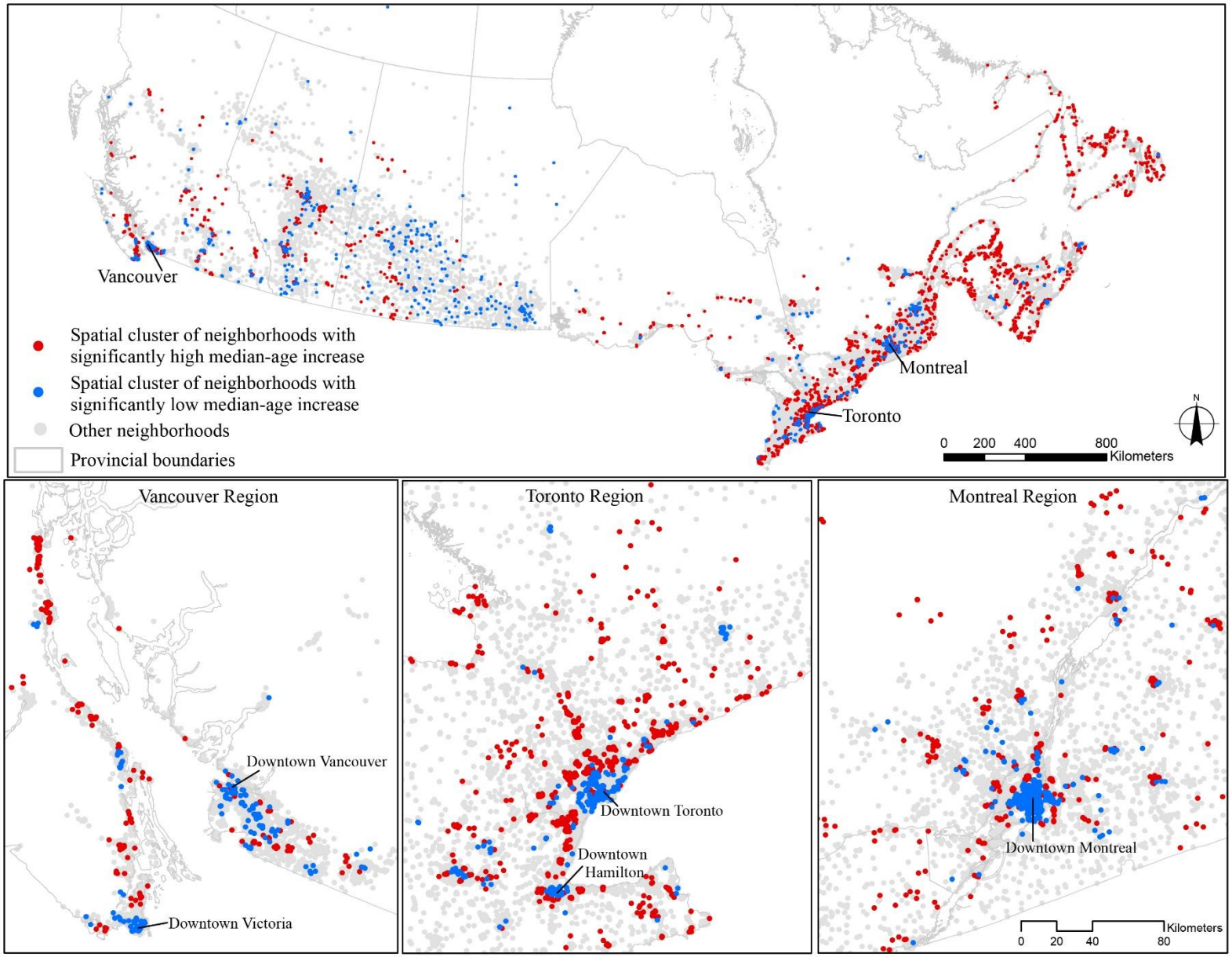


Figure 3.5 Hot and cold spots of median-age change

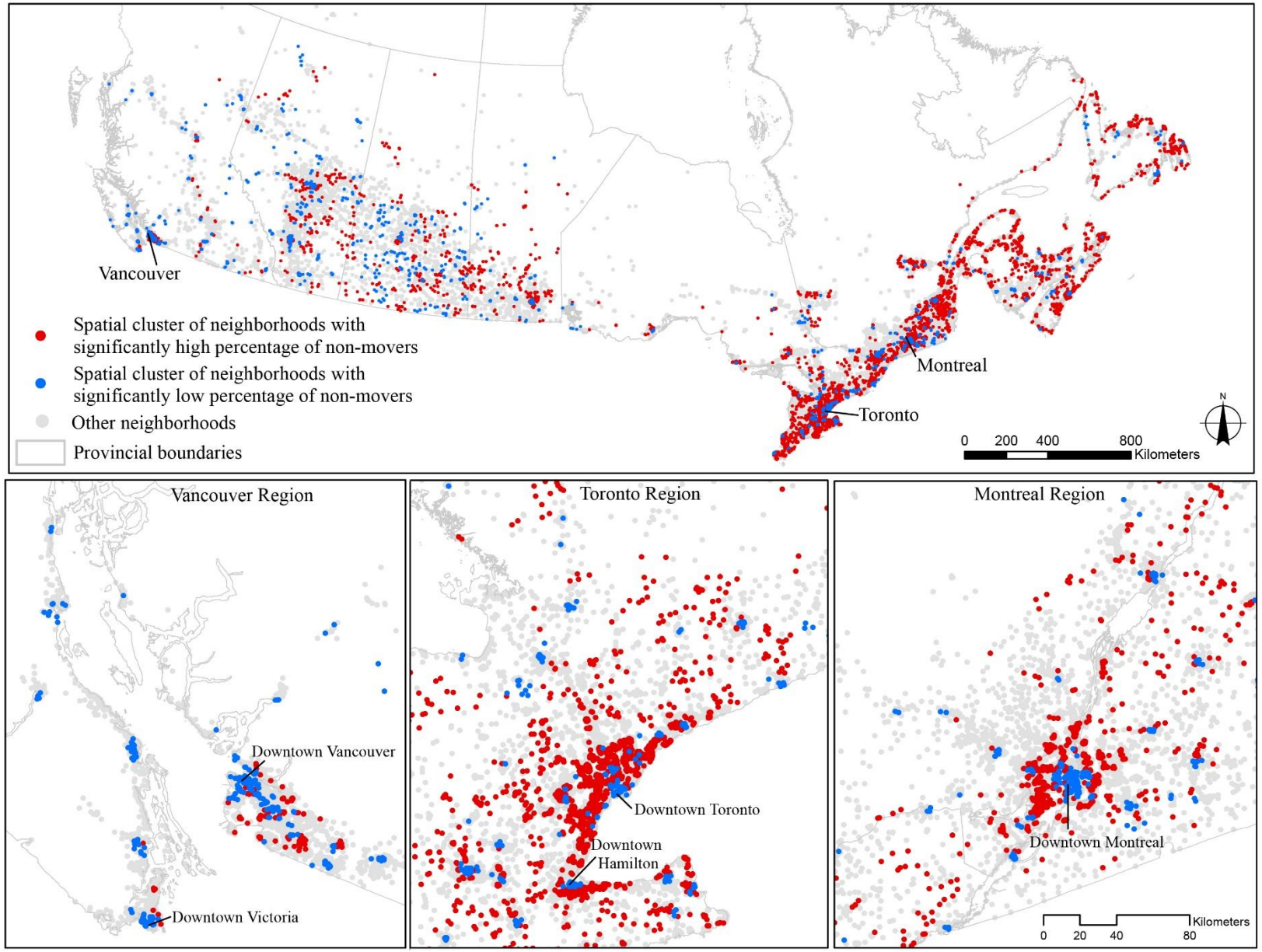


Figure 3.6 Hot and cold spots of stable neighbourhoods

3.5 Discussion

3.5.1 The spatial pattern of aging

This study combines two distinct approaches to carefully examine and interpret the spatial pattern of aging in relation to complex demographic trends of population growth and decline, moving, and aging-in-place. Across Canada, there are large variations in population density across geographical regions and highly concentrated population growth within a few metropolitan areas. The Maritime Provinces (Nova Scotia, New Brunswick, and Prince Edward Island) and Newfoundland and Labrador along the east coast of Canada have highest levels of aging. With high concentrations of neighbourhoods that have high median-age increase and high proportions of non-movers, many municipalities along the east coast are characterized by an aging pattern of stagnation – high median-age increase, high percentages of non-movers and declining populations. Nonetheless, the Halifax metropolitan area functions as a growing centre in this region, with inflow of younger population.

Though both densely populated metropolitan areas and sparsely populated remote northern regions tend to have relatively low median age, they have very different aging patterns. The metropolitan areas tend to have a growing number of older adults, but at the same time, their age profiles are driven by a more substantial increase in the younger population. The population of older adults in metropolitan areas is substantially larger than that in small cities and rural areas, and many neighbourhoods within the metropolitan areas are aging steadily, typically some inner city and/or inner suburbs built during the post-war urban expansion. Nonetheless, among the three most populous provinces, metropolitan areas in British Columbia show relatively strong trends of aging, which can be partly attributed to the fact that places along the east coast of Vancouver Island tend to attract amenity-searching older adults. Overall, rural areas are more likely to experience stagnation and outflow of younger population, and to show continued trends of aging, residential immobility, and population decline. However, these trends are much less common in the rural areas of the Prairie Provinces, particularly in parts of Alberta where the mining industry attracts working age adults.

3.5.2 Limitations of existing methods and directions for future research

The existing methods to analyze the spatial pattern of aging mainly draw on key indicators of age profiles, such as median age and the percentage of population aged 65 and over. These indicators of age profiles, though straightforward and easy to compare, can lead to an incomplete and sometimes misleading interpretation of the geography of aging. Almost inevitably, studies rely on arbitrary thresholds to determine whether a place is aged, or whether the demographic profile shows an aging trend. In addition, a specific age threshold can be problematic when comparing places over time, as the overall age structure of the country is shifting with time and the concept of being old is relative.

Moreover, the representation of the spatial pattern of aging is sensitive to the geographical unit of analysis. The result can be distorted by the fact that the geographic units have large variations in population size. For example, a geographical region with a small population is likely to show greater percentage of population growth or decline than a region with large population. This also raises the question how comparable it is between aging in dense urban areas and aging in sparsely populated rural areas. In general, the existing methods fall short in taking account of areas experiencing substantial changes in the population composition, such as remote northern communities in the territories. Similarly, these methods cannot effectively capture the neighbourhood scale patterns of aging, as the neighbourhood age profiles can be easily shifted by new developments. Therefore, future studies need to explore new methods that can better capture age structures and structural changes, and account for places with small population size and unstable population composition.

3.6 Conclusion

By mapping population aging across Canada, this study provides contextual knowledge for understanding the diversity in places where people age. It also provides nuanced perspective on the complex interactions between population aging and population change. To understand the ways in which multiple demographic trends shape the aging of places simultaneously, this chapter develops a spatial typology of aging and compares the characteristics of different aging patterns across the country. This provides a preliminary

exploration on comparing the different type of places where people age, in the context of highly uneven population distribution and population growth at the national level.

Although many studies associate population aging with population decline, with detailed empirical analysis in Canada, this chapter shows that population aging and population decline only have weak correlation among municipalities across the country. Yet the weak association is strongly influenced by a few outliers that either have substantially higher growth rates or have experienced sporadic population change during a short period. Furthermore, by empirically examining where people age in place, the results highlight the fact that aging is a ubiquitous phenomenon, and it is important to understand the extent to which aging-in-place policies can meet the needs of older adults with local resources. It also shows the need for providing more context specific guidelines in the planning for aging-in-place.

To date, the method to analyze aging in relation to place remains underdeveloped, and few studies empirically examined population aging with multiple indicators of aging at different spatial scales. Particularly, existing methods have clear limitations in understanding population aging at the neighbourhood scale. Given that the population composition of neighbourhoods reflects household structures in the neighbourhood, the next chapter develops a new approach to understand aging-in-place at the neighbourhood scale by analyzing neighbourhood age-structures and comparing the built environment characteristics and housing conditions across different types of neighbourhoods where people age.

Chapter 4 A good place to age in place? Exploring neighbourhood contexts of aging-in-place

4.1 Introduction

The concept of aging-in-place has been widely adopted as a guiding principle in public policies concerning the aging populations (Davies & James, 2011). A basic assumption of aging-in-place is that most people prefer to remain in familiar environments where their social networks and a sense of belonging have been established, which also contributes to their health and wellbeing (Gilleard, Hyde, & Higgs, 2007; Wiles et al., 2012). There has been a growing emphasis on supporting aging-in-place in public policy, given the identified associations between aging-in-place and older adults' sense of independence, security and an easy adaption to changes in physical conditions in the aging process (e.g. Cutchin, 2003; Chui, 2008; Wiles et al., 2012). Increasingly, researchers have adopted a broader definition of aging-in-place and emphasized the ability to remain in their homes or age in their own communities, where they can receive adequate service and care but remain largely independent in their everyday lives (Cutchin, 2003). In practice, aging-in-place policies often focus on avoiding involuntary relocation or institutionalization and at the same time, enabling older adults to receive assistance in one's own home or community (Chapin & Dobbs-Kepper, 2001; Chui, 2008; Vasunilashorn, Steinman, Liebig, & Pynoos, 2012). Although a supportive neighbourhood environment is central to the aging-in-place policies, the places where people age and their diverse neighbourhood environments remain under-explored.

The current aging-in-place policies and community initiatives, such as the Naturally Occurring Retirement Community Supportive Service Program (NORC-SSP) and the 'village' model, primarily focused on supporting spatially clustered aged neighbourhoods (Scharlach et al., 2012). This approach has relatively narrow scope and largely ignores the spatial heterogeneity and temporal dynamics of aging-in-place. The built environment and housing characteristics of each type of neighbourhoods are influenced by the historical periods of urban development and housing construction as well as the life-stages of each generation in these historical periods. Yet limited research has empirically examined the

neighbourhood context of aging-in-place: where do people age in place, and what types of neighbourhood environments support older adults to age in place. More often than not, guidelines to support "aging-in-place" and "age-friendly communities" resonate with classic planning ideas of good urban form, emphasizing the importance of providing a compact and walkable built environment with affordable housing and good access to services and care (e.g. WHO, 2007; Lehning, 2012). However, as widely discussed in planning literature, providing such a built environment faces significant challenges in practice (e.g. Ellis, 2002; Grant, 2002). Nonetheless, planning policies have important roles in meeting the emerging demands of a large population aging in place, especially in terms of providing suitable housing and a supportive built environment with accessible services and care.

Moreover, as a growing number of older adults are expected to age in their own homes or neighbourhoods, it is important to examine the actual neighbourhood contexts of aging-in-place, in terms of their existing built environment characteristics and housing conditions, and to analyze the extent to which the existing neighbourhood environments can or cannot support aging in place. Hence, this chapter examines the following questions. Whether there are clear age patterns among all neighbourhoods? What types of neighbourhoods, in terms of built environment features and housing characteristic, are expected to age extensively? How does the challenge of planning for aging-in-place vary in different neighbourhood contexts?

Based on analyzing age profiles of all neighbourhoods across Canada, this chapter classifies the neighbourhoods by their distinct age structures, and characterizes their built-environment features and housing characteristics. By examining characteristics of neighbourhoods by their age-structures, this study helps to identify the unique challenges of facilitating aging-in-place across neighbourhood contexts, and to clarify the planning priorities to support aging-in-place.

4.2 Background: the trend of aging-in-place

The increasing popularity of aging-in-place policies is associated with high home-ownership rates observed in the older population, especially in the baby boomer generation, and that older adults' strong preferences to age in their current homes are widely reported

(e.g. Hodge, 2008; Bayer, Ada-Helen, & Harper, 2000; Sixsmith & Sixsmith, 2008). With a closer look at the home-ownership rate by age group, the home-ownership rate typically peaks at the retirement age (65 to 69) and decreases steadily beyond age 70 (Figure 4.1). Nonetheless, comparing across generations, new generations of older adults have higher home-ownership rates than previous generations when they are in the same age group. In advanced old age particularly, home-ownership rates increase substantially in new generations of older adults. From 1996 to 2011, the home ownership rates among older adults age 85 and over has increased from 59.7% to 70%.

Supporting the suggestion that older adults prefer to stay and age in their own homes, high percentages of non-movers are observed among older adults across 20 years (Figure 4.2). In particular, among older adults over age 75, more than 80% did not move in the past 5 years and among those who moved, the majority moved to another residence in the same municipality. In comparison, more than 70% of people moved in their mid-20s in all census periods. The percentages of non-movers among people over age 60 increased over time and there was a noticeable increase among people over age 80. Nonetheless, about 20% of old adults in each age cohort moved in every census period. Though the phenomenon of moving among older adults is not as significant as that among the younger population, existing studies reported a growing heterogeneity in the spatial patterns of older adults' choices of residence and an emerging spatial-redistribution of older adults (Speare & Meyer, 1988). In particular, the spatial concentration of older adults is associated with significant changes in the demand of local services and infrastructure (Rowles & Watkins, 1993).

Encouraged by aging-in-place policies, a growing number of community initiatives have emerged. Some of them develop guidance for community planning, some foster collaboration among different sectors in the local government, and some provide supportive services through either consumer-driven networks or not-for-profit residence-based organizations (Lehning, Scharlach, & Wolf, 2012). However, most of the community initiatives focus specifically on a group of residents or a network of professions and there is a clear knowledge gap in understanding the spatial pattern of aging-in-place: where people age in place and how the meaning of aging-in-place varies with different neighbourhood environments and among different groups of older adults.

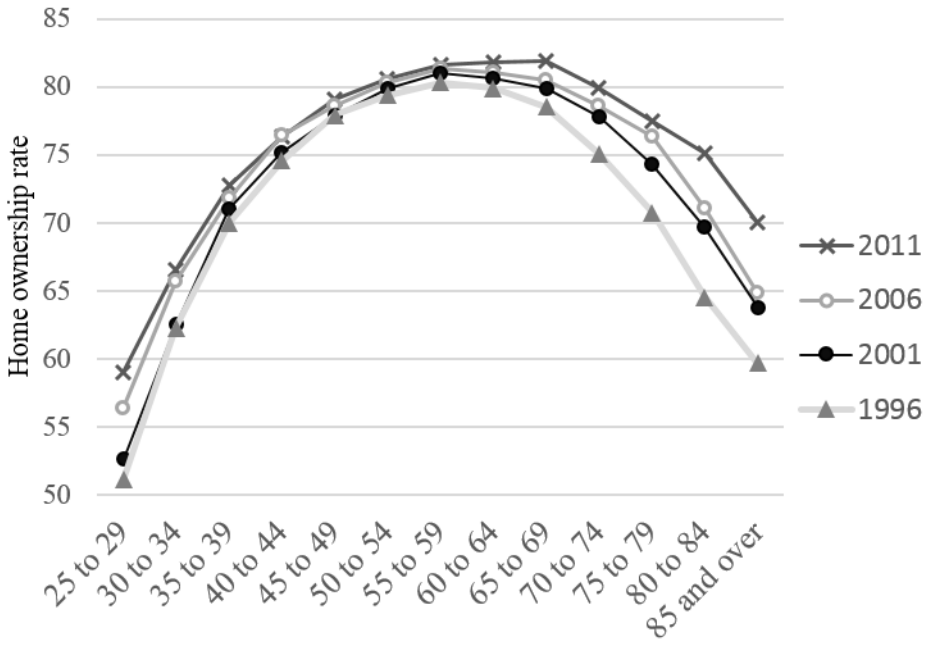


Figure.4.1 Home-ownership rate in Canada by age and period

Moreover, with a critical view, existing studies questioned that the over-emphasis of aging-in-place might lead to decreased funding in public institutions and nursing homes that provide services and care to older adults who need help most (Means, Richards and Smith, 2008). Also, it might disadvantage vulnerable older homeowners whose living environments no longer meet their needs, given the limited financial resource and policy-support for them to move to a neighbourhood with suitable housing and adequate care (Golant, 2008b). Further, in declining areas where younger people have moved out, older residents might face the challenge of financial insecurity due to the decreased tax-base and public funding that help to maintain local services. In growing areas, deprived communities are often under the pressure of gentrification and older people might be at risk of displacement in the process of redevelopment (Golant, 2008b; Kennedy & Leonard, 2001).

Therefore, to better inform aging-in-place policies and develop more specific planning interventions, it is important to understand the overall spatial pattern of aging and the variation of neighbourhood contexts within which people age in place. Further, given the changing housing choices over the life course, the temporal and spatial aspects of aging-in-place need to be explored and some widely held assumptions about the aging-in-place policies need to be re-examined: whether aging-in-place policies should primarily support

non-movers, and whether planning for aging-in-place should focus on neighbourhoods with high concentration of older adults.

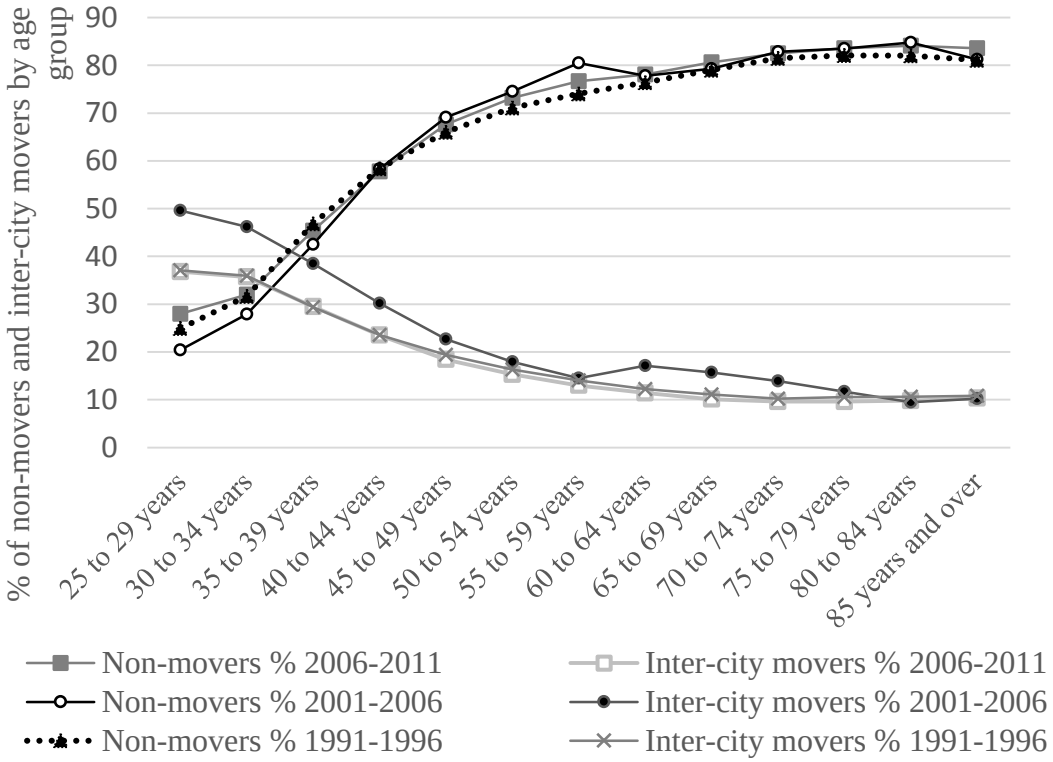


Figure 4.2 Percentage of non-movers and inter-city movers by age and period

4.3 Data and Methodology

The existing methods to analyze spatial patterns of aging have clear limitations. Mapping the spatial pattern of aging as a regional trend of median-age increase under-estimates older households living in growing urban centres with substantial inflow of younger people. Conceptualizing aging patterns as spatial clusters of older people or aging neighbourhoods under-represents the low-density and spatially scattered neighbourhoods in rural areas. Meanwhile, empirical studies that inform aging-in-place policies and the planning for age-friendly communities often use certain age thresholds, such as the age of 65, to analyze the group of older adults as a subgroup of the total population. This type of analysis tends to overlook the changes of the aging population's housing choices at different

life-stages and underestimate the impact of other age-cohorts on older adults' decision of aging-in-place (Frey, 2011; Speare & Meyer, 1988).

Addressing these methodological limitations and challenges, this chapter explores a new approach to categorize aging neighbourhoods based on the age structure of each neighbourhood, with a cluster analysis of census data at the neighbourhood scale. The purpose of this clustering analysis is to test whether a general typology of neighbourhood-level age-structure exists across Canada, and what are the distinct characteristics in age-profiles among these different types of neighbourhoods. Notably, the result is sensitive to the spatial unit of analysis, given that the age structure of a neighbourhood varies with the definition of neighbourhood boundaries. To mitigate the modifiable areal unit problem (MAUP) caused by arbitrary neighbourhood boundary definitions, this analysis adopts the most fine-grained spatial unit, that helps to maximize "internal homogeneity" within the spatial unit (Haynes, Daras, Reading, & Jones, 2007). Although the smallest census geographical unit is the dissemination block (which is similar to the smallest area bound by local streets), census data available at this level only limits to total population counts and dwelling counts. Hence, census dissemination areas (DAs) are used as neighbourhood proxies, and population counts at the dissemination block level are used to generate population weighted centroids of DAs, and to consolidate spatial boundaries of DAs from different census cycles. In addition, as DAs have relatively unified population size (400-700 people) across the country, they are suitable for a national-wide comparison of neighbourhood-scale age structures. In total, 53,806 neighbourhoods across Canada are included in the analysis.

For each neighbourhood, the age structure is calculated as a matrix of percentages of population in every 5-year age group. Because of the large sample size (n = 53,806), this analysis adopts k-means clustering, a non-computationally-intensive method, to classify all the neighbourhoods based on their age-structures. Compared with other clustering methods, k-means clustering is simple to implement, easy to interpret, and efficient for partitioning large datasets and sparse data (Rokach & Maimon, 2010). K-means clustering requires the pre-definition of the number of clusters and the selection of an optimum number of clusters is relatively arbitrary. This chapter adopts the Calinski–Harabasz pseudo F-statistic to

determine the optimum number of clusters, by choosing the most effective number of clusters that maximizes the ratio of among-clusters variance to within-clusters variance (Calinski & Harabasz, 1974). This method has been widely adopted and proved to be one of the best performing methods (Milligan & Cooper, 1985). Notably, as the age-structure of each neighbourhood is considered as independent of its surrounding neighbourhood in the k-means clustering analysis, and the age structure of each neighbourhood is compared against the overall pattern of neighbourhood-scale age structures in Canada.

Furthermore, based on the typology of aging neighbourhoods, this chapter characterizes the neighbourhood contexts of the different types of neighbourhoods, by comparing their housing characteristics and local built environment. With geospatial data of street-networks and service points in 2010, the nearby resources (in terms of locations for retail, social services and health services) of each neighbourhood are evaluated based on built environment measures generated in an 800-meter (half-mile) buffer of the population weighted neighbourhood centroids. 800-meter distance threshold is chosen as a proxy of immediate neighbourhood as it is one of the most frequently used threshold in measuring neighbourhood-scale walkable environment (e.g. Nagel, Carlson, Bosworth, & Michael, 2008). Using the 800-m buffer also provides a standardized way to compare built environment between urban and rural neighbourhoods. A set of commonly used built-environment measures, including population and dwelling densities, street connectivity (number of weighted intersections within the buffer area) and proximity to services (number of service points within the buffer area), are calculated and compared for each type of neighbourhood.

In addition, housing characteristics for each type of neighbourhood are compared with variables from the census that describe housing conditions and housing affordability. Meeting the changing housing needs of aging populations is a key component of aging-in-place policies. The housing needs of seniors are often assessed based on the characteristics of dwellings, including physical structure, size, tenure and quality, the location, nearby amenities. Also, housing affordability and suitability are commonly identified as key features that affect people's decision of aging-in-place (Davies & James, 2011; Hodge, 2008). With census data, variables included in this analysis are home ownership rate,

percentage of non-movers, dwelling structure characteristics (percentage of single-detached houses and percentage of high-rise apartments), construction period of housing, percentage of housing needs major repair, percentage of unaffordable housing (for both rental and owned housing), average household income, average dwelling values, and average monthly rent.

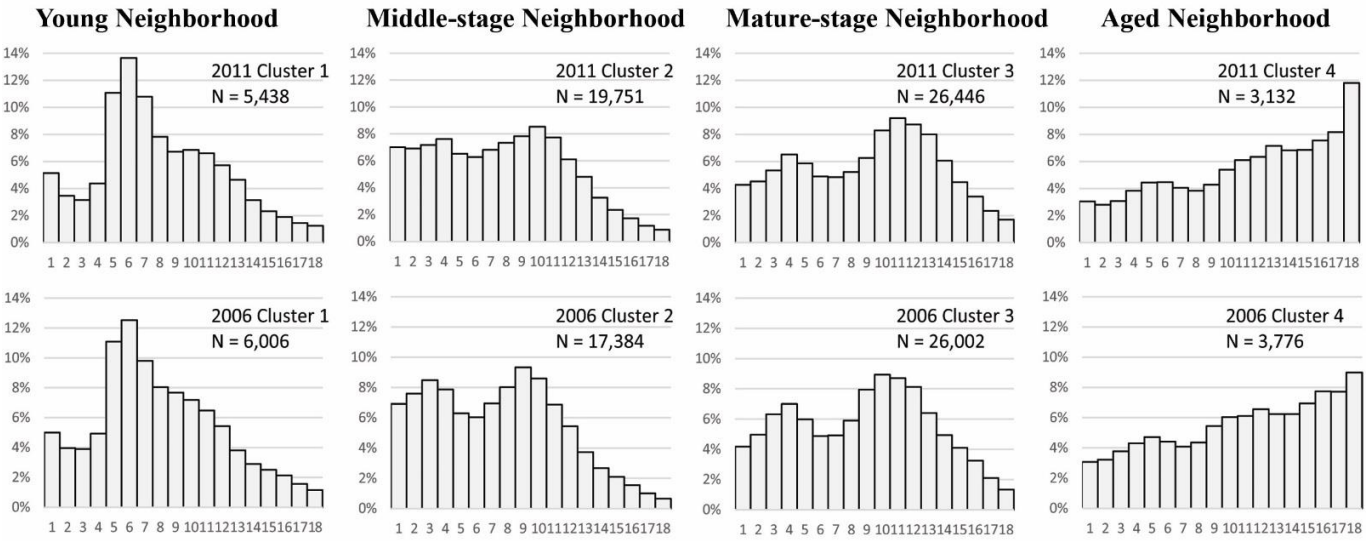
4.4 Results

4.4.1 Categorize neighbourhoods by age-structure

The results of the cluster analysis, including the typical age-structure of each cluster (age-structure of the k-means centres) and number of neighbourhoods in each cluster are shown in Figure 4.3. The results show a clear typology of neighbourhood age-structure, which corresponds to the different stages of a family life cycle: young household, middle-stage family, mature-stage family and older households (Ray et al., 1978). In each census period, four distinct clusters of neighbourhood age-structure consistently emerged. The young neighbourhood, with the percentage of residents peaking at the age groups around mid-20s and dropping substantially in older age groups. The middle-stage neighbourhood, with the highest percentages of residents in the age groups both around 30s-40s and 10 years old. The mature-stage neighbourhood, with the highest percentages of residents in the age groups both around 40s-50s and 15-19 years old; and the aged neighbourhood, with the highest percentages of residents in the age groups above age 65.

The transition of each type of neighbourhood can be observed by comparing the results of the two census periods. The young neighbourhood is characterized by a peak of population at the age of 25-29 in all census periods and there is higher concentration of the 20s age group in this type of neighbourhood over time. The middle-stage neighbourhood steadily aged and the concentration of residents in the peak age groups (adults in their 30s-40s and children around 10 years old) decreased over time. The age structure of the mature-stage neighbourhood resembles a constrictive population pyramid, and over time, the middle-age population in the mature-stage neighbourhood steadily aged and the proportion of teenagers dropped continuously. The age structure of the aged neighbourhood resembles a stationary population pyramid except for a high proportion of older population. As shown

in Figure 4.3, the proportion of older adults aged 85 years and older in the aged neighbourhoods is much higher than that in 2006.



Group No.	1	2	3	4	5	6	7	8	9
Age Group	0 to 4 years	5 to 9 years	10 to 14 years	15 to 19 years	20 to 24 years	25 to 29 years	30 to 34 years	35 to 39 years	40 to 44 years
9	10	11	12	13	14	15	16	17	18
40 to 44 years	45 to 49 years	50 to 54 years	55 to 59 years	60 to 64 years	65 to 69 years	70 to 74 years	75 to 79 years	80 to 84 years	85 years and over

Figure 4.3 Age-structure of the k-means centres for each type of neighbourhood

4.4.2 Distinct characteristics of neighbourhoods with different age-structure type

To examine the extent to which the age-structure typology, generated by the cluster analysis, can differentiate neighbourhoods with different demographic characteristics, two aging-in-place related indicators - median age and the percentage of non-movers, are compared among neighbourhoods with different age-structure types (Figure 4.4). The scatter plot shows clearly differentiated patterns among neighbourhoods with different age-structure types. Young neighbourhoods tend to have median age around 30 and substantially high residential mobility, middle-stage neighbourhoods have relatively low median age and low residential mobility, mature-stage neighbourhoods have low residential mobility but relatively high median age, and aged neighbourhoods have substantially high median age and relatively high residential mobility.

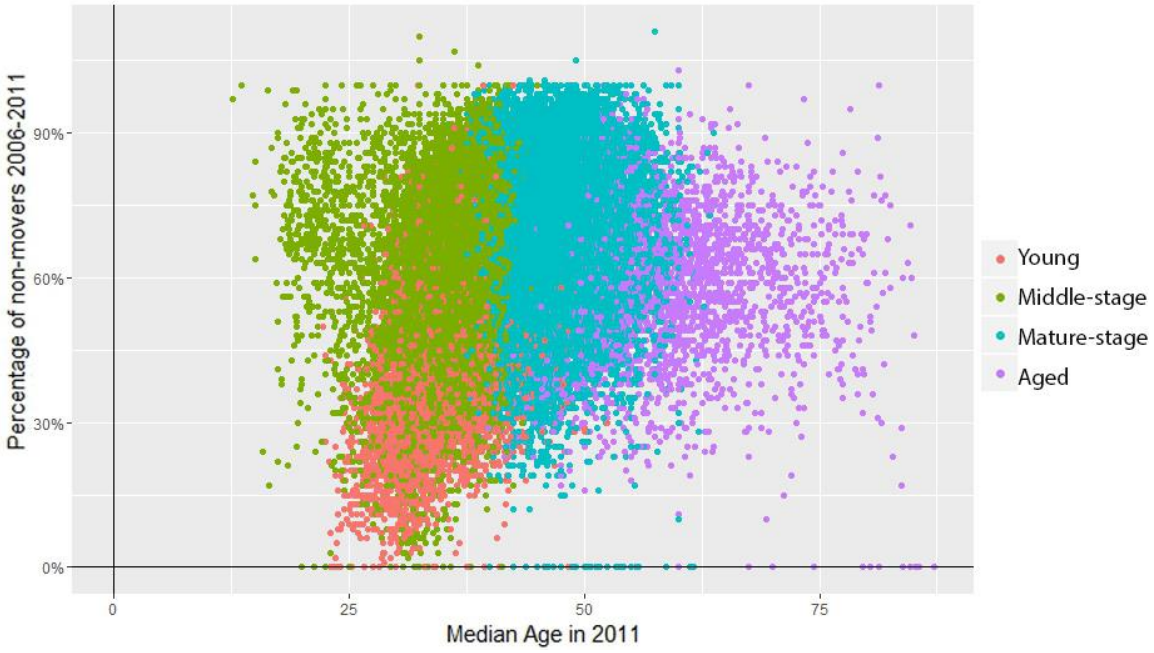
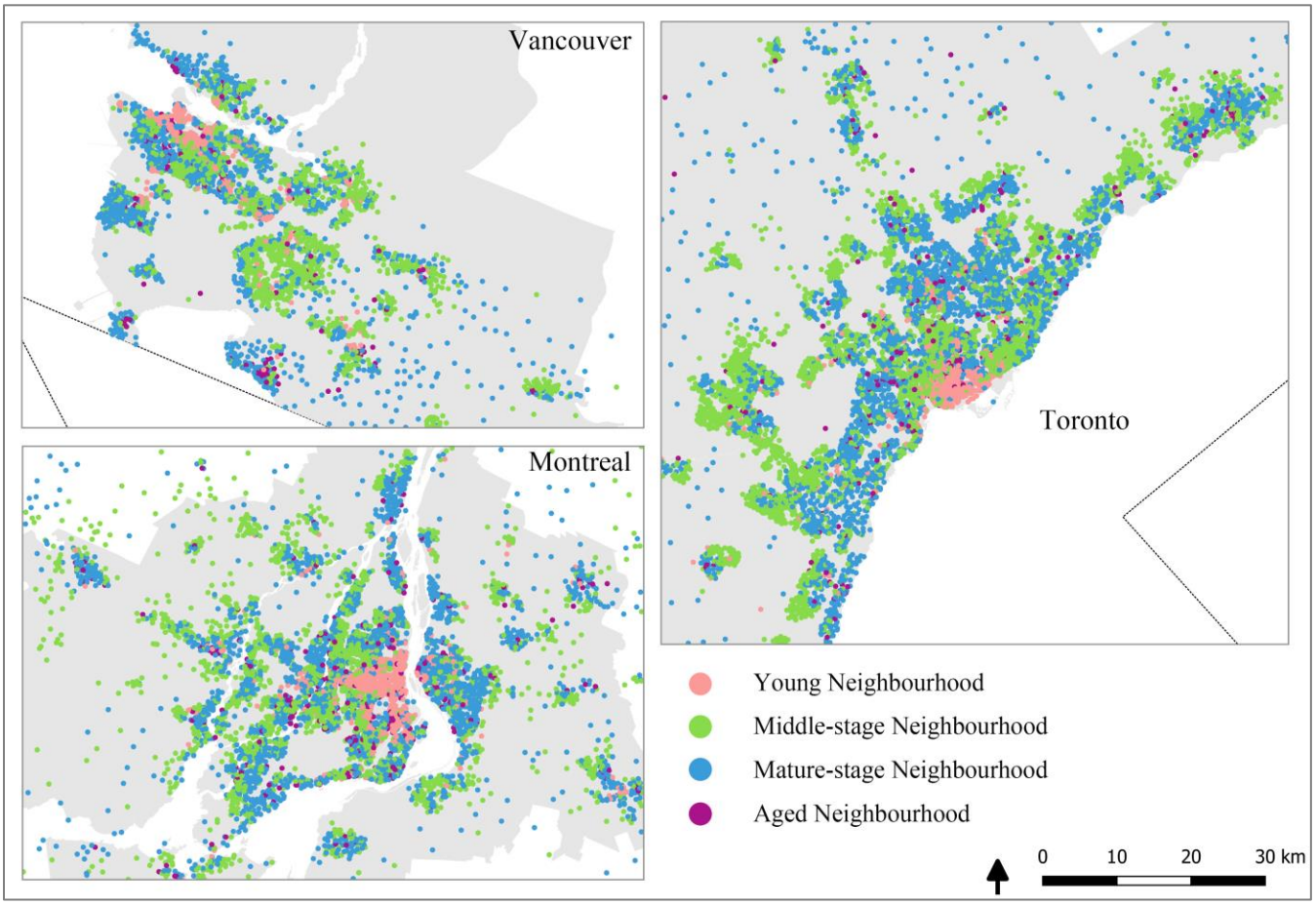


Figure 4.4 Median-age and the percentage of non-movers of neighbourhoods by age-structure types

Neighbourhoods with different age-structure types also show distinct spatial patterns at the national level. In 2011, above 48% of all neighbourhoods are at mature-stage, yet a relatively large percentage (30%) of mature-stage neighbourhoods are in rural areas. Though young neighbourhoods are only about 10% of all neighbourhoods, about 88% of them locate in metropolitan areas and only 3% in rural areas. About 36% of neighbourhoods are at the middle-stage, and 74% of them locate in metropolitan areas. Compared with other parts of Canada, high percentages of neighbourhoods in the remote northern territories are at the middle-stage. The aged neighbourhoods consist only about 6% of all neighbourhoods, and they are scattered in different areas. Among aged neighbourhoods, 56% are in metropolitan areas, 22% in other urban areas, and 22% in rural areas.

In addition, neighbourhoods with different age-structure types show clear spatial patterns in metropolitan areas. For example, the distribution of neighbourhoods by age-structure in the three largest metropolitan areas is displayed in Figure 4.5. In all three metropolitan areas, the spatial distribution of these four types of neighbourhoods shows clear patterns. Most young neighbourhoods cluster in the downtown cores. Most of the middle-stage neighbourhoods locate in two rings of the regions – the ring of inner-city/inner suburbs close to downtown cores, and the ring of outer urban fringes where new

development expands. While vast areas of suburbs (between the inner-city/inner suburbs and the outer fringe) are primarily locations for mature-stage neighbourhoods. Interestingly, the aged neighbourhoods are quite scattered in all three metropolitan areas. Hence, the aged neighbourhoods are spatially mixed with all other types of neighbourhoods in these metropolitan areas.



Note: Neighbourhoods in different regions are comparable because they are classified with the same standard.

Figure 4.5 Neighbourhoods by age structure in three largest metropolitan areas

Over time, by tracing the change in age structure type of each neighbourhood between 2006 and 2011, the result shows that most neighbourhoods stayed in the same age-structure type over the five-year period (Table 4.1). Mature-stage neighbourhood appears to be the most stable type. Particularly in rural areas, 90.7% of mature-stage neighbourhoods stayed the same. Though there are 71.1% of young neighbourhoods in metropolitan areas stayed

the same, given the high residential mobility among the younger population, it is likely that these neighbourhoods stayed young because younger adults continued to move in. In comparison, 34.2% of young neighbourhoods in rural areas became middle-stage. Interestingly, relatively high percentages of young neighbourhoods and middle-stage neighbourhoods in rural areas aged to the next stage in five-year period, while relatively high percentage of mature-stage neighbourhood in small towns became aged neighbourhoods. Despite low percentage of movers among older adults, more than 30% of aged neighbourhoods experienced sporadic age-structure change across Canada. This percentage is particularly high in rural areas (39.8%), and relatively low in small towns (25.7%).

Table 4.1 Change of neighbourhoods between 2006 and 2011

Change of neighbourhoods 2006-2011	**Rural**	**Towns**	**Metro-politan**	**Total**	**% by type of change**
Young Neighbourhood (2006)					100%
Stayed the same (2011)	83	349	3833	4265	69.5%
Sporadic change (2011)	21	91	411	523	8.5%
Became middle-stage (2011)	54	154	1144	1352	22.0%
Middle-stage Neighbourhood (2006)					100%
Stayed the same (2011)	2368	1735	10630	14733	82.0%
Sporadic change (2011)	40	94	448	582	3.2%
Became mature-stage (2011)	645	381	1626	2652	14.8%
Mature-stage Neighbourhood (2006)					100%
Stayed the same (2011)	6818	3495	11883	22196	85.4%
Became younger (2011)	624	492	2343	3459	13.3%
Became aged neighbourhood (2011)	79	79	176	334	1.3%
Aged Neighbourhood (2006)					100%
Stayed the same (2011)	574	551	1424	2549	68.7%
Sporadic change (2011)	380	191	590	1161	31.3%

4.4.3 Built-environment characteristics

Different from previous studies that focused on the living arrangements of seniors, this chapter examines the neighbourhood environment by comparing the built-environment characteristics and housing characteristics of neighbourhoods of different age-structures. Combining the geospatial data with census data at the most detailed geographical level available, a set of urban form measures, including densities, street connectivity and proximity to services, are compared to illustrate how the built environment varies between neighbourhoods of different age-structures (Table 4.2, Figure 4.6).

Table 4.2 Built-environment characteristics by neighbourhood type

Built-environment characteristics	Population density (people per Ha)		Dwelling density (units per Ha)		No. of street-intersections (weighted)		No. of retail points		No. of social-service points		No. of health-service points	
	Mean	S.D.	Mean	S.D.	Mean	S.D.	Mean	S.D.	Mean	S.D.	Mean	S.D.
Young Neighbourhood	**92.3**	**102.9**	**54.7**	**71.1**	**372.9**	**170.3**	**23.7**	**26.7**	**17.8**	**17.9**	**51.3**	**63.1**
Rural	19.7	15.6	9.6	7.6	157.1	102.3	3.6	3.5	2.6	1.8	7.1	5.5
Towns	36.5	29.7	18.8	18.1	268.2	132.5	5.4	4.6	8.3	9.3	17.9	20.7
Metropolitan	100.5	106.7	59.9	74.1	390.7	167.0	25.7	27.3	18.9	18.3	55.1	65.0
Middle-stage Neighbourhood	**44.9**	**65.4**	**16.9**	**24.8**	**218.5**	**138.1**	**7.6**	**9.9**	**5.2**	**6.3**	**13.1**	**21.6**
Rural	11.3	25.5	4.5	10.8	74.5	99.3	2.7	2.3	2.9	3.3	4.7	5.1
Towns	25.0	33.3	10.1	14.7	188.1	133.1	3.5	3.1	4.2	5.1	8.5	12.3
Metropolitan	55.7	71.9	20.7	27.1	255.4	123.5	8.5	10.5	5.5	6.6	14.3	23.0
Mature-stage Neighbourhood	**24.3**	**27.8**	**10.7**	**15.2**	**178.8**	**148.6**	**6.2**	**7.2**	**4.9**	**6.2**	**13.3**	**21.5**
Rural	7.1	11.4	3.5	4.8	59.5	93.9	3.2	2.5	3.4	3.2	6.0	5.9
Towns	18.7	14.1	9.0	7.9	183.3	152.1	4.6	3.7	5.2	6.1	11.8	14.3
Metropolitan	35.4	31.5	15.1	18.6	242.7	131.0	7.1	8.1	5.1	6.5	14.8	23.9
Aged Neighbourhood	**51.8**	**91.9**	**24.7**	**43.1**	**255.5**	**141.6**	**8.9**	**11.4**	**8.6**	**10.1**	**24.3**	**34.6**
Rural	28.0	95.6	7.7	6.7	160.3	105.5	3.6	2.7	3.9	3.4	7.5	6.4
Towns	32.2	59.3	15.0	14.7	255.5	133.0	6.1	4.2	8.2	8.3	19.3	20.3
Metropolitan	68.4	97.0	35.0	54.1	292.5	139.9	11.2	13.6	9.9	11.3	31.2	41.0

As young neighbourhoods tend to concentrate in urban centres of metropolitan areas, on average, they have higher population and dwelling densities, better connected street networks, and much closer proximity to retail, health and social services than other types of neighbourhoods. Compared with the middle-stage and the mature-stage neighbourhoods, the aged neighbourhoods tend to have relatively compact built form, characterized by higher densities, better street connectivity and higher proximity to services, across rural and urban areas. In rural areas especially, the aged neighbourhoods have higher levels of population density and proximity to retail and services than all the other types of neighbourhoods.

Overall, metropolitan areas tend to have a more compact built environment than small towns and rural areas, and young neighbourhoods in metropolitan areas have substantially higher densities and proximity to amenities than all other types of neighbourhoods across regions. Yet in rural areas and small towns, the aged neighbourhoods tend to have highest proximity to social services and health services among all types of neighbourhoods (except that young neighbourhoods in small towns have slightly higher proximity to social services).

This indicates that, first, there may be strong associations between the different periods neighbourhoods are developed and the age structure of neighbourhoods; second, there may be intentional selection of moving to or staying in residential locations that have relatively good access to social and health services among older adults. In addition, the results show a clear gap between the built-environment characteristics of the mature-stage neighbourhood and that of the aged neighbourhood. On average, the mature-stage neighbourhoods have the least compact built form, with the lowest levels of densities, street connectivity and proximity to retail and services.

Despite the large variation in built-environment characteristics across geographical regions, a clear pattern can be observed between the characteristics of a compact environment (connectivity and proximity to retail) and the age-structure type of neighbourhoods (Figure 4.6). Places that show substantially high levels of street density and proximity to retail are primarily young neighbourhoods. Though the built environment characteristics of aged neighbourhoods vary amongst themselves, few of them have extremely low levels of connectivity and proximity.

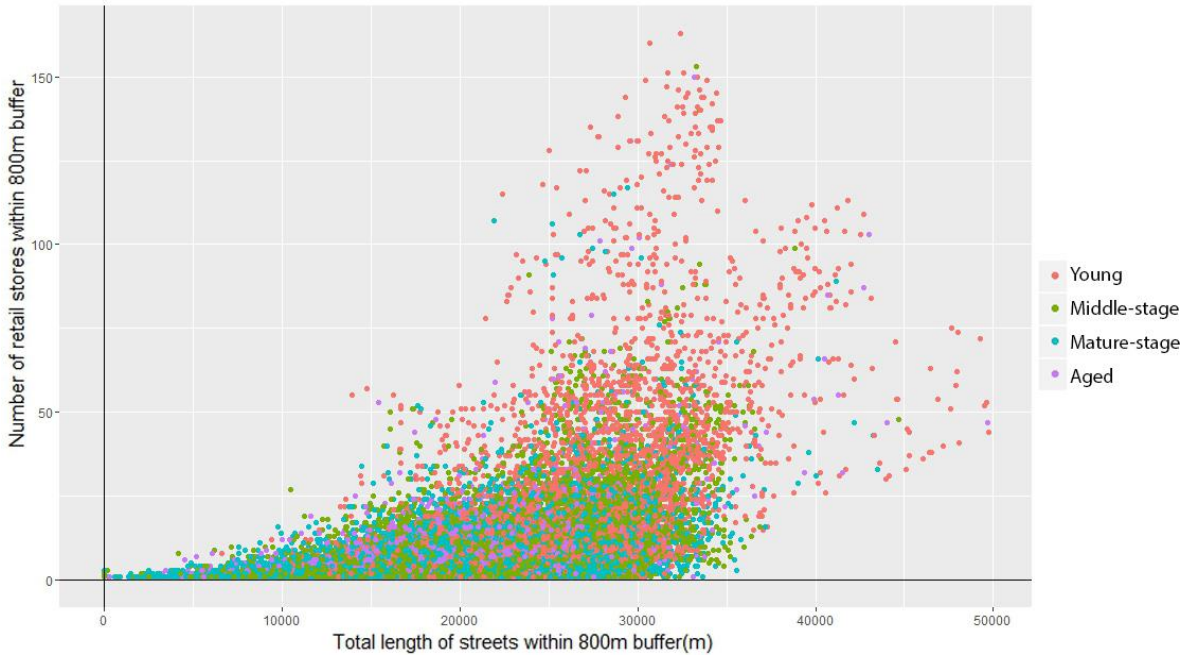


Figure 4.6 Density of streets and retail locations by neighbourhood type

4.4.4 Housing characteristics

Previous research that examined housing conditions of older households in the American context highlighted that aging-in-place policies, which emphasize providing resources for old people to stay in their own homes as they age, may disadvantage vulnerable older homeowners, who tend to be over 75 years old and living alone in the oldest housing stock with poor living conditions (Golant, 2008c). With a different approach, this chapter analyzes a set of housing characteristics of the different types of neighbourhoods, including home-ownership rate, the percentage of non-movers, dwelling conditions, income, housing values, and affordability (Table 4.3, Table 4.4).

Mature-stage neighbourhoods tend to have the highest percentage of non-movers and highest home-ownership rate. They also tend to have relatively low percentages of unaffordable housing for both homeowners and renters. In contrast, young neighbourhoods tend to have the highest percentage of unaffordable housing, especially for renters. Young neighbourhoods also tend to have the lowest percentage of single-detached houses; the highest percentage of housing that needs major repair, and the highest share of old housing stock (dwellings built before the 1960s). Similar to young neighbourhoods, aged neighbourhoods tend to have low percentage of single-detached dwellings, especially in urban areas. Aged neighbourhoods also tend to have the lowest self-reported housing values, especially in rural areas.

Aged neighbourhoods tend to have high percentages of high-rise apartment units (apartments that are five stories and above), and substantially higher percentages of subsidized housing than that in other types of neighbourhoods. These neighbourhoods are likely to include a variety of subsidized senior housing, "naturally occurring retirement communities", high-rise apartments that are parts of the large-scale social housing projects built in the 70s, and new real-estate developments designed for seniors such as assisted living residence. As shown in Figure 4.5, these neighbourhoods tend to be spatially mixed with other types of neighbourhoods. Among these aged neighbourhoods, though the percentage of unaffordable housing for homeowners is relatively low, the percentage of unaffordable housing for renters is among the highest. Compared with mature-stage

neighbourhoods, aged neighbourhoods tend to have much lower housing values but higher rent.

Table 4.3 Housing characteristics by neighbourhood type (2011)

Housing characteristics	% Non-movers (2006-2011)		% Single-detached houses		% High-rise apartment units		Ownership rate		% Housing built before 1960s		% Housing needs major repair	
	Mean	S.D.	Mean	S.D.	Mean	S.D.	Mean	S.D.	Mean	S.D.	Mean	S.D.
Young Neighbourhood	**41.1**	**15.4**	**19.3**	**24.8**	**15.1**	**28.9**	**38.5**	**25.8**	**40.5**	**33.5**	**9.0**	**12.0**
Rural	43.5	22.1	45.9	28.7	0.8	4.6	48.7	28.1	22.2	26.0	7.5	13.7
Towns	38.5	15.2	36.1	26.2	2.2	9.4	45.0	25.6	28.9	32.4	7.8	12.8
Metropolitan	41.4	15.2	16.7	23.3	16.9	30.2	37.6	25.6	42.2	33.5	9.1	11.8
Middle-stage Neighbourhood	**62.2**	**15.9**	**62.6**	**31.9**	**2.1**	**11.4**	**75.3**	**24.8**	**23.7**	**31.9**	**5.5**	**11.2**
Rural	66.6	16.7	81.5	18.8	0.1	0.9	79.9	18.8	26.7	26.4	8.6	15.8
Towns	59.1	15.8	71.1	23.9	0.3	2.9	75.7	21.2	23.4	29.8	6.0	10.9
Metropolitan	61.7	15.5	57.0	33.5	2.9	13.3	74.4	26.2	23.2	33.1	4.8	10.1
Mature-stage Neighbourhood	**70.4**	**14.2**	**73.8**	**27.8**	**1.8**	**9.7**	**80.6**	**20.6**	**30.6**	**29.0**	**5.9**	**11.1**
Rural	72.4	15.2	85.1	16.0	0.1	1.0	83.5	15.0	35.7	23.6	9.5	14.1
Towns	67.0	14.5	70.8	26.2	1.0	5.6	75.4	22.4	31.8	28.4	6.2	11.5
Metropolitan	70.3	13.2	68.5	31.3	3.0	12.7	80.6	22.1	27.6	31.2	4.0	8.6
Aged Neighbourhood	**59.2**	**15.6**	**39.5**	**31.9**	**17.5**	**29.8**	**56.9**	**28.7**	**26.8**	**26.0**	**5.3**	**10.1**
Rural	62.9	16.2	66.6	22.2	0.8	4.6	68.4	20.2	34.6	23.1	7.4	12.8
Towns	57.6	15.2	42.0	28.6	7.5	17.5	54.4	28.5	28.5	27.3	4.4	8.8
Metropolitan	58.3	15.3	28.1	29.6	27.9	34.6	53.6	30.4	23.2	25.8	4.9	9.2

Notably, the results show no direct association between a neighbourhood with concentration of older residents and a high percentage of old housing stock or dwellings that need major repair. Different from previous research that emphasized the disadvantage of vulnerable older homeowners living in the oldest housing stock (Golant, 2008b), findings of this chapter indicate decreasing affordability in the aged neighbourhoods – places with high concentration of older adults. These neighbourhoods tend to have relatively compact built environment and good access to services and care. With decreasing affordability, there are unique challenges for low-income renters to age in place in these neighbourhoods.

Table 4.4 Housing affordability by neighbourhood type (2011)

Housing affordability	% unaffordable ownership		% unaffordable rental		% subsidized housing		Avg. housing value (thousand$)		Avg. Rent ($)	
	Mean	S.D.	Mean	S.D.	Mean	S.D.	Mean	S.D.	Mean	S.D.
Young Neighbourhood	**16.6**	**18.2**	**38.8**	**19.8**	**4.8**	**10.9**	**364.3**	**189.1**	920	274
Rural	11.3	18.5	26.0	25.9	5.0	10.9	350.1	235.4	988	316
Towns	12.2	15.6	33.5	22.9	6.0	12.2	264.4	116.6	936	421
Metropolitan	17.1	18.4	39.7	19.0	4.7	10.8	375.6	191.1	916	253
Middle-stage Neighbourhood	**16.1**	**14.8**	**15.0**	**23.3**	**4.9**	**16.1**	**350.0**	**197.3**	886	294
Rural	10.7	12.7	8.5	19.5	6.7	20.1	238.2	99.4	710	236
Towns	11.9	12.7	16.7	25.3	5.1	16.1	249.4	108.2	833	282
Metropolitan	17.8	15.1	15.9	23.5	4.5	15.2	387.7	208.5	926	293
Mature-stage Neighbourhood	**12.7**	**12.8**	**12.1**	**22.2**	**3.2**	**12.7**	**336.3**	**262.0**	758	283
Rural	10.8	11.9	9.7	21.2	3.5	13.4	214.4	123.9	621	205
Towns	11.3	12.2	16.7	24.9	4.0	14.0	230.3	114.4	697	200
Metropolitan	14.1	13.3	12.0	21.7	2.8	11.8	429.5	304.2	865	308
Aged Neighbourhood	**13.2**	**14.2**	**32.2**	**26.3**	**14.1**	**23.8**	**303.2**	**193.4**	830	316
Rural	10.7	12.7	25.5	27.2	15.8	25.1	200.6	93.9	646	195
Towns	10.9	13.3	33.4	25.9	12.4	21.6	229.9	93.5	754	245
Metropolitan	15.0	14.8	34.2	25.7	14.1	24.0	371.7	220.8	926	338

Furthermore, data from the 2006 and 2011 census cycles is compared to explore how housing affordability of each type of neighbourhood changed over time. As both the age-structure of neighbourhoods and their housing characteristics change simultaneously, it is challenging to draw direct linkages between the age-structure change and the change in housing characteristics, especially given that many variables not measured consistently across census cycles. Therefore, to explore a general trend of change in housing characteristics of neighbourhoods with different age-structure types, comparable measures are extracted from the 2006 and 2011 census, and a cross-sectional comparison between the different types of neighbourhood is displayed in Table 4.5.

Table 4.5 Compare housing characteristics by neighbourhood type between 2006 and 2011

Housing characteristics		Young Neighbourhood		Middle-stage Neighbourhood		Mature-stage Neighbourhood		Aged Neighbourhood	
		Mean	S.D.	Mean	S.D.	Mean	S.D.	Mean	S.D.
Ownership rate	2006	41.4	27.1	76.9	24.5	80.4	19.4	58.0	28.1
	2011	38.5	25.8	75.3	24.8	80.6	20.6	56.9	28.7
% non-movers in 5 years	2006	40.7	16.0	58.0	17.5	68.6	13.2	58.4	14.3
	2011	41.1	15.4	62.2	15.9	70.4	14.2	59.2	15.6
% dwellings built before 1960	2006	39.8	32.0	20.3	27.2	31.5	26.4	30.0	24.0
	2011	40.5	33.5	23.7	31.9	30.6	29.0	26.8	26.0
% housing needs major repair	2006	8.7	6.9	7.4	9.5	7.4	6.5	6.5	6.1
	2011	9.0	12.0	5.5	11.2	5.9	11.1	5.3	10.1
% single-detach dwelling	2006	22.2	26.7	65.7	30.6	73.0	27.9	42.8	33.0
	2011	19.3	24.8	62.6	31.9	73.8	27.8	39.5	31.9
Avg. monthly rent ($)	2006	771	217	767	251	666	249	726	282
	2011	920	274	886	294	758	283	830	316
Avg. monthly cost ($)	2006	966	445	1051	415	872	337	765	345
	2011	1107	496	1209	398	999	357	930	353
Avg. median household income (thousand $)	2006	45.3	18.5	66.4	27.5	60.1	27.5	41.3	19.7
	2011	50.2	23.1	73.0	32.7	67.7	34.0	47.1	24.6
Avg. value of dwelling (thousand $)	2006	270.9	153.9	267.9	152.1	257.3	196.8	233.2	151.4
	2011	364.3	189.1	350.0	197.3	336.3	262.0	303.2	193.4

Between 2006 and 2011, home-ownership rate decreased in both young neighbourhoods and aged neighbourhoods. Meanwhile, the percentage of non-movers decreased slightly in aged neighbourhood. As with the percentage of single-detached dwellings, the percentage of dwellings constructed before 1960s, and the percentage of dwellings needing major repair decreased in aged neighbourhoods. As shown in the above analysis, these neighbourhoods also have high percentages of apartment units and locate in places with relatively compact built environment. On average, the median household income in aged neighbourhoods increased slightly, but remained the lowest. Similarly, though the average dwelling values increased substantially in all types of neighbourhoods, the average housing values of aged neighbourhoods stayed the lowest. At the same time, aged neighbourhoods experienced high increases of average monthly rent and average monthly cost.

A high percentage of neighbourhoods in Canada are at the mature stage. From 2006 to 2011, this type of neighbourhood showed relatively fewer changes in housing characteristics than other types of neighbourhoods: the home-ownership rate remained high (more than 80%), the percentages of non-movers slightly increased, the median household income and average dwelling values stayed relatively high, and the average monthly cost as well as average monthly rent remained relatively low. In contrast, renters in young neighbourhoods showed the highest increase of average monthly rent, while residents in aged neighbourhoods have the highest increase of average monthly cost.

The mature-stage neighbourhoods tend to have most stable living environment and they show a trend of steadily aging-in-place. However, a remaining question is whether older residents in the mature-stage neighbourhoods will stay in the same residence as they turn advanced old age, and whether the aging-in-place policies should focus on enabling and encouraging older residents in the stable mature-stage neighbourhoods to stay.

4.5 Discussion

4.5.1 Analyzing the age structure of neighbourhoods

This chapter adopts a relatively simple k-means clustering method, and the result shows an overall pattern of neighbourhood-scale age structure across Canada. The spatial location of each neighbourhood is not considered in the classification of age structure types. Hence, neighbourhoods across geographical regions are analyzed with the same standard. Alternatively, the age-profile of each neighbourhood can be compared against its surrounding neighbourhoods, or all neighbourhoods in the same city or the same province, and the results will vary with the level of analysis – both the k-means centre and the membership of each neighbourhood will vary accordingly. However, conducting cluster analysis separately for different geographical regions makes it difficult to compare neighbourhood age structures across geographical region.

As the cluster analysis in this chapter focuses on age composition, which is measured consistently with the same magnitude across diverse geographical regions, it is feasible to capture a macro-level typology of neighbourhood-scale age structures with this nation-wide dataset. At the same time, studies that conduct a micro-level analysis with a smaller

population size can adopt clustering methods that take account of spatial relationships among neighbourhoods.

Nonetheless, a sensitivity test is conducted to compare cluster results generated at different geographical levels. Comparing the results of clustering at the national level and at the provincial level (with Ontario as an example), 90.1% of the classification results are the same. While comparing the results at the national level and at the metropolitan area level (the Toronto region as an example), the matched percentage is 79.8%. The main difference is some mature-stage neighbourhoods compared within Toronto are middle-stage when compared across Canada. Though the k-means clustering method adopted in this analysis has clear limitations, it shows a clear typology of neighbourhood-scale age-structure, and at a macro level, each type of neighbourhood has distinct built environment and housing characteristics. With more advanced clustering techniques and more cycles of census data, future studies can build on this analysis and explore both the spatial and temporal dimensions of neighbourhood age structures.

4.5.2 Planning for aging-in-place in different types of neighbourhood

There are unique challenges to plan for aging-in-place in different types of neighbourhoods. The aged neighbourhoods have relatively compact built environment and relatively good access to amenities, yet relatively high percentages of housing in these neighbourhoods are unaffordable, especially for renters. At the same time, 39.8% of aged neighbourhoods in rural areas experienced a change in age-structure between 2006 and 2011, which may be a result of inadequate local amenities to support aging-in-place in these neighbourhoods.

The mature-stage neighbourhood is primarily home to the generation of baby boomers. As shown in above analysis, this type of neighbourhood has the least compact built environment and most affordable housing. As people in mature-stage neighbourhood age in place, many of these mature neighbourhoods may have substantial increase in the demand for better access to amenities health and social services and housing types that are more suitable for older people, such as smaller units which are affordable and easy to maintain. However, as the mature neighbourhoods also provide relatively affordable living

environment, it is questionable whether as residents get older in these neighbourhoods, they will relocate to a more compact built environment and whether they will have enough economic resource that enables them to move for better amenities. As the majority of neighbourhoods in Canada are already at the mature-stage and the percentages of home-ownership and non-movers of mature-stage neighbourhoods are high, it can be expected that the age-structure of many existing mature-stage neighbourhoods may gradually transform into that of aged neighbourhoods. Consequently, large-scale changes to the existing housing stock can be expected if the new generation of older adults gradually downsize their dwellings, choose to rent instead own a house, and relocate to places with better access to amenities such as social services and care (which tend to be a relatively compact built environment).

Nonetheless, as great variations exist in the household income and dwelling values across geographical regions, older residents of aged neighbourhoods and mature-stage neighbourhoods in small towns and rural areas may not be able to afford moving to places with more compact built environment. In addition, given the strong concentration of young neighbourhoods in urban centres, where amenities are most accessible, and the decreasing housing affordability in these places, it is questionable whether older adults from aged neighbourhoods and mature-stage neighbourhoods can relocate to urban centres for amenities.

The dichotomy of aging-in-place (staying) and residential mobility (moving) fails to recognize the different needs of older adults aging in place in diverse neighbourhood contexts. Arguably, older adults look for a certain type of neighbourhood environment that can adapt to their changing needs in later life. While staying in the same place may be a result of residential immobility in later life, which can be caused by the surging housing price and the general lack of amenities in place. Therefore, it is misleading to conceptualize planning for aging-in-place as encouraging non-moving. Rather, planning policies need to address the emerging demands of each type of neighbourhood and provide alternative affordable housing options that are more suitable for older people, such as assisted living residence, service-enriched rental housing, and affordable clustered home care (Nolan & Maher, 2000; Golant, 2008a). Moreover, with increasing demands for easily accessible

amenities and decreasing affordability in the good places for aging-in-place, planning policies also need to investigate the growing inequality of aging-in-place.

4.6 Conclusion

This chapter identifies a clear typology of neighbourhood age-structure with cluster analysis and provides a more nuanced understanding of the aging-in-place concept. The results show four distinct types of neighbourhoods. (1) The young neighbourhood, characterized by a high concentration of the younger population. (2) The middle-stage neighbourhood, characterized by a high percentage of families with young children. (3) The mature-stage neighbourhood, characterized by high percentages of mature-stage families and non-movers. (4) The aged neighbourhood, with high concentration of older adults, especially the oldest old.

Further, this chapter examines the neighbourhood-scale contextual differences of aging-in-place by comparing the local built environment features and housing characteristics. The findings offer insights on the unique challenges of planning for aging-in-place in different neighbourhood contexts. In aged neighbourhoods, planning policies need to emphasize the housing and financial security and to avoid potential displacement of low-income older adults due to the rising living cost or lack of sustainable support in these neighbourhoods. For steadily aging mature-stage neighbourhoods, planning policies need to identify the emerging needs of the aging residents as they experience changes at their later life stages, and to support residential mobility for older adults who are in need for alternative housing.

Based on the findings, this chapter challenges some widely held assumptions about the aging-in-place policies. First, planning for aging-in-place is not primarily about supporting older residents not to move. Instead, it needs to examine the changing needs of the older residents over the life-course, to what extent the local environment can support such needs, and what alternative options can be provided, under the financial constraints of both the older residents and the public sector. Second, planning for aging-in-place needs to examine a broader range of aging communities beyond the focus on neighbourhoods with high concentration of older adults. As both young and aged neighbourhoods tend to have

relatively compact built environments, there is potential for planning policies to encourage a higher degree of mix in age groups at the neighbourhood level. Nonetheless, findings of this chapter also show low levels of affordability in both young and aged neighbourhoods, which tend to have relatively compact built environment and good access to amenities. Therefore, future research needs to examine what features of social and built environment can provide good places for aging-in-place for older adults at different life-stages, and how planning interventions can address the problem of decreasing affordability in the good places for aging-in-place.

By comparing the built-environment and housing characteristics of neighbourhoods with different age-structure, this chapter provides a big picture of distinct neighbourhood contexts of aging-in-place, which helps to compare similarities and unique challenges in planning for aging-in-place across geographical regions. The result shows that the mature-stage neighbourhoods are expected to age substantially over the next decade, and these neighbourhoods tend to have a low-density car-dependent built environment. With a closer examination on aging in a largely car-depend environment, the next two chapters analyze the impact of automobility (or the lack of automobility) on aging populations in Canada.

Chapter 5 Mobility gap over the life course: a cohort analysis of older men and women in Canada

5.1 Introduction

Increased transportation mobility is found among aging populations across developed countries (e.g. Newbold, Scott, Spinney, Kanaroglou, & Páez, 2005; Rosenbloom, 2001; Schwanen & Páez, 2010). Due to the flexible schedule and free time after retirement, and the increasing demand for healthcare and social services, older adults tend to make more frequent and relatively shorter trips for daily activities than their working age counterparts (Rosenbloom, 2001; Schwanen & Páez, 2010). Yet in countries with car-dependent built environments, such as Canada, the United States and Australia, older adults' increased mobility is mainly driven by growing automobility, and their active travel and transit use remain limited (e.g. Newbold, Scott, Spinney, Kanaroglou, & Páez, 2005; Collia, Sharp, & Giesbrecht, 2003; King & Scott-Parker, 2016). Compared with previous cohorts of older adults, higher levels of car-ownership and longer average time for holding driving licenses are expected among the aging baby boomers (Banister & Bowling, 2004; Newbold et al., 2005).

Transportation mobility is essential to older adults' quality of life, as it reduces the risk of older adults being homebound and provides access to a variety of socioeconomic opportunities and resources (Banister & Bowling, 2004; Hanson, 2010; Sugiyama & Thompson, 2007). A growing body of literature, especially research in gerontology, has identified the ability to continue driving as closely related to older adults' physical and mental health (e.g. Choi & Mezuk, 2013; Kim, 2011; Siren and Haustein, 2016). In addition, older adults' strong preference for car-travel is widely observed, as automobility is perceived as providing flexibility, convenience, security and a sense of independence for older adults (Li, Raeside, Chen, & McQuaid, 2012; Davey, 2004).

However, aging populations are highly diverse and there are great variations in their travel needs, preferences, and mobility barriers. Interrelated factors such as gender, age, birth-cohort, household characteristics, socio-economic status, and neighbourhood

characteristics are identified as significantly associated with older adults' travel behaviours (Banister & Bowling, 2004; Hildebrand, 2003; Mercado & Páez, 2009). Despite an overall increase in automobility among aging populations, existing studies found that women are much less likely to drive in old age than men. Older women also tend to have more mobility barriers, especially given that high percentages of women in advanced old age live alone with limited economic resources (Rosenbloom, 2001; Kim, 2011; Li, Raeside, Chen, & McQuaid, 2012).

In the Canadian context, though previous research explored cohort differences in travel behaviours (Newbold & Scott, 2017; Newbold et al., 2005), there has been limited research examining how automobility differs between older males and females over the life course, and how the gender gap in transportation mobility has changed over time. In 2016, the sex ratio among older Canadians age 85 and over was about 54 men per 100 women (Statistics Canada, 2016). Despite the projected substantial increase in both the number and percentage of older females, limited discussions have addressed the gender differences in transportation mobility, and particularly automobility, at the national level.

This chapter therefore explores the gender difference in mobility behaviours and its variations among different generations, with multiple cycles of population-representative cross-sectional survey data – the General Social Survey (GSS) time-use cycles. Notably, because of the design of the GSS, the analysis of gender difference in this chapter is based on a binary male/female variable, and the analysis of age/cohort trends is based on biological age. Although the survey data restricts nuanced discussions on the social constructs of gender or age, it enables a macro-level understanding of the intersection between gender and aging in mobility behaviours, which also informs the generation of context-specific research questions that can address nuanced conceptualizations of gender and age/aging. Hence, this chapter adopts descriptive cohort analysis and multivariate regression models to examine the following research questions. (1) How do mobility behaviours vary with gender and cohort groups? (2) Is there a significant gender gap in automobility among older adults? How does the gender difference in automobility vary across cohorts and how does it change over time? (3) What are the relationships between transportation mobility/immobility and

the socioeconomic status and health status of aging populations? How these relationships are different in the eldest cohort as people reach advanced old age?

5.2 Literature review

An increasing car dependency among the elderly has been observed in the western developed world over the last decades (S. Rosenbloom, 2001). In the U.S., for example, statistics show that older people depend on private cars for more than 90% of their travel needs (Collia et al., 2003). With rising car dependency, the level of transportation mobility can be substantially different between people who have access to a car and those who must rely on other means of transportation (Bailey, 2004). The increase in car-dependency can be attributed to the self-reinforcing "system of automobility": as private cars become popular because of the autonomy, flexibility, and high-speed mobility they provide, the built-environment is transformed to accommodate car-use, including the building of highway systems, low-density housing at urban edges, and decreased funding for the expansion of public transportation (Urry, 2004). Moreover, the "system of automobility" restrains the opportunity for the expansion of alternative transportation modes.

Previous research has shown that older adults have heterogeneous transportation needs and preferences, these variations are associated with generational life experiences and lifestyle (Wachs, 1979). In many developed countries, however, the system of automobility has enduring impact on the travel behaviours of the post-war generations. Studies highlighted that as the aging baby boomers are generally accustomed to driving at younger ages, their preference for automobile over other travel modes is likely to persist even when they voluntarily or involuntarily stop driving (Siren & Haustein, 2016). Among the new generations of older adults, the percentage of non-drivers has declined significantly over time, license-holding rates have increased, and more seniors have kept their drivers' licenses in advanced old age (Choi & Mezuk, 2013).

Gender differences in travel behaviours have been long discussed in both transportation research and gender studies (Hanson, 2010). Previous research suggests that compared with men, women tend to drive fewer miles, travel less by car, travel more by public transportation, engage in more chained trips and non-work-related trips, and have

lower levels of transportation mobility (Crane, 2007; Cresswell & Uteng, 2008; Sandra Rosenbloom, 2006; Vance & Iovanna, 2007). With a focus on older adults, empirical research identified that older women are more likely to stop driving or reduce driving frequencies voluntarily or prematurely (before a substantial decrease in physical functioning) (Rosenbloom, 2001; Siren & Haustein, 2016), and that older women are more likely to travel as car-passengers than older man (King & Scott-Parker, 2016). Nonetheless, older women's driving decisions may depend on their living arrangements. Hassan and colleagues (2015) found that older women would prefer to travel as car-passenger but single or widowed older women may choose to drive.

Despite the fact that driving cessation is almost inevitable for older adults and there is a need to provide alternative mobility options, previous research argued that public transportation cannot support comparable levels of activity-participation and quality of life. In the United States, Kim (2011) found that providing transit services within walking distance does not solve the transportation deficiency among the elderly, because transit routes that are primarily designed for commuters do not meet older adults' diverse travel demands. Also, studies suggested that to accommodate the special needs of aging populations, public transportation systems need substantial improvements and sufficient funding (Li et al., 2012; Mercado, Páez, & Newbold, 2010).

Moreover, recent studies have identified a series of negative health impacts associated with driving cessation, including depressive symptoms, decreased physical functioning, and feelings of isolation(e.g. Ragland, Satariano, & MacLeod, 2005; Edwards et al., 2008; Peel, Westmoreland, & Steinberg, 2002), as well as the association between driving cessation and reduced outdoor activities and decreased social networks among older adults (Mezuk & Rebok, 2008). Because of the mobility gap caused by driving cessation, the insufficiencies of using public transportation as an alternative, and the negative health consequences associated with decreased automobility, researchers have suggested that policies should help older adults continue driving as long as they are able to (Choi & Mezuk, 2013; Kim, 2011). They also argued that older females tend to stop driving due to "a lack of routine and confidence" and thus policy should support them to continue driving (Siren and Haustein, 2016, p.32).

In a car-dependent built environment, studies found that older former drivers tend to rely on their social networks, especially family members and friends, to support their travel tasks by driving them to destinations, and this derived demand generates more car trips and increased vehicle miles travelled than older adults driving by themselves (Alsnih & Hensher, 2003). In addition, King and Scott-Parker (2017) found that older Australians' driving time declined with age, but their travel demands are not substituted by travelling as car-passengers or with other modes. However, in a walkable built environment, high mode share of walking was found among older adults and walking is regarded as an important alternative to travelling by car (Stjernborg, Emilsson, & Stahl, 2014).

Though the gap in automobility has been commonly discussed in existing literature, relatively few studies have examined its generational variations (Tilley & Houston, 2016). Particularly, with a growing aging population, it is important to understand the implication of (the lack of) transportation mobility for an increasing number of females in advanced old age, and the extent to which the gender gap of automobility will continue in new generations of older adults.

5.3 Method

5.3.1 Survey data

To understand the change in travel behaviours among different cohorts over time, this study uses the General Social Survey (GSS) time-use cycles and combines all the available data collected in 1986, 1992, 1998, 2005 and 2010. The GSS contains a series of nation-wide cross-sectional surveys that have recurring topics roughly every five years. The time-use cycles include a retrospective one-day time-use diary, with detailed information on the duration and the type of places (for each episode of activity) or travel modes (for each episode of travel). In addition, contextual information such as socioeconomic status and self-reported health are also collected from each respondent. The GSS uses a complex survey design, and for each cycle, survey weights are provided by the Statistics Canada to facilitate nationally representative analysis.

To use survey weights for the pooled multiple cycles, the study adjusts the weights for each survey cycle *Wi* according to the ratio between its total weighted population *Ni* and

the sum of total weighted population for all the included survey cycles $\sum Ni$. This method is a simple and widely applicable way to integrate data from different cycles into one sample (Wendt & Wendt, 2007). Therefore, the adjusted survey weights $Wi´$ can be calculated as:

$$Wi´ = Wi \times Ni / \sum Ni$$

Given that the GSS time use cycles have included more questions in recent surveys, have changed the focus of certain groups of questions, and have framed some questions differently in different cycles, this study extracted all the comparable data from 1986 to 2010, and prepared separate data sets for information that is only available in recent surveys. The extracted variables from 1986 to 2010 include age group, gender, education levels, household income levels, immigration status, travel episodes and durations by car, active modes and transit. To add more data in the analysis, data from 1992 to 2010 is pooled separately, with more variables included: self-rated health (5 levels from excellent to poor), urban versus non-urban residents, and travel episodes and durations of driving and travelling as car-passengers. Furthermore, from the 2005 and 2010 data, detailed information on car-access and transit-access is obtained, including: whether the respondent has a valid driver's license, whether he or she lives close to transit, how often he or she has access to car, and how often he or she uses transit over a year.

5.3.2 Cohort analysis

In transportation research, age thresholds, such as the age 65, are commonly used to identify the population of older adults (e.g. Páez, Scott, Potoglou, Kanaroglou, & Newbold, 2007; Schwanen & Páez, 2010). However, a sole focus on age in the analysis often falls short in capturing changes in the aging process of different population groups. In contrast, tracking the changes in travel behaviours for different cohorts can better capture heterogeneous transportation choices among different groups of aging populations, and help to understand how their mobility choices change over time. Cohort analysis has been traditionally used to understand social change, which is interrelated with the life experiences of different birth cohorts (Ryder, 1965). In analyzing behaviour patterns of aging populations, cohort analysis brings a life course perspective and considers the cumulative cohort effect - the fact that individuals' current behaviours are influenced by their past life

experiences (O'Brien, 2015). From a public policy perspective, understanding the cohort differences and their changing trends are important for policy making targeting future generations of aging populations. Longitudinal data with each participant followed over a long period is ideal for a cohort analysis, however, this type of data is often not available. Alternatively, a cohort table can be constructed by linking individuals within the same birth cohort across replicated cross-section surveys, and then, a cohort analysis can be conducted at an aggregated level, assuming the population of each birth cohort is largely the same over time periods. However, without cross-time linkage at the individual level, this method cannot control for the changing mortality rates and migration rates within each cohort in different periods.

With the Canadian GSS data, Newbold and Scott (2017) compared travel behaviours among five birth cohorts: Millennials (born after 1980s), Generation X (born between 1965 and 1979), late boomers (1955–1964) and early boomers (1946–1954), and the Greatest generation (born before 1946). To gain a closer examination on the diverse groups of older adults, this study classifies birth cohorts at a 10-year interval and includes all the cohorts that can be traced from 1986 to 2010. Therefore, according to the age group defined in each survey cycle, five birth cohorts are included in the analysis. The eldest Pre-1930 cohort (born before 1933) that turned advanced old age in 2010. The 1930s-1940s pre-war generation (1934-1943) that became over 65 years old in 2010. The 1940s-1950s early baby-boomers (1944-1953), the 1950s-1960s late baby-boomers (1954-1963), and the 1960s-1970s generation (1964-1973) that became middle aged in 2010. As the 1986 data does not include millennials, this youngest cohort is excluded in this analysis. The sample size and weighted population for each cohort in each period are displayed in Table 5.1.

Table 5.1 Sample size and weighted population by birth cohort

Survey Period	Total sample size and weighted survey population		Sample size and weighted population by birth cohorts				
			1960s-1970s	**1950s-1960s**	**1940s-1950s**	**1930s-1940s**	**Pre-1930s**
1986	N	9946	1776	2708	1862	1016	2584
	weighted N	19892784	4195005	4568881	3690533	2559767	4878598
1992	N	9815	1964	2435	1557	1023	2069
	weighted N	21294313	4223867	4746054	3798565	2563696	4136690
1998	N	10749	2072	2372	1807	1194	1889
	weighted N	24260137	4614892	5251509	4101949	2659503	3573249
2005	N	19597	3465	3861	3389	2547	2455
	weighted N	26095818	4538416	5310489	4275500	2692189	2757590
2010	N	15390	2453	2968	3029	2061	1578
	weighted N	28075610	4767862	5359175	4211015	2518049	2011477
	Age in 1986		15-24	25-34	35-44	45-54	55+
	Age in 2010		35-44	45-54	55-64	65-74	75+

Note: the 1986 survey contains 16,390 records, but only 9,946 of them are included in the episode file that reports time-use diaries. This study used the episode file with 9,946 records and its corresponding survey weights provided by Statistics Canada.

5.3.3 Statistical analysis

This chapter analyzes three types of travel behaviours, including the percentage of people who stayed at home, participation rates in travelling by different modes, and average travel time by different modes. The results are compared between males and females for each cohort and each period. Chi-squared tests are used to identify the period of time when females and males within the same birth cohort have significant differences in their participation of travelling by car, active modes, or transit. Similarly, t-tests are used to identify the period when there is a significant difference in their travel time by different modes. Further, their participation rates in driving and travelling as car passengers are compared with data from 1992 to 2010. Also, with information regarding access to car and access to transit in the 2005 and 2010 cycles, the percentages of older adults holding a valid driver's license, with frequent access to car, living close to transit, and with frequent access to transit, are analyzed for each cohort and gender group.

Building on the descriptive analysis, generalized linear models with survey weights are used to compare how the relationships between contextual factors and transportation mobility vary by gender and how they differ between all cohort groups and the eldest cohort. More specifically, binomial logit models are used to (1) explore socio-demographic factors and health status that are associated with males and females who stayed at home (immobile),

and (2) compare the socio-demographic factors, health status, social time, and walking activity associated with frequent car use and frequent transit use. Dependent variables include staying at home (versus participation in travelling outdoors) (binary), frequent use of car (binary), and frequent use of transit (binary). Independent variables include geographical region (urban versus rural), self-rated health status, and commonly used indicators of socioeconomic status, such as household income, education, living arrangement (or household size), immigration status (because the Canadian population is ethnically diverse, with large percentages of immigrants, immigration status is used instead of race).

Given that the question of rating health status is framed differently in 1986, and the responses are incomparable to other cycles, the 1986 cycle is eliminated in regression models that include self-rated health as an independent variable. In addition, because early surveys did not include questions on car-access or transit-access, and the 2005 survey only asked these questions from half of its total sample (9,746 out of 15,390 total respondents), the 2010 data (N= 19,597) is used in models comparing the socio-demographic context of frequent car use and frequent transit use. The statistical analyses of weighted survey data are conducted in R 3.3.3, with the *survey* package version 3.32-1.

5.4 Results

5.4.1 Immobility by gender and cohort

The health risk of a sedentary lifestyle in old age, especially among homebound older adults who have difficulties travelling outdoors, has been an important concern regarding healthy aging (WHO, 2003). Though the GSS data cannot show the extent to which older adults are homebound due to the lack of transportation mobility, this chapter analyzes the cohort and gender difference of being immobile by comparing percentages of males and females who stayed at home by cohort and by period (Figure 5.1). Further, controlling for period variations, the socio-demographic context of being immobile for both genders and for the oldest cohort (which has the lowest participation rates in travelling outdoors) is analyzed with binomial logit models (Table 5.2). Among cohorts born before the 1970s, men tend to travel outside more than women do, but the gender differences are very small

among early baby boomers in their 50s and early 60s, and among late baby boomers in their late 40s and early 50s. For the 1930s-1940s cohort, percentages of people staying at home decreased in the pre-retirement age (late 50s for women and early 60s for men) and increased in late 60s, but the gender gap became smaller over time. However, high percentages of women in the eldest (pre-1930s) cohort stayed at home in each period. In 2010, above 45% of women in the pre-1930s cohort (over age 75) stayed at home on the survey day, but only about 25% of men over age 75 did not travel outside.

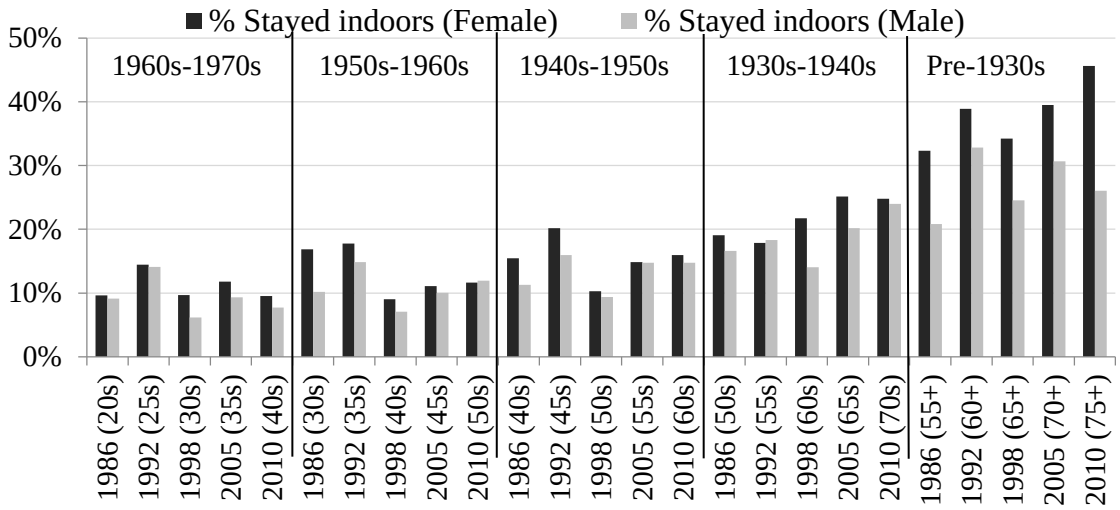


Figure 5.1 Percentage of males and females who stayed indoors (weighted)

Period effects of outdoor travel can be observed. Overall, the participation in outdoor travel is relatively low in 1992 and significantly higher in 1998, which may reflect the economic downturn in the early 1990s and a strong recovery in the late 90s. Controlling for period variations, younger cohorts for both males and females are more likely to travel outdoors. Compared with their male counterparts, females in the baby boomer cohorts and younger cohorts are catching up in their participation of outdoor travel, especially with a significantly low odds ratio of staying indoors in the cohort born after 1970s.

Among all cohort groups, the participation in travel behaviours varies significantly by household income. Compared with middle-income females, females with high household income are 22% less likely to stay indoors, and those with low household income are 42% more likely to stay indoors. In contrast, outdoor travel among males varies less by household income. In the eldest cohort, only the difference between females with high income and

middle household income remains significant. However, across cohort groups, respondents who reported household income as unknown (in which case, the respondents are likely to be a dependent of the household) are more likely to stay indoors.

Respondents with lower education (attended high school and below) are less likely to travel outdoors across cohorts. In the eldest cohort, the association between lower education level and less outdoor travel is stronger in males than in females. However, this trend reversed when all cohorts are considered. Particularly, women with high levels of education (university and above) are significantly less likely to stay indoors.

Compared with rural residents, urban dwellers are more likely to travel outdoors. In the eldest cohort, female urban dwellers are 28% less likely to stay indoors, but the difference between males living in urban and rural areas is not significant. Similarly, the difference in travelling outdoors between male immigrants and male natives is insignificant across cohorts, while female immigrants are 22% more likely to stay indoors than female natives, and the difference is even larger in the eldest cohort. In addition, men's outdoor travel does not vary significantly with household size, but women living in a single-person household are significantly less likely to stay indoors. Even in the eldest cohort, women with smaller household size are more likely to travel outdoors.

Respondents who reported health status as fair or poor have significantly lower participation in outdoor travel than those who reported good health in both males and females across cohorts. Differences between respondents in good, very good, or excellent health conditions are insignificant in general, but men reporting excellent health in the eldest cohort are significantly more likely to travel outdoors than men reporting good health.

Table 5.2 Socio-demographic contexts of staying indoors (binary) (weighted)

	All Cohorts		Pre-1930s Cohort	
	Male	**Female**	**Male**	**Female**
Variables	**OR(95%CI)**	**OR(95%CI)**	**OR(95%CI)**	**OR(95%CI)**
Household income (ref=Mid-income)				
Low	1.38 (1.20,1.58)***	1.42 (1.26,1.59)***	1.22 (0.89,1.65)	1.41 (1.07,1.84)*
High	0.81 (0.70,0.95)**	0.78 (0.68,0.91)***	1.13 (0.71,1.78)	0.89 (0.48,1.64)
Unknown	1.54 (1.35,1.75)***	1.41 (1.26,1.57)***	2.0 (1.48,2.69)***	1.68 (1.29,2.18)***
Education (ref=Mid-education)				
High (university and above)	0.96 (0.83,1.11)	0.90 (0.79,1.02).	1.20 (0.82,1.74)	1.00 (0.72,1.39)
Low (high school and below)	1.32 (1.18,1.48)***	1.35 (1.23,1.48)***	1.45 (1.11,1.89)**	1.34 (1.12,1.62)**
Unknown	1.02 (0.72,1.44)	1.47 (1.10,1.95)**	1.20 (0.67,2.17)	1.47 (0.90,2.38)
Urban dweller	0.73 (0.66,0.81)***	0.80 (0.73,0.87)***	0.86 (0.68,1.08)	0.72 (0.61,0.85)***
Immigration (ref = Native)				
Immigrant	1.07 (0.94,1.21)	1.22 (1.10,1.36)***	1.29 (0.99,1.68).	1.38 (1.13,1.69)**
Unknown	1.34 (0.84,2.13)	1.88 (1.26,2.80)**	1.27 (0.59,2.72)	1.83 (0.96,3.48).
Household size (ref=3 persons)				
1 person	0.96 (0.82,1.12)	0.84 (0.74,0.97)*	0.86 (0.55,1.35)	0.63 (0.44,0.91)*
2 persons	0.98 (0.85,1.13)	0.93 (0.82,1.05)	0.75 (0.48,1.16)	0.67 (0.46,0.98)*
4 and above	0.91 (0.78,1.06)	0.97 (0.85,1.10)	0.98 (0.44,2.20)	1.08 (0.57,2.02)
Health status (ref=Good)				
Excellent	0.91 (0.79,1.05)	0.92 (0.82,1.04)	0.58 (0.40,0.82)**	0.84 (0.64,1.09)
Very Good	0.99 (0.87,1.12)	0.92 (0.83,1.02).	1.12 (0.84,1.48)	0.90 (0.74,1.10)
Fair	1.37 (1.17,1.6)***	1.37 (1.21,1.54)***	1.50 (1.11,2.04)**	1.46 (1.18,1.81)***
Poor	2.55 (2.04,3.2)***	2.21 (1.86,2.62)***	1.92 (1.25,2.94)**	2.69 (1.96,3.70)***
Unknown	1.36 (0.87,2.13)	0.65 (0.43,1.00)*	0.86 (0.43,1.72)	0.69 (0.35,1.37)
Period (ref=2005)				
1992	1.12 (0.98,1.28).	1.04 (0.93,1.17)	1.05 (0.79,1.40)	0.89 (0.72,1.10)
1998	0.59 (0.51,0.68)***	0.67 (0.60,0.75)***	0.69 (0.51,0.94)*	0.71 (0.57,0.88)**
2010	1.01 (0.90,1.14)	1.04 (0.94,1.15)	0.83 (0.62,1.12)	1.36 (1.10,1.70)**
Birth cohort (ref =1950s-1960s)				
Pre-1930s	2.38 (2.02,2.81)***	3.51 (3.04,4.05)***		
1930s-1940s	1.66 (1.41,1.95)***	1.78 (1.53,2.07)***		
1940s-1950s	1.28 (1.10,1.49)**	1.23 (1.07,1.41)**		
1960s-1970s	0.82 (0.70,0.97)*	0.95 (0.83,1.10)		
After-1970s	0.69 (0.57,0.82)***	0.65 (0.56,0.76)***		
Intercept	0.14***	0.14***	0.31***	0.59*
AIC	17784.45	25176.59	3405.56	6505.95
No. of Observations	24560	30991	2931	5060

*** p < 0.001 **p < 0.01 *p < 0.05 . p < 0.1

5.4.2 Different travel behaviours between men and women by cohort

Participation rates in travelling by different modes are further analyzed (Figure 5.2, Table 5.3). Chi-squared test results indicate whether the difference between males and females is significant for each cohort in each period. Compared with other modes, the participation rate in car-travel remains highest from 1986 to 2010 for each cohort. Males tend to have higher participation rates in car-travel than females over the life course, and the gender differences are significant particularly among older adults age over 65. There are clear cohort differences in car-travel. In the 1930s-1940s cohort, 73.8% of males in their early 60s travelled by car and the participation rate of their female counterparts is only 68.5%. However, in the early baby boomer cohort, 78.3% of males and 75.7% of females in their early 60s travelled by car.

Although females tend to travel less and participate less in car-travel than males, their participation rates in travelling by active modes and by transit tend to be higher than their male counterparts over the life course. Particularly, females in their late 60s and early 70s have significantly higher participation rates in active travel than males. The participation rates in travel by active modes are relatively high among younger age groups. In the age of late 50s and early 60s, both males and females in the baby boomer cohorts participated less in active travel than previous cohorts did. The participation rate in travel by transit remains moderate among people over age 30, a gradual decrease of transit-use in the aging process can be observed among both older males and females, except for an increase in 2005 among older females in the Pre-1930s cohort, and increases in 2010 among older females in the baby boomer cohorts.

Among those who travelled outside, differences in average trip durations between genders are compared, and t-test results indicate whether the trip durations are significantly different between genders. In each cohort, middle-aged (40s to 50s) males tend to take significantly longer car-trips than females, yet the gender difference is mostly insignificant among older adults. Only few significant differences in trip duration are observed between males and females travel with active modes or transit. Among older adults, the average duration of active travel is mostly under 15 minutes, car-travel ranges between 20 minutes to 30 minutes, while the average travel time by transit is between 30 minutes to 50 minutes.

Though participation rates in travelling by transit are relatively low among older adults, transit trips tend to be longer trips.

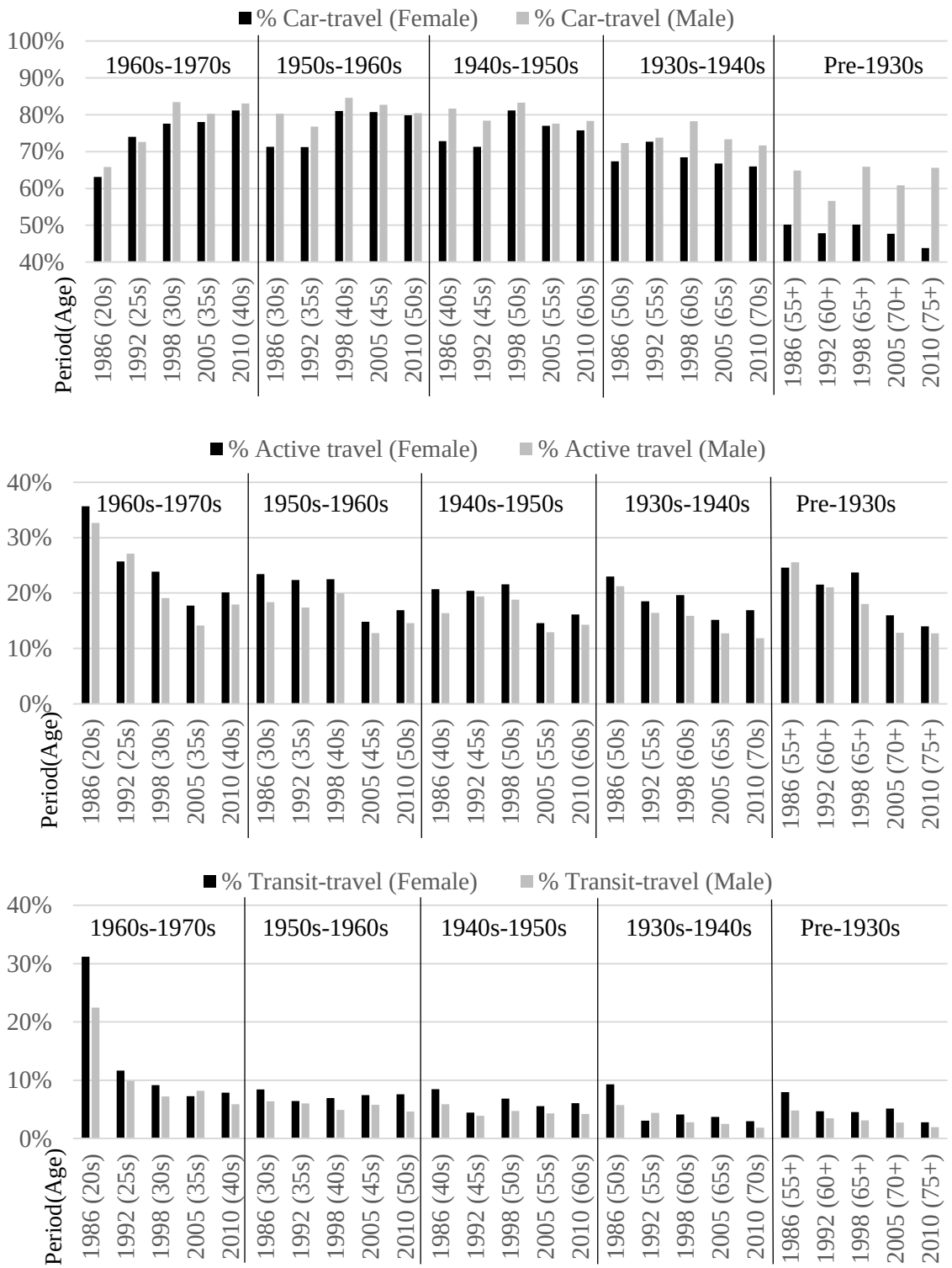


Figure 5.2 Percentage of males and females travelled by different modes (weighted)

Table 5.3 Difference in participation rates and average duration of travel between men and women by transportation mode

Modes		**Car Travel**				**Active Travel**				**Travel by Transit**			
		Participation Rate (%)		Avg. Duration (min)		Participation Rate (%)		Avg. Duration (min)		Participation Rate (%)		Avg. Duration (min)	
Cohort	Age	Diff.	sig.	Diff.	p(t)	Diff.	sig.	Diff.	p(t)	Diff.	sig.	Diff.	p(t)
	20s	2.7	0.206	1.0	0.611	-3.0	0.460	**6.8**	**0.014**	**-8.8**	**0.002**	-1.4	0.542
1960s	25s	-1.4	0.157	**6.0**	**0.000**	1.4	0.660	2.8	0.163	-1.7	0.104	2.4	0.514
-	30s	**5.8**	**0.002**	**5.3**	**0.000**	**-4.8**	**0.047**	2.2	0.131	**-1.9**	**0.018**	-5.9	0.114
1970s	35s	2.3	0.341	**4.7**	**0.000**	**-3.6**	**0.005**	0.1	0.938	1.0	0.406	7.5	0.282
	40s	1.9	0.236	**4.3**	**0.002**	-2.2	0.138	2.7	0.060	**-2.0**	**0.008**	5.9	0.469
	30s	**9.0**	**0.000**	2.3	0.105	**-5.0**	**0.008**	4.5	0.222	**-2.0**	**0.049**	3.7	0.528
1950s	35s	**5.5**	**0.004**	**4.3**	**0.001**	**-5.0**	**0.002**	1.7	0.468	-0.4	0.568	-0.0	0.997
-	40s	**3.5**	**0.019**	**4.2**	**0.000**	-2.5	0.272	-1.9	0.190	**-2.0**	**0.015**	-2.3	0.606
1960s	45s	2.0	0.292	**3.8**	**0.003**	**-2.0**	**0.034**	-0.1	0.928	**-1.6**	**0.037**	-3.3	0.508
	50s	0.6	0.808	**7.3**	**0.000**	-2.4	0.164	1.6	0.318	**-3.0**	**0.021**	-7.8	0.058
	40s	**8.9**	**0.000**	**6.4**	**0.008**	**-4.3**	**0.038**	5.9	0.097	**-2.6**	**0.032**	**12.3**	**0.023**
1940s	45s	**7.1**	**0.000**	**3.5**	**0.013**	**-1.0**	**0.040**	-0.4	0.868	-0.5	0.212	4.4	0.586
-	50s	2.1	0.252	**3.6**	**0.017**	-2.8	0.234	0.9	0.544	-2.2	0.069	3.5	0.557
1950s	55s	0.6	0.844	**7.0**	**0.000**	**-1.6**	**0.010**	**2.6**	**0.029**	-1.3	0.551	-3.3	0.365
	60s	2.6	0.342	**5.2**	**0.007**	-1.8	0.219	1.7	0.268	-1.9	0.104	-7.4	0.276
	50s	**5.0**	**0.001**	**7.3**	**0.000**	-1.7	0.883	-0.2	0.972	**-3.5**	**0.012**	-10.3	0.438
1930s	55s	1.1	0.980	2.1	0.325	-2.1	0.097	-1.4	0.640	1.4	1.000	-12.2	0.150
-	60s	**9.8**	**0.003**	**4.4**	**0.077**	-3.7	0.264	1.0	0.562	-1.3	0.391	3.9	0.832
1940s	65s	**6.6**	**0.009**	0.7	0.720	**-2.4**	**0.035**	-0.1	0.977	**-1.2**	**0.015**	2.7	0.717
	70s	**5.7**	**0.001**	1.4	0.543	**-5.0**	**0.002**	**4.8**	**0.031**	-1.1	0.134	-9.9	0.394
	55+	**14.6**	**0.000**	**8.3**	**0.003**	1.0	0.986	**14.9**	**0.000**	**-3.1**	**0.002**	11.4	0.075
	60+	**8.8**	**0.000**	1.5	0.364	-0.5	0.117	**7.8**	**0.002**	**-1.2**	**0.013**	15.8	0.154
Pre-1930s	65+	**15.7**	**0.000**	0.4	0.831	**-5.7**	**0.006**	3.3	0.071	-1.4	0.240	-9.8	0.403
	70+	**13.2**	**0.000**	**5.3**	**0.026**	**-3.2**	**0.005**	0.9	0.507	**-2.4**	**0.010**	4.0	0.661
	75+	**21.8**	**0.000**	-4.5	0.233	-1.3	0.155	1.1	0.601	-0.9	0.112	5.3	0.653

Note: Results of participation rates are weighted. Diff. values show the differences between men and women, and negative Diff. values indicate higher values among women. Sig. values are p values of Chi-squared test between males and females in the same cohort. Chi-squared test and average duration calculations are unweighted

A larger gap between males and females can be observed in their participation in driving and travelling as car-passengers. As shown in Figure 5.2, the participation rate in driving among males over 30 remains high (mostly over 70%), except for the pre-1930s cohort, and the percentage of males travelling as car-passengers remains lower than 10%. Among older adults in the 1930s-1940s cohort, their participation rate in driving declined steadily between 1998 and 2010 (9.5%), but their participation in travelling as car-passengers only increased slightly (2.8%) when they reached their 70s. Although younger cohorts of females tend to drive more than previous cohorts, females are much less likely to

drive in older age than males. At the same time, the percentage of females travelling as car-passengers remains above 20% for each cohort over time. In the 1930s-1940s cohort, about 30% of older females travelled as car-passenger, and their participation rates in driving are slightly above 40%. However, the decrease in participation rate in driving among older females is also not accompanied with an increase in travelling as car-passenger, especially among the pre-1930s cohort.

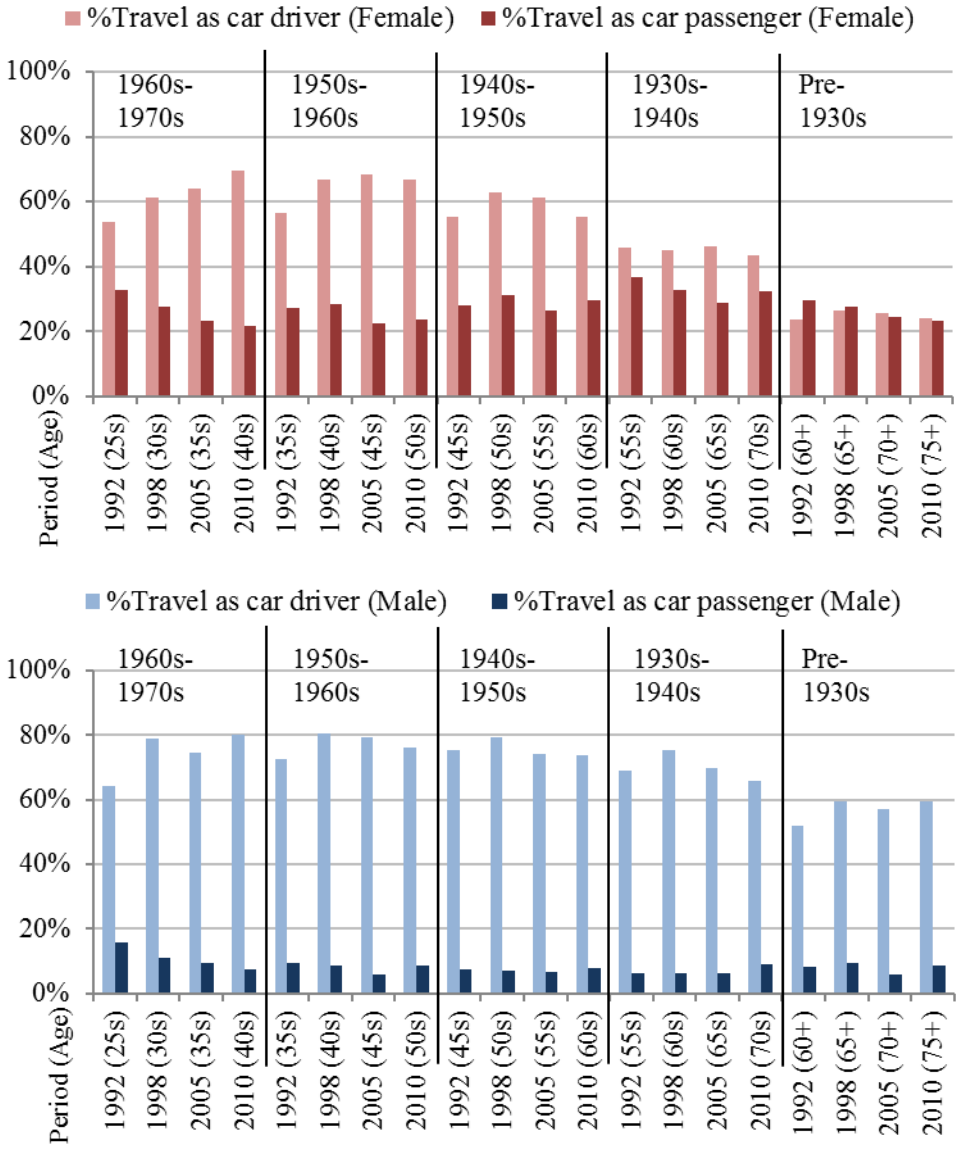


Figure 5.3 Percentage of males and females travelled as drivers and passengers (weighted)

5.4.3 Socio-demographic context of frequent car use and frequent transit use

With data from 2005 and 2010, the access to car and transit by cohort and gender is analyzed in Figure 5.4 and Figure 5.5. Except for the eldest cohort, the percentages of males holding a driver's license are over 90% in both periods, and the percentages among females are above 80%. Among older males in the Pre-1930 cohort and the 1930s-1940s cohort, the percentage of holding a driver's license only decreased less than 1% from 2005 to 2010. The percentages of holding a driver's license among females increased in each cohort, particularly, the percentage among females in their early 70s (in the 1930s-1940s cohort) increased 3.7%. In 2010, about 91% of men and 87% of women reported having frequent access to car. Among birth cohorts between the 1930s and the 1970s, the percentage of having frequent access to car remains above 95% among males, and above 91% among females in both 2005 and 2010. In the eldest cohort, however, the percentage decreased 4.9% among older males, and 18.8% among older females. Among the eldest cohort in 2010, about 52.1% of women and 84.9% of men have a valid driver's license and frequent access to car, and 19.6% of women and 6.9% of men have frequent access to car but without a driver's license.

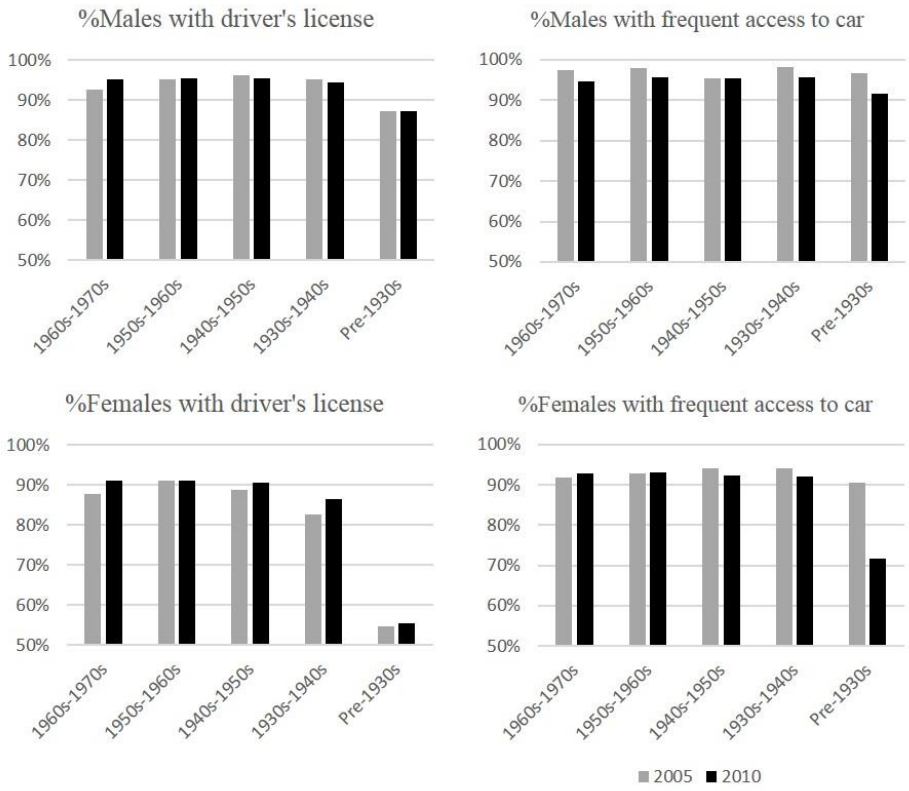


Figure 5.4 Percentages of males and females have a driver's license and frequent access to car (weighted)

In 2010, the percentage of Canadians who live close to transit services (including subways, trains and buses) is above 60% for each cohort and the percentage is increased in younger cohorts from 2005 to 2010. Yet the percentage of frequent transit users remains under 30% and decreases in each cohort. This result indicates a potential mismatch between transit provision and transit use. Compared with older males, older females are more likely to live close to transit and to be frequent transit users. Yet the percentage of frequent transit users among older females in the eldest cohort decreased 12.4%. In 2010, about 15.5% of women and 7.6% of men in the eldest cohort (aged 75 and over) lived close to transit and used transit frequently, and 39.6% of women and 39.4% of men in this cohort lived close to transit but did not use transit over the whole year.

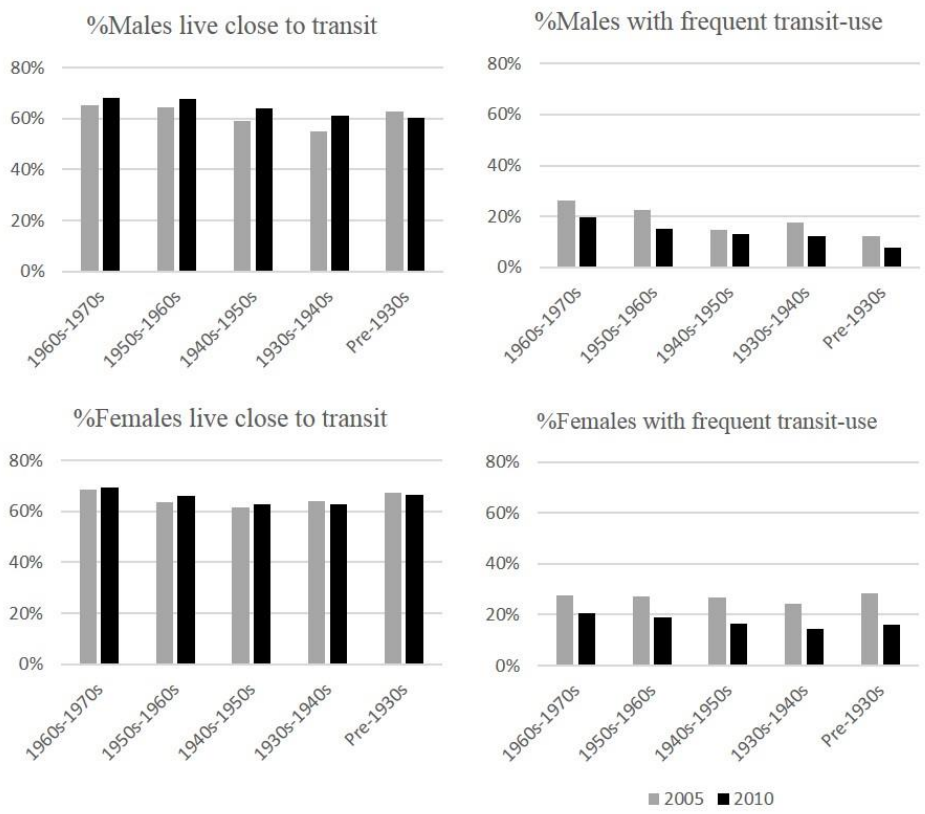


Figure 5.5 Percentages of males and females live close to transit and use transit frequently (weighted)

To explore the demographic and socioeconomic differences between frequent transit users and frequent car users, and to compare the differences between all cohort groups and the eldest cohort, a set of generalized linear models are developed with 2010 data (Table 5.4). Compared with late baby boomers, young generations born after the 1970s are about 3 times more likely to use transit frequently. Differences between middle-aged cohorts (born between 1940s and 1970s) in both frequent transit use and frequent car use are insignificant. However, the older cohorts (aged 65 and over) are significantly less likely to use transit frequently. Particularly, compared with the late baby boomers, respondents from the eldest cohort are 44% less likely to use transit frequently and 47% less likely to use car frequently.

Females are significantly more likely to be frequent transit users and less likely to be frequent car users than males across cohort groups. Particularly in the eldest cohort (aged 75 and over in 2010), women are more than twice as likely to use transit frequently than males, and about 58% less likely to use car frequently than men. Among all cohort groups,

respondents with low household income are more likely to use transit frequently and less likely to use cars frequently, but there is no significant difference between respondents with middle income and high income. In the eldest cohort, however, respondents with high household income are less likely to use transit frequently. Similarly, comparing to respondents with middle level education (some college), respondents with lower education levels are more likely to be frequent users of transit and less likely to be frequent car users among all cohort groups. Yet at the same time, respondents with higher education level are more likely to use transit frequently, even in the eldest cohort.

Compared with rural residents, urban dwellers are significantly more likely to be frequent users of transit, and the difference is particularly strong in the eldest cohort. Although urban dwellers are less likely to be frequent users of cars, the difference in frequent car-use between urban and rural residents decreases in the eldest cohort. Compared with those who are Canadian-born, immigrants, who tend to have shorter experience in the culture of automobility, are more likely to be frequent users of transit and less likely to be frequent users of cars, such differences between immigrants and natives are particularly strong in the eldest cohort. Frequent car-use and transit-use vary significantly with living arrangements. Among all cohort groups, respondents living alone, in a mixed type (with relatives or roommates), or in a single-parent household, are more likely to use transit frequently and less likely to use a car frequently. In the eldest cohort, these household types are still significantly associated with less chances of frequent car use, but only the mixed type of household is associated with higher chances of frequent transit use.

Table 5.4 Socio-demographic contexts of frequent car-use and transit-use (weighted)

	All Cohorts		Pre-1930s Cohort	
	Frequent transit use (binary)	**Frequent car use (binary)**	**Frequent transit use (binary)**	**Frequent car use (binary)**
Variables	OR(95%CI)	OR(95%CI)	OR(95%CI)	OR(95%CI)
Gender (female)	1.16 (1.03,1.30)*	0.70 (0.60,0.83)***	2.19 (1.38,3.55)**	0.42 (0.29,0.60)***
Household Income (ref=Mid-income)				
Low	1.45 (1.23,1.71)***	0.46 (0.36,0.58)***	0.94 (0.51,1.75)	0.41 (0.21,0.76)**
High	1.09 (0.92,1.30)	1.01 (0.75,1.37)	0.10 (0.01,0.46)*	0.76 (0.28,2.25)
Unknown	1.69 (1.42,2.01)***	0.45 (0.35,0.58)***	0.83 (0.45,1.55)	0.34 (0.18,0.63)***
Education (ref=Mid-education)				
High (university and above)	1.75 (1.51,2.02)***	1.10 (0.88,1.38)	1.66 (0.91,2.98).	0.93 (0.57,1.54)
Low (high school and below)	1.17 (1.01,1.35)*	0.64 (0.53,0.77)***	1.18 (0.76,1.85)	0.86 (0.62,1.19)
Unknown	0.73 (0.42,1.30)	0.73 (0.39,1.37)	0.28 (0.02,1.41)	0.57 (0.23,1.45)
Urban dweller	6.47 (5.07,8.25)***	0.44 (0.35,0.54)***	11.73 (4.2,52.0)***	0.65 (0.43,0.95)*
Immigration (ref = Native)				
Immigrant	2.06 (1.79,2.38)***	0.68 (0.56,0.82)***	2.21 (1.45,3.36)***	0.56 (0.40,0.78)***
Unknown	1.84 (0.68,4.96)	0.59 (0.24,1.43)	0.50 (0.00,5.54)	0.42 (0.07,2.53)
Living arrangement (ref=Couple)				
Core family	1.11 (0.95,1.30)	0.75 (0.58,0.96)*	1.57 (0.57,3.86)	1.05 (0.45,2.75)
Mixed type	1.62 (1.21,2.17)**	0.34 (0.24,0.49)***	4.1 (1.17,12.75)*	0.18 (0.07,0.47)***
Single	1.37 (1.14,1.65)***	0.31 (0.24,0.40)***	0.99 (0.49,2.07)	0.25 (0.13,0.45)***
Singe-parent	1.57 (1.27,1.94)***	0.40 (0.30,0.54)***	0.68 (0.25,1.69)	0.34 (0.19,0.62)***
Health status (ref=Good)				
Excellent	0.95 (0.8,1.140)	1.48 (1.15,1.90)**	1.54 (0.84,2.77)	0.69 (0.44,1.09)
Very Good	0.99 (0.86,1.14)	1.28 (1.05,1.56)*	1.11 (0.68,1.80)	1.35 (0.92,1.98)
Fair	1.07 (0.89,1.29)	0.81 (0.64,1.03).	0.76 (0.42,1.34)	0.63 (0.43,0.92)*
Poor	0.89 (0.64,1.23)	0.51 (0.36,0.72)***	0.85 (0.34,1.93)	0.47 (0.27,0.82)**
Unknown	0.42 (0.12,1.54)	0.71 (0.28,1.79)	0.96 (0.08,6.45)	0.60 (0.17,2.57)
Number of walking trips				
Active travel	1.44 (1.38,1.51)***	0.67 (0.64,0.71)***	1.42 (1.20,1.68)***	0.80 (0.70,0.92)**
Recreational walking	1.16 (1.02,1.32)*	0.82 (0.69,0.98)*	1.41 (0.93,2.09).	0.87 (0.63,1.22)
Time spent with social contacts (hour)				
with household member	0.96 (0.95,0.98)***	1.05 (1.02,1.07)***	0.93 (0.87,0.99)*	1.04 (0.98,1.09)
with non-household member	0.98 (0.97,1.00)**	1.05 (1.03,1.07)***	0.92 (0.86,0.98)*	1.05 (1.01,1.10)*
Birth cohort (ref =1950s-1960s)				
Pre-1930s	0.56 (0.43,0.72)***	0.53 (0.40,0.70)***		
1930s-1940s	0.71 (0.56,0.89)**	1.35 (1.00,1.83).		
1940s-1950s	0.88 (0.72,1.06)	1.03 (0.79,1.36)		
1960s-1970s	1.16 (0.96,1.39)	0.84 (0.63,1.12)		
After-1970s	3.52 (2.98,4.15)***	0.29 (0.23,0.37)***		
Intercept	0.02***	96.43***	0.01***	72.51***
AIC	13640.37	8234.64	1010.88	1276.264
Number of Observations	15390	15390	1578	1578

*** p < 0.001 **p < 0.01 *p < 0.05 . p < 0.1

Among all cohort groups, better self-rated health status is associated with higher chances of frequent car use, while respondents with fair or poor health status are less likely to use cars frequently. Particularly in the eldest cohort, respondents who reported poor health status are 53% less likely to use cars frequently. However, frequent transit use does not vary significantly with health status across cohorts. In addition, frequent car use is associated with less active travel or recreational walking among all cohort groups, while frequent transit use has significant positive associations with active travel and recreational walking, even in the eldest cohort. Yet frequent transit use is associated with less social time spent with household members or non-household members.

5.5 Discussion

5.5.1 Gender differences in transportation mobility across cohorts

In line with previous research (Mercado & Páez, 2009; Newbold & Scott, 2017; Newbold et al., 2005; Páez et al., 2007; Scott et al., 2009), this chapter shows that automobility remains important over the life course of the aging populations in Canada, and the use of public transit remains limited among older adults. The overall participation rate in car-travel is much higher than travelling with other modes for each cohort and gender group. Within each cohort, older females are more likely to travel by active modes and by transit than are their male counterparts. Yet a noticeable decline in older females' participation rates in travelling with alternative modes is observed in recent periods, especially among females turning advanced old age. Comparing across age groups, automobility among older adults has increased over time. However, in the eldest cohort, high percentages of older adults stayed indoors, and there is a wider gender gap of being immobile among those in advanced old age.

The results also recapture findings in other contexts that older females are less likely to hold a driver's license and more likely to travel as car-passengers than older males (e.g. Li et al., 2012; King & Scott-Parker, 2016). Although gender differences in driving and car-travel frequency remain significant, particularly in advanced old age, a smaller gender gap in automobility is seen among the boomer cohorts. An increase in the percentage of older

females holding a driver's license is observed in recent periods, especially among females in the birth cohorts between the 1930s and the 1950s.

Mobility is gendered, and the gender difference is interrelated with social roles at different life stages (Cresswell & Uteng, 2008; Hanson, 2010). Recent studies have shown that with younger generations of women participating more in the labor-market and attaining higher levels of education, mobility levels between gender groups are converging (e.g. Rosenbloom & Herbel, 2009; Tilley & Houston, 2016). Tilley and Houston (2016) reported a gender turnaround in mobility levels among younger populations in the UK. Similarly, in Canada, women's participation rates in driving steadily increases by cohort (as shown in Figure 5.3).

As emphasized by recent studies, mobility levels among aging populations and among new generations of females have remained high and have been increasing over time (e.g. Newbold et al., 2005; Schwanen & Paez, 2010; Tilley & Houston, 2016). Despite an overall increase of automobility over time, there are still significant gaps in transportation mobility between the eldest cohort and the overall aging populations, and between females and males in advanced old age. For a growing population of the oldest-old, in which females are about two thirds of the population, there is a potential risk that they face a substantial decrease in automobility (led by a sudden change of health condition or living arrangement), and no alternative transportation option is readily available or easily accessible to them.

Compared with their male counterparts, older women's transportation mobility varies more by socioeconomic status, living arrangements and rural/urban settings, and women's transportation mobility may be more affected by changes in socioeconomic factors and family structures in the aging process. Although baby boomer generations and younger generations of females tend to have substantially higher levels of mobility, and especially automobility, there are significant variations in mobility levels among females across cohort groups. Females that are immigrants, rural residents, or with relatively low household income, may still have substantial mobility deficiency and relatively high risks of being homebound as they age.

5.5.2 Mobility options for non-drivers

The observed preference for automobility among older adults and the concerns regarding safety of driving in old age leads to heated debates on driving cessation policies and the provision of accessible transit services. Two distinct perspectives have shown in previous studies that provide policy suggestion on supporting transportation mobility for aging populations. On one side, scholars argued that having access to a car and being able to continue driving are important aspects of older adults' health and well-being (Choi & Mezuk, 2013; Siren & Haustein, 2016; Anu Siren, Hakamies-Blomqvist, & Lindeman, 2004). Existing research shows that older adults, especially older men, are reluctant to ask family and friends for transport assistance in everyday activities, and consequently, older non-drivers undertake substantially less discretionary travel (such as for leisure), which has negative impacts on their quality of life (e.g. Alsnih & Hensher, 2003; Davey, 2007). Emphasizing the convenience and high levels of mobility cars provide, scholars argue that transportation policy needs to focus primarily on helping older adults continue driving (Kim, 2011; Siren & Haustein, 2016). One the other side, scholars argue for stricter evaluations of older drivers to ensure safety, and emphasize the need for affordable (subsidized) mobility options; improvements on accessibility, comfort, flexible routes and security of public transit; the adoption of assistive technologies for older adults with age-related disability (e.g. Mercado, Páez, & Newbold, 2010; Metz, 2003; Metz, 2000).

Across Canada, the percentage of car-travel is overwhelmingly high, and public transit can hardly compete with private cars, or provide an equivalent level of mobility for the growing population of older adults. However, considering both the social context and the built-environment context, the system of automobility hinders the mobility and accessibility of older adults who are unable to drive or have limited access to a car. Particularly, over the life course, people with relatively poor health have significantly higher chances to stay indoors, and lower changes to use either car or transit frequently. In addition, without adequate transit infrastructure, older rural residents are much more car-dependent. As shown in above analysis, in the eldest cohort, females living in rural areas are 28% more likely to stay indoors.

The dominance of car-use over alternative modes is embedded in the car culture that has strong influence on the baby boomer generations over the life course. Among older cohorts, however, as females tend to take on more domestic activities and have less access to a car (Pooley, Turnbull, & Adams, 2005; Tilley & Houston, 2016), they tend to drive less and travel more as car-passenger than males. Consequently, they tend to give up driving earlier and have less frequent access to a car. Similarly, immigrants who tend to have less experience with the Canadian driving culture are more likely to use transit frequently.

Older adults that have relatively poor health conditions and live in places away from transit infrastructure are most likely to be disadvantaged by a gradual decrease in mobility in the car-dependent environment. Despite suggestions that transportation policy should focus on helping older adults, especially older females, to continue driving (e.g. Siren et al., 2004; Kim, 2011; Li et al., 2012; Siren & Haustein, 2016), the deficiency in transportation mobility among these disadvantaged groups cannot be reconciled by stronger support for driving. Instead, an overemphasis on automobility may lead to a stronger disparity of transportation mobility among aging populations. With a large population of females in advanced old age in the coming decades, their demands in mobility options need special attention in policy-making.

Nonetheless, the above analysis shows that transit-use decreased in advanced old age, and above 39% of older adults aged 75 and over lived close to transit but did not use transit over the whole year. This indicates a potential spatial mismatch - older adults who need affordable transit services most do not live in locations where transit services are readily available and accessible, while older adults living close to transit have adequate socioeconomic resources to support frequent car use.

With new assistive technologies and new forms of automobility, such as self-driving cars and rideshare applications, transportation mobility levels among new generations of older adults are likely to increase over time. Also, the gender gap of automobility among older adults, resulted in the factor that females are more likely to stop driving in old age, may diminish in the coming decades. Although a majority of car-travel, especially among males, has been driving with private cars, driving may not be as prevalent among new generations of older adults and automobility may show in more varied forms – it can be

driving private cars, travelling by car as a passenger with household members, or sharing a car with non-household members.

Notably, frequent users of transit tend to take more walking trips, both in terms of active travel and recreational walking, yet they also tend to spend less time with social contacts. A growing amount of research has identified associations between healthy aging and physical actives such as walking (see Chapter 2), yet few studies have compared health impacts of active travel, transit-use and automobility at the same time. While car-travel is associated with increased sedentary time, it shows positive associations with social time with family and friends, and it provides high levels of mobility, easy access to opportunities and social participation, which are important for older adults' quality of life. In contrast, walking and travelling by transit are associated with more physical activities and potentially some informal social interactions with other pedestrians or transit users. With ever increasing transportation mobility for new generations of older adults, the experience of travel and the health impact of travel may become more important for their decisions on mobility options.

5.6 Conclusion

Beyond a widely shared understanding of age differences in travel behaviours, this chapter disaggregates mobility behaviours by gender and explores how social factors influence older males and females differently. In Canada, automobiles remain a primary mobility option for each cohort and gender group. The analysis shows a significant gender gap in automobility among older adults, particularly among the eldest cohort. However, women's participation rate in driving steadily increases by cohort, and the percentage of older females holding a driver's license increases in recent periods. Although younger generations of women show much higher levels of transportation mobility, the mobility gaps between the eldest cohort and the overall aging populations, and between females and males in advanced old age remain significant. Particularly, among women in the eldest cohort, there is a decline in travelling with cars or alternative modes in recent periods. In addition, older women's transportation mobility varies more by socioeconomic status, living arrangements and rural/urban settings than their male counterparts. Females that are immigrants, rural residents, or with relatively low household income, may still face

deficiency in transportation mobility, especially with a sudden change of health condition or living arrangement in the aging process.

Moreover, in both gender groups, people with relatively poor health have significantly higher chances to stay indoors, and lower chances to use either cars or transit frequently over the life course. Mobility is empowering and providing alternative mobility options for those who do not drive is important for preventing transport-related social exclusion and accumulative disadvantage of non-drivers in old age (Hanson, 2010; Lucas, 2012; Crystal, Shea, & Reyes, 2017). Previous research on public transit for aging populations have addressed the importance of affordability, accessibility, comfort, and safety (e.g. Metz, 2003; Mercado et al., 2007; Mercado et al., 2010), analysis in this chapter points the need to understand the potential spatial mismatch between locations with accessible transit service and places where older adults who need affordable transit services live.

Across cohorts, women show higher participation rates in active travel and travel by transit than men. Even with higher levels of automobility, it is not clear whether new generations of older females will develop higher dependency on private cars, or whether they will still use alternative modes more than their male counterparts. As females are about two thirds of the population of the oldest-old (age 80 and over), their preferences or attitudes towards mobility options need to be better understood in transportation policies that aim at improving mobility of older adults.

This chapter shows clear differences in travel behaviours between the young-old (age 65 to 75) and the old-old (age 75 and over). To understand age differences in transportation mobility and the impact of automobility on activity participation, the next chapter focuses on the age effect on travel behaviours, and examines how the activity participation in aging populations differentiate between car-users and non-car-users in a highly car-dependent built environment of Canada.

Chapter 6 Active without car? Exploring the relationship between automobility and active aging

6.1 Introduction

Staying physically and socially active in old age is key to healthy aging (Rowe & Kahn, 1997). Empirical studies indicate that social participation has positive impacts on various health outcomes, such as self-rated health, mobility disability and depression, and the effects are particularly strong among older adults (Cherry et al., 2013; Richard et al., 2013; Vogelsang, 2016). At the same time, the health benefits of physical activities in old age have been well documented (e.g. Van Cauwenberg et al., 2016).

To promote opportunities for health, social participation and security for the aging population, the World Health Organization (WHO) proposed the concept of "active aging" and further developed guideline and checklist for creating "age-friendly communities" that can support "active aging" (WHO, 2002; WHO, 2007). Increasingly, planning and public health authorities have acknowledged the important role of an enabling built environment in helping older adults stay physically and socially active, and various programs have been implemented to implement micro-scale interventions such as barrier-free design, accessible public facilities, and safe streets (Sykes & Robinson, 2014).

Informed by theses policy frameworks, it is widely accepted that an age-friendly environment should be walkable and have easy access to transit, and such an environment can potentially increase the level of physical activity and social interaction among older adults (Annear et al., 2012). In a car-dependent built environment, however, older adults with decreased level of automobility tend to have restrained access to a variety of destinations, and studies have identified associations between car-travel and older adults' quality of life and health (Banister & Bowling, 2004; Davey, 2007; Kim, 2011).

Two distinct visions on promoting healthy aging can be observed in the existing literature. One vision emphasizes the importance of automobility for healthy aging. With empirical evidence showing the association between driving and older adults' quality of life,

the negative health consequences of driving cessation, and the challenge of substituting car-travel with other modes of transportation in one's later life. Yet this perspective often neglects the fact that the car-dependent built environment creates social exclusion of those who have limited mobility choice and contributes to inequalities in social participation and health among older adults (e.g. Abbott & Sapsford, 2005; Bailey, 2004; Davey, 2007; Shergold & Parkhurst, 2012). The other vision highlights the positive associations between walkable neighbourhoods and older adults' participation in physical and social activities. This perspective, however, often focuses on the neighbourhood scale, without analyzing the extent to which these neighbourhood-scale strategies can influence the travel behaviours and activity participations among older adults in a largely car-dependent built environment. Hence, the relationship between healthy aging and/or active aging and automobility remains inconclusive. Moreover, though a decrease of automobility is an important life transition, very few studies analyzed or compared the trajectories of automobility and activity participation over the life course. Therefore, it is not clear to what extent older people's participation in social and physical activities depends on car-travel and how such car-dependency varies between age-cohorts and social-groups.

Adopting a multilevel model framework of Age-Period-Cohort analysis, this chapter links the Canadian General Social Survey data from 1992 to 2010 and explores the relationships between automobility and activity participation over the life course. The following questions are examined. (1) How do the patterns of travel and activity participation change in the aging process? (2) Does the level of participation in activities become more polarized between people travelling by car and people who did not travel by car in older age? (3) What types of activities are more car dependent for older adults?

6.2 Literature Review

Older adults' participation in social and physical activities has strong impacts on their travel behaviours and quality of life (e.g. Banister & Bowling, 2004; van den Berg, Arentze, & Timmermans, 2011). With data from a longitudinal survey, Vogelsang (2016) identified that concurrent involvement in group-exercises, meeting friends, volunteering and religious attendance is associated with better health outcomes (Vogelsang, 2016). Transportation

research indicates that compared with younger age groups, older adults make as many social trips and travel as long distance for social activities. In addition, because of geographically dispersed social networks, older adults tend to rely more on automobiles and remote communication to participate in social activities (van den Berg et al., 2011).

With enhanced health conditions and increased total wealth observed among the baby boomer generations, the travel demand for activity participation is expected to increase continuously in new generations of older adults (Newbold et al., 2005). However, the aging populations are highly diverse, and the travel behaviours and activity participation rates vary among different subgroups of older adults. Statistics in the US show that compared with older drivers, non-drivers make 15% fewer trips for health related social services, 59% fewer trips for shopping and eating outside, and 65% fewer trips for general social activities (Bailey, 2004). Also, it is found that older people who reside in more affluent neighbourhoods have more social activities regardless of individuals' socio-economic characteristics (Bowling & Stafford, 2007), and it is also observed that they tend to generate more motorized trips and travel longer distance by car (Mercado & Páez, 2009).

Moreover, it is reported that older adults who stopped driving tend to have decreased access to opportunities, services, social networks, and economic and political activities, and the decrease of mobility contributes to the "mobility-related social exclusion" and undermines the quality of life for disadvantage older people (Kenyon, Lyons, & Rafferty, 2002). In addition, studies found that, among older adults, there is substantial subjective transportation deficiency, which means activities are not undertaken because of the perceived inconvenience of travel (Kim, 2011; Siren & Hakamies-Blomqvist, 2004).

In Canada, with a long standing car-oriented development pattern, transportation infrastructure often prioritizes car-use, car ownership remains high, more people keep a driver's license in old age, and the preference for car-travel among older adults is high and is likely to increase (Mercado et al., 2010; Newbold & Scott, 2017). Arguably, with a growing number of healthy and wealthy older adults, those who have limited access to cars, are likely to face increasing mobility challenges because there are fewer resources devoted to mobility options other than automobility. The activity participation, travel demands, and

social inequalities among older adults are widely discussed in the existing literature. Yet limited research examines the relationships between automobility and activity participation from a life course perspective, that is whether the automobility gap between different social groups increases in the aging process, and how the trajectories of activity participation differ between people who travel by car and people who do not travel by car in the aging process.

6.3 Method

6.3.1 Survey data

This study uses the General Social Survey (GSS) time-use cycles. The GSS is a multiple-cycle cross-sectional survey that provides a statistically representative sample of population in Canada. The existing time-use cycles collected data in 1986, 1992, 1998, 2005 and 2010. In order to facilitate comparison, this chapter uses the recent four cycles that have similar design of questions and variable-categories. The GSS time-use data includes a wide range of physical and social activities, as well as sedentary behaviour. There are two distinct advantages of understanding activity patterns of the aging population with the GSS data. The GSS codebook has very detailed classification of activity types, including 10 major activity types and over 160 minor ones (the most recent 2010 data included 264 types of activities), at the same time, the GSS time-use data contains detailed travel diary, including travel modes, travel time, and travel purposes for all episodes of activities in a day. Therefore, the strength of using the GSS data is that it provides direct links between individual's daily activity patterns, travel behaviours, and time constraints.

A clear limitation of this data set, however, is that it only contains each respondent's daily activity of one day. Hence, the survey response does not represent the respondent's typical schedule of everyday life. Nonetheless, at an aggregated level, the survey is designed to be representative of the nation’s population of all age groups (who are above 15 years old), and is sampled almost evenly for each day of the week, and for each month of the year. For each survey cycle, the sample size and the weighted population by age group is displayed in Table 6.1. To capture the overall patterns of travel and activity participation in the Canadian population, this study uses survey weights for both descriptive and statistical analyses. Furthermore, in order to estimate the changing activity patterns of the population

over time, the weights are rescaled so that the total weighted population is not the sum of the weighted population for each period but a weighted average (the method is explained in Chapter 5, section 5.3.1).

Table 6.1 Number of respondents and weighted data by age group by period

Age group	Period	1992	Column %	1998	Column %	2005	Column %	2010	Column %
15-19	N	767	7.8%	672	6.3%	1247	6.4%	761	4.9%
	Weighted	1825441	8.6%	2036083	8.4%	2126211	8.1%	2212516	7.9%
20-24	N	812	8.3%	743	6.9%	1242	6.3%	616	4.0%
	Weighted	1961332	9.2%	2022853	8.3%	2220220	8.5%	2293526	8.2%
25-29	N	1152	11.7%	950	8.8%	1391	7.1%	852	5.5%
	Weighted	2262535	10.6%	2163288	8.9%	2175203	8.3%	2369427	8.4%
30-34	N	1290	13.1%	1122	10.4%	1669	8.5%	1072	7.0%
	Weighted	2440323	11.5%	2451604	10.1%	2198776	8.4%	2332562	8.3%
35-39	N	1145	11.7%	1285	12.0%	1796	9.2%	1198	7.8%
	Weighted	2305731	10.8%	2723206	11.2%	2339640	9.0%	2338292	8.3%
40-44	N	907	9.2%	1087	10.1%	2057	10.5%	1255	8.2%
	Weighted	2064171	9.7%	2528303	10.4%	2714524	10.4%	2429570	8.7%
45-49	N	650	6.6%	983	9.1%	1804	9.2%	1416	9.2%
	Weighted	1734394	8.1%	2212731	9.1%	2595965	9.9%	2757722	9.8%
50-54	N	530	5.4%	824	7.7%	1837	9.4%	1552	10.1%
	Weighted	1335396	6.3%	1889218	7.8%	2282090	8.7%	2601453	9.3%
55-59	N	493	5.0%	642	6.0%	1552	7.9%	1517	9.9%
	Weighted	1228300	5.8%	1438082	5.9%	1993410	7.6%	2260174	8.1%
60-64	N	489	5.0%	552	5.1%	1413	7.2%	1512	9.8%
	Weighted	1155821	5.4%	1221421	5.0%	1502003	5.8%	1950841	6.9%
65-69	N	519	5.3%	555	5.2%	1134	5.8%	1171	7.6%
	Weighted	1052743	4.9%	1124119	4.6%	1190186	4.6%	1433734	5.1%
70-74	N	454	4.6%	545	5.1%	937	4.8%	890	5.8%
	Weighted	913263	4.3%	968127	4.0%	1026204	3.9%	1084315	3.9%
75-79	N	312	3.2%	384	3.6%	741	3.8%	693	4.5%
	Weighted	545168	2.6%	740716	3.1%	819391	3.1%	860112	3.1%
80+	N	295	3.0%	405	3.8%	777	4.0%	885	5.8%
	Weighted	469695	2.2%	740287	3.1%	911995	3.5%	1151365	4.1%
Total	N	9815		10749		19597		15390	
	Weighted	21294313		24260137		26095818		28075610	

6.3.2 Variables

Based on the one-day diary of travel and activity participation of each respondent, this chapter analyzes the changing participation rates in each type of travel and activity of each age group and social group. To facilitate comparison over time and to conduct statistical analysis of the pooled data, this study uses the participation in car-travel as a measure of automobility. Although recent surveys include questions on driver's license and access to

car, the participation in car-travel is the most consistent measure for automobility over survey cycles. Also, to better understand the alternatives to automobility, respondents' participation rates in travel by active modes and by transit are analyzed and compared with that in car-travel.

While Vogelsang (2016), defined social participation as the involvement in all social, organizational and communicational activities, this study uses a detailed classification of social and physical activities based on the activity categories in the GSS, and examines social participation, socializing, shopping and obtaining services, active sports, recreational walking, hobbies, communication, and passive leisure. More specifically, social participation consists of the engagement in political and civic activities, religious activity or other not-for-profit organizational activities (such as support group), volunteer work or other unpaid assistance to non-household members. Socializing includes attending cultural or sports events, visiting friends or relatives, and attending social gatherings. The category shopping and obtaining services refers to the purchase of goods and a variety of services, such as governmental, financial, and medical services. The participation of active sports includes exercising and practicing or coaching a variety of sports for leisure or competitively. As recreational walking is often emphasized as an important physical activity among older adults, this study categorizes it as one type of activity, which is separated from active sports and walking for transportation purposes. Hobbies mainly include painting, singing, dancing, photography, home crafts, games, chat groups, and computer use for leisure. Passive leisure mainly consists of TV-watching, listening to the radio and reading, which is often associated with sedentary time at home (e.g. Shibata et al., 2015). Communication mainly refers to sharing conversations in person, over the telephone, or through letters.

In addition, the following variables showing demographic and socio-economic status are obtained from the survey data: gender, immigrant status, education levels (Bachelor and above, Post-secondary, High school and below), household income (low, middle, high), urban versus rural, household size (single-person, two persons, three persons, four persons and above). In addition, self-rated health is obtained from all survey cycles. Five levels are used to describe health status: "Excellent", "Very Good", "Good", "Fair", and "Poor". Notably, some questions such as household income have different answer options in earlier

surveys. To compare consistently across multiple cycles, this study classifies "high", "middle", and "low" levels of household income according to the distribution of respondents' answers for each survey cycle, so that the classification scheme captures the respondents' relative positions in the population at a specific period.

6.3.3 Multilevel age-period-cohort analysis

This chapter adopts a series of multilevel models to analyze the changing activity patterns among the aging population over time. Age-period-cohort (APC) analysis has long been used in demography, epidemiology, and social sciences. However, the identification problem, caused by the linear dependency between age, period and cohort (period equals the sum of age and year-of-birth), remains a major methodological challenge in age-period-cohort analysis (Mason, Mason, Winsborough, & Poole, 1973; Bell & Jones, 2013; O'Brien, 2017). Traditionally, age-period-cohort models are designed for aggregated data, which is often organized in an age-period table, with aggregated values for each age-period group as outcome variables (O'Brien, 2015). In recent years, the Hierarchical Age-Period-Cohort (HAPC) model was developed to avoid the identification problem by measuring age at the micro level (individuals), and measuring cohort and period at aggregated levels (population groups), with micro-level data from repeated cross-sectional surveys (Yang & Land, 2006; Yang & Land, 2013). The HAPC model has received growing popularity in applied research and precipitated intensive debates among statistical methodologists (e.g. Yang, 2008; Zheng, Yang, & Land, 2011; Reither et al., 2015; Bell & Jones, 2017; O'Brien, 2017). An important criticism of the HAPC model is that the model cannot solve the identification problem as it claims, because constraints are implicitly induced in the model, by choosing different factors as random effects and different widths (years) in coding age, period and cohort intervals (Bell & Jones, 2017; Luo & Hodges, 2016; O'Brien, 2017). Hence, results of the HAPC model or a mixed-model approach to APC analysis in general, are sensitive to decisions on which factors are treated as fixed or random effects, and how age, period, cohort are coded or categorized.

Despite ongoing debates, there is emerging consensus among statistical methodologists. (1) The multilevel model framework, as adopted by the HAPC model,

provides an intuitive conceptual model for the analysis of repeated cross-sectional survey data (Yang and Land, 2013; Bell, 2014; Bell and Jones, 2017). As argued by Yang and Land (2013), the cross-sectional survey design is a multilevel design, in which individual-level variables (such as age) are nested in, and at the same time, cross-classified by the year of survey (period) and the individual' birth-cohort. (2) The existing APC models commonly rely on additional constraints, which are usually based on arbitrary choices (Yang, Fu and Land, 2004), and the HAPC model has constraints inherent in the data structure and model specification (O'Brien, 2017). Therefore, it is important to explain the reasoning for decisions that add constraints to the model and acknowledge the model's limitations (O'Brien, 2017; Bell & Jones, 2017).

This chapter adopts the multilevel model framework to analyze the pooled GSS time-use survey data for two major reasons. First, the multilevel model framework is well suited for repeated cross-sectional survey data, as discussed above. Second, this framework allows the investigation on temporal variations in individual-level covariates, such as gender and income, and therefore enables the study of heterogeneity among aging populations over the life course (Yang & Land, 2013; Bell, 2014). Nonetheless, the following constraints and limitations are worth noting. First, because the Canadian GSS typically repeat one topic of survey in a five-year cycle and many questions are different between recent cycles and earlier ones, there are relatively few periods of data available. Second, as the publicly available GSS data only reports age as a categorical variable, which is classified at a five-interval, this study includes age as a categorical variable at the individual level (five-year interval), and uses the given survey years as periods (approximately five-year interval). As argued by Luo and Hodge (2016), using unequal width intervals for age, period, cohort does not solve the identification problem. Instead, it adds implicit constraints to the model that are difficult to explain. Therefore, this analysis adopts the five-year interval to categorize birth cohort (which is the most detailed classification with the publicly available data). In addition, a ten-year interval classification of cohort is used to conduct a sensitivity test. Results of fixed effects (age effects) in this analysis are not sensitive to the different cohort intervals, but models with five-year cohort intervals outperform models with ten-year cohort intervals (based on BIC values).

As discussed above, though the multilevel APC model considers the age, period, and cohort effects simultaneously, the result is sensitive to the choice of fixed or random effects. As period trends and cohort trends cannot be effectively traced with four cycles of time-use survey, this analysis focuses on the age effect of respondents' activity participation. Therefore, this analysis uses age as the fixed effect, and period and cohort as cross-classified random effects. To understand the changes in activity participation over the life course, this analysis uses the participation in a specific type of activity (including travel) as a binomial dependent variable. For example, the multilevel age-period-cohort model of an individual's participation in car-travel can be specified as follows.

Level 1 "within-cell" model:

$$\textit{Logit}\ \mathbf{Pr(CARTRAVEL}_{ijk}\mathbf{=1)} = \beta_{0\,jk} + \beta_1\,\mathbf{AGE}_{\,ijk} + \beta_2\,\mathbf{SEX}_{\,ijk} + \beta_3\,\mathbf{IMMIGRANT}_{\,ijk} + \beta_4\,\mathbf{EDUCATION}_{\,ijk} + \beta_5\,\mathbf{INCOME}_{\,ijk} + \beta_6\,\mathbf{HEALTH}_{\,ijk} + \beta_7\,\mathbf{URBAN}_{\,ijk} + \beta_8\,\mathbf{HOUSEHOLDSIZE}_{\,ijk}$$

Level 2 "between-cell" model:

$$\beta_{0\,jk} = \gamma_0 + \mathbf{u}_{0j} + \mathbf{v}_{0k}\ ,\ \ \mathbf{u}_{0j} \sim \mathbf{N}(0, \tau_u),\ \ \mathbf{v}_{0k} \sim \mathbf{N}(0, \tau_v)$$

Combined model:

$$\textit{Logit}\ \mathbf{Pr(CARTRAVEL}_{ijk}\mathbf{=1)} = \gamma_0 + \beta_1\,\mathbf{AGE}_{\,ijk} + \beta_2\,\mathbf{SEX}_{\,ijk} + \beta_3\,\mathbf{IMMIGRANT}_{\,ijk} + \beta_4\,\mathbf{EDUCATION}_{\,ijk} + \beta_5\,\mathbf{INCOME}_{\,ijk} + \beta_6\,\mathbf{HEALTH}_{\,ijk} + \beta_7\,\mathbf{URBAN}_{\,ijk} + \beta_8\,\mathbf{HOUSEHOLDSIZE}_{\,ijk} + \mathbf{u}_{0j} + \mathbf{v}_{0k}$$

for

i = 1,2,…, n_{jk} individuals within cohort j and period k ;

j = 1,2,…,12 birth cohorts;

k = 1,2,…,4 survey cycles.

To explore differentiated levels of automobility among different groups of aging populations, interactions between age and socioeconomic covariates, such as gender, household income levels, and health status, are added to the model shown above. Furthermore, to explore the participation gap in a variety of activities between car users and non-car-users over the life course, the interaction between age and the participation in car-travel (binary) is added in a series of multilevel models that estimate the relationship between activity participation (binary) and age (categorical). Using social participation (SP) as an example, the combined model with interaction between age and car-travel can be specified as follows.

Combined model:

$$\textit{Logit}\ \mathbf{Pr(SP=1)} = \gamma_0 + \beta_1 \mathbf{AGE}_{ijk} + \beta_2 \mathbf{CARTRAVEL}_{ijk} + \beta_3 \mathbf{AGE}_{ijk} * \mathbf{CARTRAVEL}_{ijk} + \beta_4 \mathbf{SEX}_{ijk} + \beta_5 \mathbf{IMMIGRANT}_{ijk} + \beta_6 \mathbf{EDUCATION}_{ijk} + \beta_7 \mathbf{INCOME}_{ijk} + \beta_8 \mathbf{HEALTH}_{ijk} + \beta_9 \mathbf{URBAN}_{ijk} + \beta_{10} \mathbf{HOUSEHOLDSIZE}_{ijk} + \mathbf{u}_{0j} + \mathbf{v}_{0k}$$

for

$i = 1,2,\ldots, n_{jk}$ individuals within cohort j and period k ;
$j = 1,2,\ldots,12$ birth cohorts;
$k = 1,2,\ldots,4$ survey cycles.

Addressing the limitation that only a few cycles of data are available, which prevents a thorough analysis of the period and cohort effects, the relationships between car-travel and activity participation among different cohorts of older adults are analyzed with separate multilevel models. Three cohort groups are included in the analysis: the pre-war cohort (born before the 1940s), the early baby boomers (born between the 1940s and 1950s), and the late baby boomers (born between the 1950s and 1960s). The statistical software R (version 3.4.1) is used for this analysis. Multilevel models are developed with package *lme4* (version 1.1-14) (Bates et al., 2015), and the visualization of predicated probabilities is conducted with package *effects* (version 4.0-0) (Fox et al., 2003).

6.4 Results

6.4.1 Descriptive statistics

For each age group, the socioeconomic characteristics and health status of respondents are displayed in Table 6.2. A Chi-squared test is used to identify the independence between age groups and respondents' socioeconomic status and health status. Overall, slightly more than half of the respondents are female, and this percentage increases in older age. In each age group, more than 65% of respondents are urban dwellers (residents in census metropolitan areas and census agglomeration areas) and more than 72% are born in Canada, and majority of respondents have self-reported good or very good health. Among older adults, there are relatively higher percentages of low-education level, low-income level, and small household size. Notably, for most survey questions, there is missing data because respondents reported unknown or gave no response. Given that the percentage of missing

data tends to be relatively high among older adults, missing data is included in the analysis as an "Unknown" category. In particular, about half of the oldest (80 and over) and youngest (15 to 19) age group did not report household income.

Table 6.2 Socioeconomic and health status of respondents (weighted)

Age Group / Variables (Column %)	15-19	20-24	25-29	30-34	35-39	40-44	45-49	50-54	55-59	60-64	65-69	70-74	75-79	80+
Gender(Female)	χ2 (296.2***)													
	48.8	49.0	49.7	49.9	50.0	50.0	50.1	50.3	50.6	51.1	52.1	54.6	55.6	63.0
Immigration	χ2 (529.1***)													
Native	88.0	84.0	82.3	79.2	76.6	74.7	76.4	76.3	76.3	76.1	74.6	75.7	76.1	72.8
Immigrant	10.5	14.3	15.1	18.1	20.4	22.3	21.1	21.1	21.1	20.4	21.7	20.0	20.2	20.7
Unknown	1.5	1.7	2.6	2.7	3.1	3.0	2.5	2.6	2.6	3.4	3.7	4.3	3.7	6.6
Education	χ2 (6269.5***)													
High	0.8	15.4	27.4	26.9	27.5	26.3	25.2	22.8	22.1	18.4	16.3	12.6	10.4	10.9
Middle	21.2	57.6	48.1	44.4	43.3	42.4	39.9	39.2	35.7	33.6	30.8	25.4	26.1	23.8
Low	76.3	24.9	21.9	25.5	25.8	28.1	32.0	35.1	39.2	44.3	49.0	57.2	57.9	56.6
Unknown	1.8	2.1	2.6	3.1	3.4	3.3	3.0	3.0	3.0	3.7	3.9	4.8	5.7	8.7
Household Income	χ2 (7472.1***)													
Low	11.0	19.7	19.1	15.7	14.9	14.2	13.2	15.0	19.4	25.9	31.6	34.7	35.5	33.6
Middle	17.7	25.9	35.8	34.0	33.1	30.5	28.9	30.3	30.0	29.0	26.2	22.1	17.2	12.4
High	17.1	21.3	24.4	30.4	32.7	34.9	37.5	34.0	27.6	15.5	9.5	6.9	4.8	4.2
Unknown	54.1	33.1	20.7	19.8	19.4	20.4	20.4	20.7	23.0	29.7	32.7	36.3	42.5	49.8
Health status	χ2 (1901.0***)													
Excellent	24.2	23.1	22.6	22.3	21.4	21.7	21.4	20.4	19.3	19.8	16.6	14.7	12.8	9.5
Very Good	37.2	36.6	35.3	35.4	36.9	34.1	32.3	31.8	30.6	29.0	32.0	27.6	23.1	26.1
Good	28.1	29.8	29.5	29.3	27.9	28.4	30.1	29.9	30.3	29.0	30.0	31.3	34.1	32.1
Fair	7.9	7.7	7.9	8.1	8.4	9.4	10.1	11.2	12.4	13.6	13.1	16.2	18.2	18.5
Poor	1.1	0.9	2.0	1.7	1.9	2.7	3.2	3.9	4.4	4.7	4.2	5.4	5.9	6.1
Unknown	1.5	2.0	2.7	3.1	3.5	3.7	2.9	2.8	3.0	3.8	4.1	4.8	5.9	7.6
Urban dweller	χ2 (68.3***)													
	68.4	73.5	72.2	70.0	69.9	71.1	70.5	70.8	68.1	67.5	65.8	65.6	68.3	68.9
Household Size	χ2 (17471.0***)													
1 person	1.2	6.3	9.4	8.8	8.9	8.1	10.0	11.8	14.6	16.1	21.0	27.3	35.6	49.9
2 persons	7.6	23.8	34.1	24.4	17.6	17.3	24.8	38.8	53.0	62.0	65.9	58.5	54.5	43.7
3 persons	20.7	25.1	25.6	23.3	19.9	20.1	22.0	22.8	18.5	13.0	9.7	8.5	6.2	4.3
4 and above	70.6	44.9	31.0	43.5	53.7	54.5	43.2	26.6	14.0	8.9	3.4	5.7	3.8	2.1

Significance: 0.000***, 0.001**, 0.05*, 0.1 .
Data source: Statistics Canada, General Social Survey (1992, 1998, 2005, 2010).

With the pooled survey data, the participation rates in travel by different modes, and in social and physical activities, are compared across age groups (Figure 6.1). Regarding travel patterns, the participation in driving peaks at the age mid-40s (more than 70%), and drops steadily over age 50. Among people aged 80 and over, less than 30% participated in

driving. The participation rate in travel as car passenger is highest among young people below 20 (as many have not obtained driver's license at this age), lowest in the middle age (below 20%) and slightly increases among older adults aged 65 to 74, but decreases again among those aged 75 and older. The participation rates in both active travel and travel by transit are highest among the youngest group, but drop substantially among the middle aged. A slight increase of active travel can be observed among older adults in their 70s, but not among those aged 80 and over. Transit use among people aged 60 and over is even lower than transit use among the middle aged.

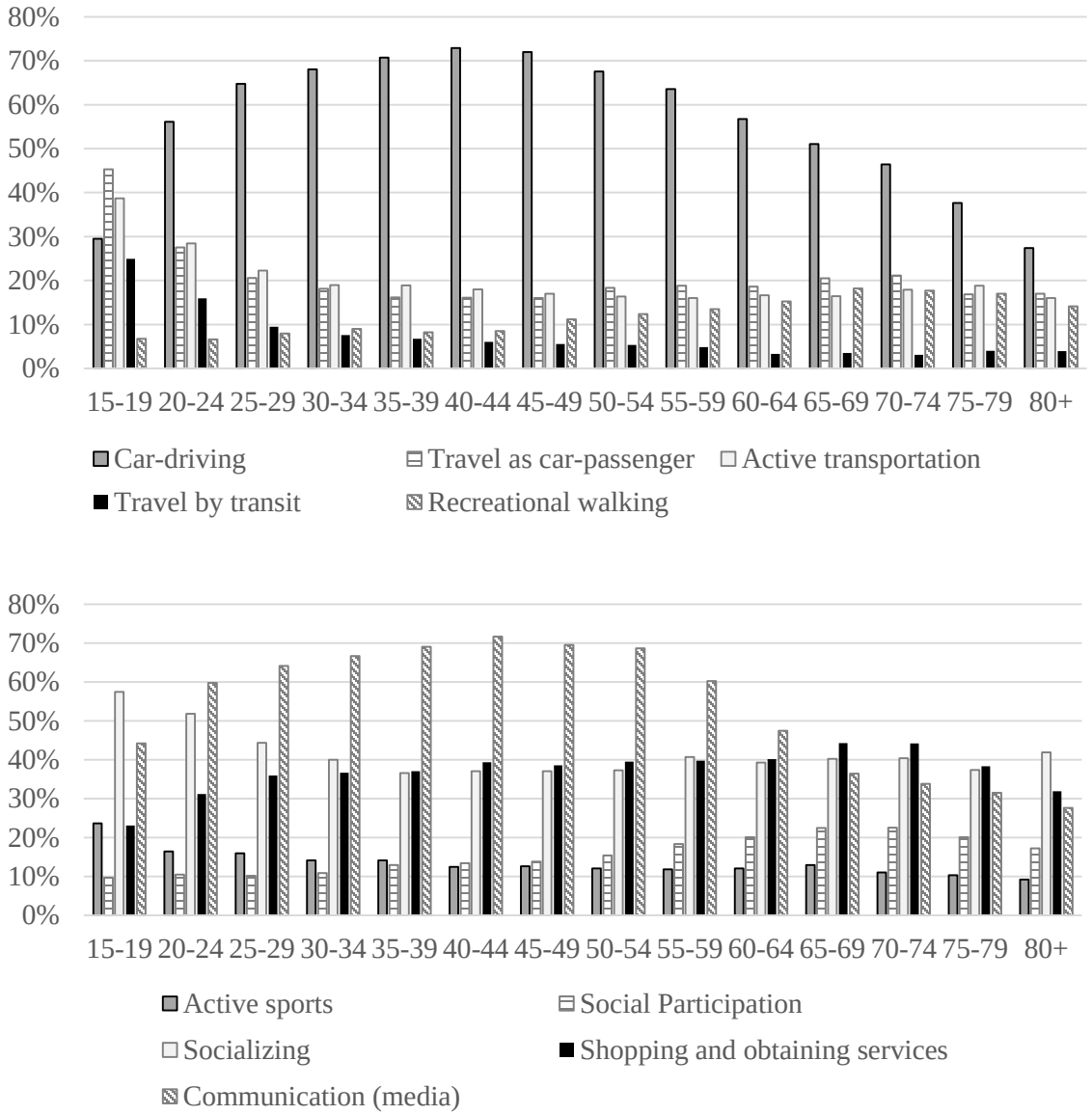


Figure 6.1 Travel and Activity participation by age group (weighted)

Regarding activity patterns, social participation increases substantially in the late 50s and peaks between the age 65 and 74. The social participation rate is higher among older adults aged 80 and over than among those in their early 50s. The participation rate in socializing is highest among the youngest age group. It drops in the 20s, and remains stable during mid-life and later life. In contrast, the participation in recreational walking steadily increases after the age mid-40s, and peaks between 65 and 69. The participation in shopping and obtaining services is lowest among the youngest group and highest among older adults between 65 and 74, but it decreases among those 75 and over.

6.4.2 Age effects of travel by different modes

Three multilevel models are used to analyze the age effects on the participation in travelling by car, active mode, and transit respectively (Table 6.3). Given that the GSS time-use survey reports a respondent's participation in travel and other activities on a random day, this analysis considers the participation in travel by each mode as a binary variable, and includes the same population in all three models.

After controlling for cohort effects, period effects and socio-economic covariates, the odds ratio of car-travel peaks among people who are in their 40s. The odds ratio drops significantly after the 50s. Compared with people in their early 40s (40-44), older adults between 75 and 79 are about 60% less likely to travel by car, and people who are 80 years and over are about 70% less likely to travel by car. People in the youngest age group are significantly more likely to travel by active modes and by transit than all other age groups. The odds ratio of travel by transit decreases substantially among older adults who are over 60, whereas the odds ratio of travel by active modes drops steeply among older people who are 80 and above.

Overall, females, immigrants, highly-educated, urban dwellers, people living in one-person households, and people with low household income are less likely to travel by car and more likely to travel by transit and active modes. In particular, urban dwellers have more than 3 times higher chances travel by transit than their rural counterparts. People with poor health are 47% less likely to travel by car than people with good health, but only 20% less likely to travel by active modes. Notably, though females are 22% less likely to travel

by car than males, they are 12% more likely to travel by active modes and 24% more likely to travel by transit, a large percentage of older females stay inactive.

Table 6.3 Age effects of travel by different modes (weighted)

Variables	Model 1. Travel by car (binary)	Model2. Travel by active modes (binary)	Model3. Travel by transit (binary)
Fixed Effects	**Odds Ratio(95%CI)**	**Odds Ratio(95%CI)**	**Odds Ratio(95%CI)**
Intercept	4.86***(3.99, 5.91)	0.26*** (0.20, 0.33)	0.03***(0.02, 0.03)
Age Group (ref=40-44)			
15-19	0.55***(0.48, 0.64)	3.08***(2.62, 3.62)	7.38***(5.98, 9.10)
20-24	0.68***(0.60, 0.76)	1.71***(1.47, 1.99)	3.15***(2.59, 3.84)
25-29	0.81***(0.73, 0.91)	1.17* (1.02, 1.34)	1.61***(1.34, 1.95)
30-34	0.82***(0.74, 0.91)	0.97 (0.86, 1.09)	1.25* (1.05, 1.50)
35-39	0.84** (0.76, 0.93)	1.02 (0.92, 1.14)	1.11 (0.94, 1.31)
45-49	1.00 (0.90, 1.12)	0.91 (0.82, 1.02)	0.89 (0.75, 1.07)
50-54	0.89* (0.79, 0.99)	0.88* (0.78, 1.00)	0.88 (0.72, 1.08)
55-59	0.88* (0.78, 1.00)	0.82** (0.72, 0.94)	0.82. (0.65, 1.04)
60-64	0.69***(0.60, 0.78)	0.84* (0.73, 0.97)	0.54***(0.40, 0.72)
65-69	0.63***(0.55, 0.72)	0.74***(0.63, 0.88)	0.44***(0.32, 0.60)
70-74	0.62***(0.53, 0.71)	0.79* (0.65, 0.96)	0.34***(0.23, 0.50)
75-79	0.39***(0.33, 0.45)	0.82. (0.65, 1.02)	0.41***(0.27, 0.63)
80+	0.28***(0.24, 0.33)	0.59***(0.46, 0.75)	0.30***(0.19, 0.49)
Gender (Female)	0.88***(0.85, 0.92)	1.12***(1.07, 1.17)	1.24***(1.16, 1.32)
Immigration (ref = Native)			
Immigrant	0.70***(0.66, 0.74)	1.00 (0.95, 1.06)	1.93***(1.79, 2.08)
Unknown	0.60***(0.50, 0.74)	0.77* (0.61, 0.98)	1.50* (1.07, 2.11)
Education (ref = Middle)			
High	0.91** (0.85, 0.97)	1.40***(1.32, 1.49)	1.43***(1.30, 1.56)
Low	0.75***(0.72, 0.79)	1.00 (0.94, 1.05)	0.91* (0.84, 0.99)
Unknown	0.70***(0.59, 0.82)	1.35** (1.11, 1.64)	1.18 (0.89, 1.56)
Household Income (ref=Middle-income)			
Low	0.58***(0.54, 0.61)	1.35***(1.26, 1.45)	1.33***(1.20, 1.48)
High	1.45***(1.36, 1.55)	0.94* (0.88, 1.00)	0.86** (0.78, 0.95)
Unknown	0.69***(0.65, 0.73)	1.01 (0.94, 1.07)	1.24***(1.13, 1.36)
Health status (ref="Good")			
Excellent	1.10** (1.03, 1.17)	1.03 (0.97, 1.10)	0.88** (0.80, 0.96)
Very Good	1.09** (1.03, 1.15)	1.01 (0.96, 1.07)	0.95 (0.88, 1.03)
Fair	0.78***(0.73, 0.84)	0.97 (0.89, 1.05)	1.03 (0.92, 1.17)
Poor	0.53***(0.47, 0.60)	0.80** (0.69, 0.93)	0.86 (0.68, 1.09)
Unknown	1.48***(1.19, 1.84)	0.82 (0.64, 1.06)	0.57** (0.39, 0.83)
Urban dweller	0.88***(0.84, 0.93)	1.26***(1.19, 1.32)	3.56***(3.21, 3.95)
Household Size (ref=1 person household)			
2 persons	1.31***(1.22, 1.41)	0.62***(0.57, 0.67)	0.63***(0.56, 0.71)
3 persons	1.29***(1.19, 1.41)	0.60***(0.55, 0.66)	0.56***(0.49, 0.65)
4 and above	1.47***(1.35, 1.59)	0.59***(0.54, 0.64)	0.51***(0.45, 0.58)
Random Effects-Variance Components (S.D.)			
Cohort Effect	0.002 (0.042)	0.004 (0.059)	0.026 (0.161)
Period Effect	0.023 (0.151)	0.040 (0.199)	0.000 (0.000)
Goodness of Fit (BIC)	53957.4	49650.2	26013.8

Significance: 0.000***, 0.001**, 0.05*, 0.1 .

6.4.3 Differentiated automobility over the life course

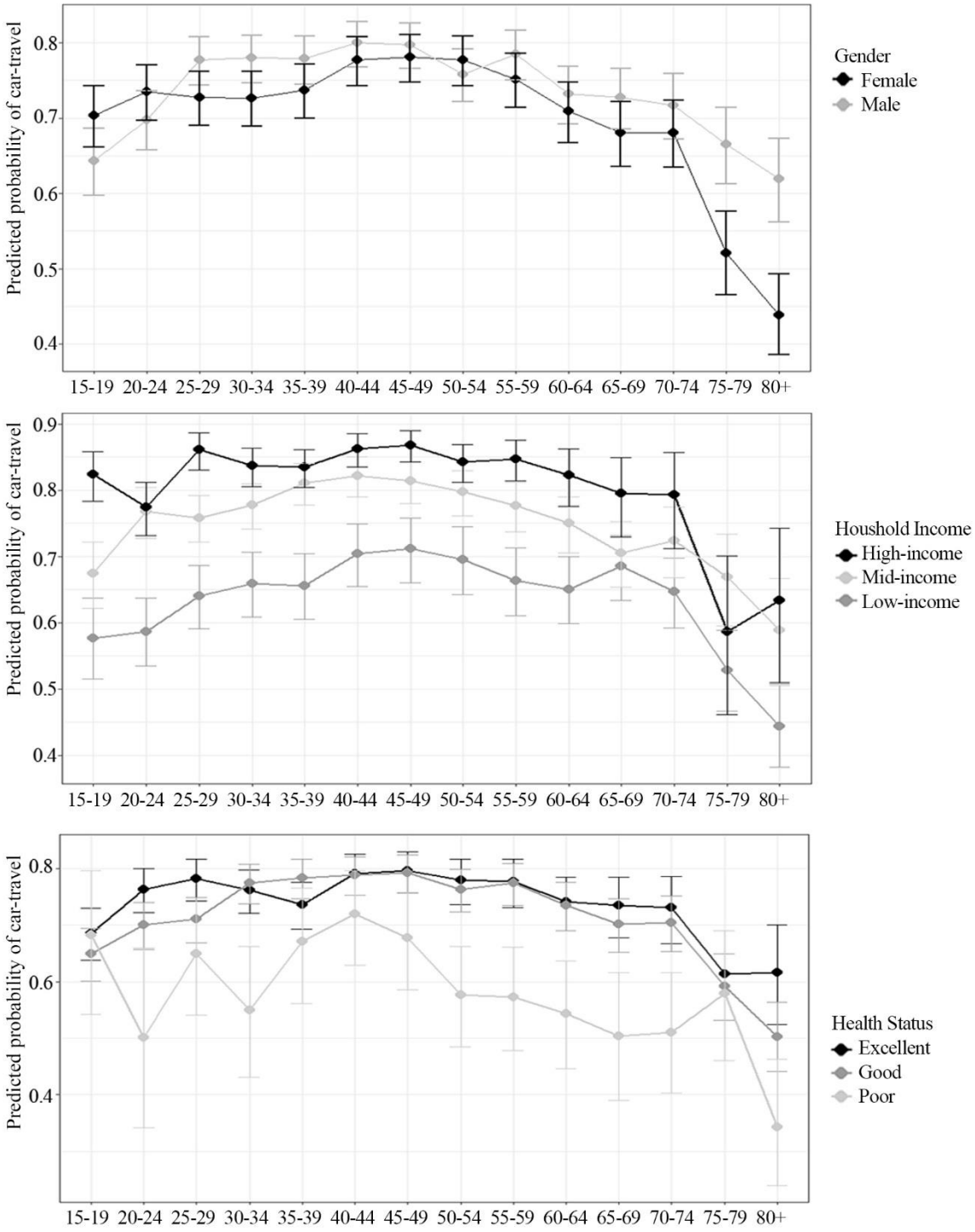
To understand how the trajectory of automobility over the life course is differentiated between gender groups and among people with different levels of income and health status, the probability of car-travel by the respondent's age, socioeconomic status, and self-rated health is analyzed through adding interaction terms to Model 1 (see Table 6.3). With period effects and cohort effects controlled, the model results can be used to estimate the probability of car-travel over the life course among different subgroups of the population (Figure 6.2).

Males tend to have higher levels of automobility than females over the life course. However, females under 25 are more likely to travel by car than their male counterparts. This can partly be explained by the phenomenon that relatively low percentages of young adults drive, and females are more likely to be car-passengers than males. The predicted probability of travel by car remains high (above 70%) among males in their 60s, but it drops to about 60% when they reach 80 years old. In comparison, the probability of female travel by car falls steadily in their late 50s, and a very steep decrease in car-travel (from about 68% to 52%) can be observed in their late 70s, and the probability of car-travel among female age 80 and over is below 45%. Among older adults aged 75 and over, the level of automobility between males and females is clearly differentiated, and the trend indicates a wider gap in more advanced old age.

Compared with respondents with low levels of household income, those with higher household income have higher levels of automobility in every age group. For each income group, the level of automobility is highest among the mid-aged (early 40s to early 50s) and drops substantially after 75. Notably, respondents from middle-income household have only a small automobility gap with those from high-income household, between the age 30s and 50s, but the gap increases between late 50s and late 60s. After the retirement age (65) especially, there is an increase in car-travel among low-income respondents, which results in a narrow gap between the low-income and middle-income. A large standard error is found among respondents aged 70 and over from high-income households (particularly the 75-79

age group), this indicates that the sample size for high-income respondents aged 75 and older is too small to estimate this interaction correctly.

The probability of car travel among respondents who reported good health and excellent health has a similar trend until the late 70s. The level of automobility among respondents who reported excellent health remains higher than those who reported good health in old age, however, the difference becomes smaller between age 65 and 74. However, from age 80 and over, respondents reporting good health show a substantial decrease in car-travel, while the level of automobility stays the same among respondents who reported excellent health. Among respondents reporting poor health, the level of automobility remains lower than their counterparts did, though the predicted probability of car-travel fluctuates in certain age groups. As relatively few young respondents reported poor health, the standard errors among respondents between early 20s and early 30s who reporting poor health are high. From early 40s to early 70s, respondents reported poor health are much less likely to travel by car than their counterparts, yet an increase of car-travel can be observed in the 70s among respondents with poor health. Among people aged 80 and over, however, the level of automobility clearly differentiates among respondents reporting excellent, good and poor health.



Note: to show the variation clearly, respondents with "unknown" income are included in the model but not illustrated in the figure. Similarly, respondents with the two intermediate levels of self-rated health, "Very Good" and "Fair", and those with no response are included in the model but not displayed in the figure.

Figure 6.2 Predicted probability of car-travel over the life course by gender, income, and health status (weighted)

6.4.4 Automobility and activity participation over the life course

A series of multilevel models are used to explore the variations in the level of participation in activities between people who travelled by car and people who did not travel by car over the life course. Controlling for the contextual variables (as shown in Table 6.3), the predicted probability of participating in various activities is displayed in Figure 6.3. Over the life course, car users show higher levels of participation in social activities, socializing, active sports, and shopping. However, car-users tend to participate less in communicating through media after age 70, and they are less likely to spend time on passive leisure before their mid-30s.

The predicted probability of social participation increases from the late 40s to the early 60s among all respondents. Car users show a substantial increase in social participation after 65, while the participation rate remains stable among non-car-users. Among older adults aged between 65 and 79, car users have 20% higher chances of social participation than non-car-users. Yet among older people aged 80 and over, car users show more noticeable decrease in social participation than non-car-users.

Participation in socializing (through cultural activities or entertainment with others) decreases dramatically between age 15 and mid-30s, which may be a result of increased time pressure associated with education or entering the work force. The lowest participation rates can be observed among car users between age 35 and 54 (about 43%), and non-car-users in their early 30s and late 70s (about 25%). In the transition from young-old (age 65 to 75) to old-old (age 75 and above), car users' participation in socializing increases in their mid-50s and remains relatively high till age 75. In contrast, the participation rate of older non-car-users fluctuates and shows an overall decline between age 55 and 79. The difference of participation rate between car users and non-car-users is smallest during mid-life (about 15%), and stays around 20% in both earlier life and later life, except for a smaller difference in the age group 80 and above.

A substantial decline in active-sports participation can be observed between age 15 and 40 for all respondents, and the participation rate is around 10% for the middle-aged. Among car users, the participation rate increases during their 60s, but decreases from age

70. Among non-car-users, the participation rate decreases in their early 60s but increases in older age. The difference in active-sports participation between car users and non-car-users is highest in their mid-60s, which is about 8%, and the difference shrinks to about 2% in the age 80 and over.

Although the predicted probability of recreational walking remains relatively low (mostly between 5% and 20%), non-car-users are more likely to participate in recreational walking than car users in all age groups. The predicted participation rate is particularly high among non-car-users in their 60s and 70s. Similarly, relatively high participation rate can be found among car users in their mid-60s and 70s. Yet a noticeable decrease can be observed between both non-car-users and car users aged 80 and above.

Compared with other types of activities, shopping and obtaining services shows the largest participation gap between car users and non-car-users, especially in age 70 and above (about 50% difference). The participation rate in shopping remains around 15% among non-car-users over the life course, except for a decrease in their early 60s and an increase in late 70s. While the participation rate among car users steadily increases from young age to late 50s, and drastically increases between age 60 and 74. Despite a continued decline in the participation rate among car users age 75 and over, car users are still about 45% likelier to shop than non-car-users from age 80 and above.

Non-car-users are more likely to spend time on hobbies than car users in most age groups except for people in their 40s. A larger difference between non-car-users and car users is found among younger people under age 40. The predicted participation rate fluctuates among people in their 50s and early 60s, and decreases continuously after age 65. Yet the difference between non-car-users and car users widens as older adults in their late 60s gets to advanced old age (80 and over).

Among car users, the participation in communication declines substantially after their early 50s. Though the participation rate among non-car-users also decreases between early 50s and late 60s, there is a slight increase in their 70s. Among respondents age 75 and above, non-car-users are about 5% higher chances to communicate with others in person or through media.

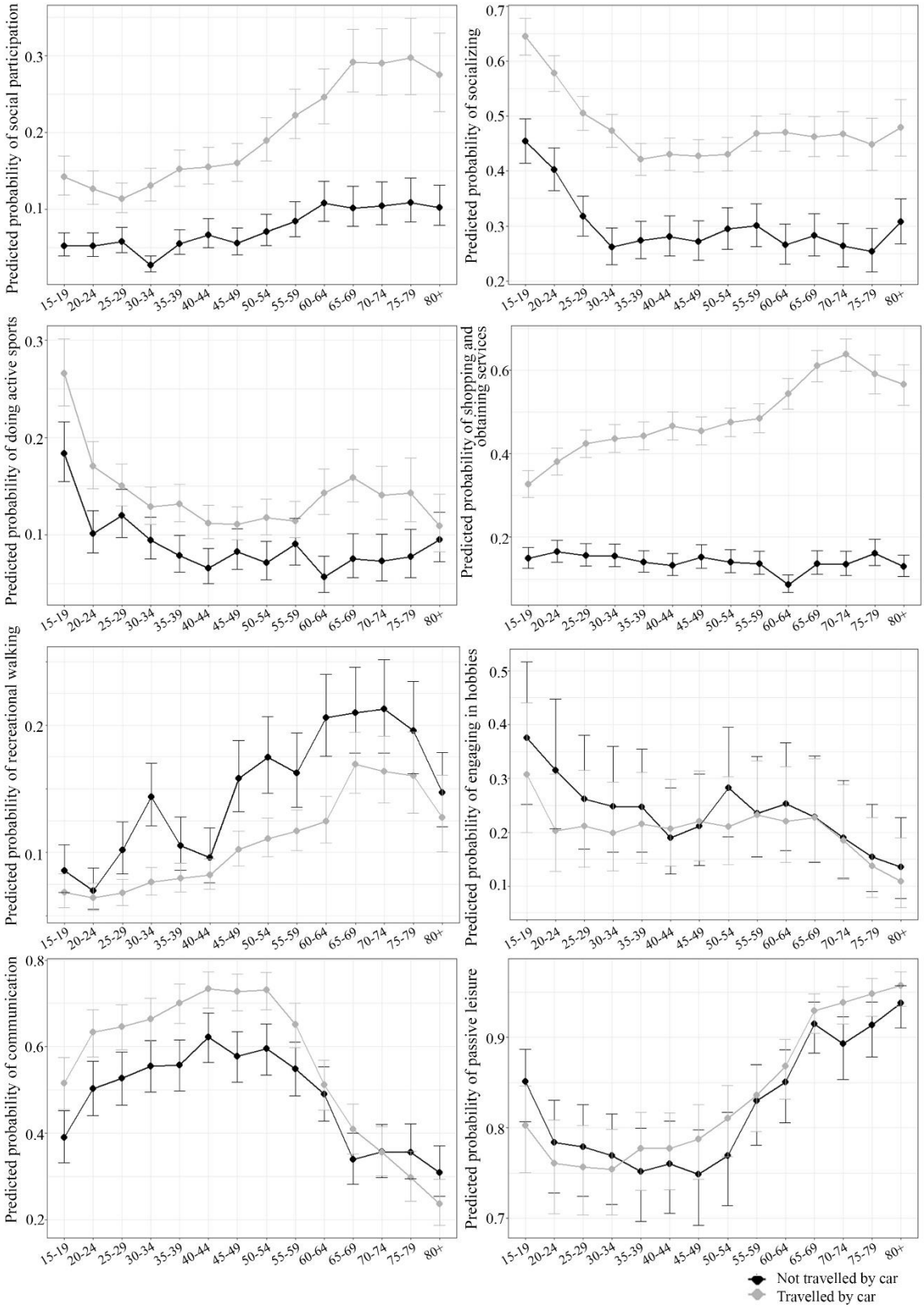


Figure 6.3 Predicted probability of activity participation over the life course by car-users and non-car-users (weighted)

The participation in passive leisure decreases between age 15 and mid-30s, and increases drastically after age 50. Car users are less likely to spend time on passive leisure than non-car-users among respondents younger than age 35, however, this trend reverses among respondents aged 35 and older. Particularly, car users in their late 40s, early 50s and early 70s, show about 5% higher chances to engage in passive leisure than non-car-users.

Overall, shopping and obtaining services appears to be the most car-dependent activity among all the types of activities included in the analysis, as it shows the highest participation gap between car users and non-car-users, and a slow decline of participation rate among older non-car-users. Different from a conventional understanding that older adults become less active in the aging process, this analysis shows that older adults, especially older car users, are more likely to engage in social participation, socializing, active sports and shopping, than their working age counterparts. Nonetheless, the participation in paid work and education almost disappears in older age, and much higher percentages of older adults stayed at home and/or being inactive than their working age counterparts (as shown in Figure 5.1).

6.4.5 Relationships between car-travel and activity participation in older adults

To further explore the varied relationships between automobility and the activity participation among different generations of older adults, mixed effects models are developed for subgroups of the aging populations (Table 6.4). Three generations of older adults are analyzed: the oldest pre-war cohort (aged 65 and over in 2010), the early baby boomer cohort (aged between 55 and 64 in 2010), and the late baby boomer cohort (aged between 45 and 54 in 2010). The mixed effects model for each subgroup of the aging populations is controlled for socioeconomic status and health status, as well as period effects and age effects.

Table 6.4 Car-travel and activity-participation among older cohorts (weighted)

	Model 4. Car-travel in the pre-war cohort (binary)	Model 5. Car-travel in the early boomers (binary)	Model 6. Car-travel in the late boomers (binary)
Fixed Effects	**Odds Ratio(95%CI)**	**Odds Ratio(95%CI)**	**Odds Ratio(95%CI)**
Intercept	0.62. (0.36, 1.07)	0.40***(0.26, 0.62)	0.79 (0.54, 1.17)
Participation in activities (binary)			
Social participation	5.41***(4.68, 6.25)	4.99***(3.94, 6.32)	4.04***(3.18, 5.12)
Socializing	3.28***(2.94, 3.67)	2.73***(2.34, 3.18)	2.42***(2.12, 2.77)
Active Sports	2.78***(2.32, 3.33)	2.05***(1.64, 2.57)	2.03***(1.68, 2.47)
Recreational walking	0.68***(0.59, 0.78)	0.75** (0.62, 0.91)	0.78** (0.64, 0.94)
Shopping	21.78***(18.87, 25.14)	11.43***(9.52, 13.72)	11.57***(9.76, 13.71)
Hobbies	0.88* (0.78, 0.98)	0.73***(0.62, 0.86)	0.74***(0.63, 0.86)
Passive leisure	1.41***(1.20, 1.66)	1.65***(1.41, 1.94)	1.15. (1.00, 1.32)
Communication	1.50***(1.35, 1.68)	4.25***(3.65, 4.94)	4.59***(4.01, 5.24)
Travel by active modes	0.15***(0.13, 0.17)	0.22***(0.19, 0.26)	0.19***(0.16, 0.22)
Travel by transit	0.14***(0.11, 0.19)	0.11***(0.09, 0.14)	0.10***(0.08, 0.13)
Gender (Female)	0.57***(0.52, 0.64)	0.74***(0.65, 0.84)	0.77***(0.68, 0.86)
Immigration (ref = Native)			
Immigrant	0.81***(0.71, 0.91)	0.70***(0.60, 0.82)	0.85* (0.73, 0.98)
Unknown	0.84 (0.54, 1.30)	0.47** (0.27, 0.81)	1.08 (0.61, 1.91)
Education (ref = Middle)			
High	0.88 (0.73, 1.05)	0.98 (0.82, 1.18)	1.03 (0.88, 1.21)
Low	0.80***(0.70, 0.90)	0.78**(0.68, 0.91)	0.89 (0.78, 1.03)
Unknown	0.77 (0.53, 1.11)	1.66. (0.98, 2.84)	0.71 (0.45, 1.10)
Household Income (ref=Middle-income)			
Low	0.63***(0.54, 0.73)	0.60***(0.49, 0.73)	0.59***(0.49, 0.70)
High	1.55***(1.27, 1.90)	1.45***(1.21, 1.73)	1.52***(1.30, 1.78)
Unknown	0.71***(0.62, 0.82)	0.74** (0.62, 0.89)	0.72***(0.61, 0.85)
Health status (ref="Good")			
Excellent	1.09 (0.93, 1.27)	1.11 (0.92, 1.33)	0.95 (0.81, 1.13)
Very Good	1.14. (0.99, 1.30)	1.11 (0.94, 1.31)	0.90 (0.78, 1.05)
Fair	0.70***(0.60, 0.82)	0.76* (0.60, 0.95)	0.78* (0.63, 0.96)
Poor	0.43***(0.34, 0.55)	0.60** (0.43, 0.83)	0.39***(0.28, 0.54)
Unknown	1.10 (0.69, 1.75)	0.94 (0.52, 1.71)	0.88 (0.49, 1.60)
Urban dweller	0.96 (0.86, 1.08)	1.16* (1.00, 1.35)	1.04 (0.91, 1.20)
Household Size (ref=1 person household)			
2 persons	1.32***(1.15, 1.51)	1.55***(1.22, 1.96)	1.28. (1.00, 1.63)
3 persons	1.12 (0.92, 1.35)	1.99***(1.54, 2.56)	1.34* (1.05, 1.73)
4 and above	1.04 (0.83, 1.29)	1.93***(1.50, 2.47)	1.65***(1.31, 2.09)
Random Effects-Variance Components (S.D.)			
Age Effect	0.365(0.605)	0.024(0.153)	0.000(0.000)
Period Effect	0.020(0.143)	0.049(0.222)	0.045(0.212)
Goodness of Fit (BIC)	9876.5	6338.7	7750.5

Significance: 0.000***, 0.001**, 0.05*, 0.1 .

Among the aging populations, respondents engaging in social participation, socializing, active sports, and shopping are much more likely to be car users. The odds ratios are larger in earlier cohorts, which indicate that these activities are more car-dependent for older generations. In contrast, respondents who spent time on recreational walking, hobbies, active travel, and transit-use, are less likely to travel by car. Respondents in the pre-war cohort who participated in recreational walking or active travel are even less likely to use cars, compared with their baby-boomer counterparts. Yet among those who travelled by transit, respondents in the pre-war cohort are slightly more likely to use car, compared with their baby-boomer counterparts.

In line with the analysis above, though females are less likely to travel by car than males, females in the boomer cohorts are more likely to use a car than those in the pre-war cohort. Interestingly, immigrants in the pre-war cohort are more likely to travel by car than those in the early boomer cohort. The impact of household income on car use is similar among the three cohorts, while the negative impact of lower health status (self-rated as "Poor" or "Fair") on car use is stronger in the pre-war cohort.

6.5 Discussion

6.5.1 Main findings

Confirming previous literature, there are clear gender differences in older adults' participation in car-travel. Older females travel less by car and are more likely to reduce car-travel in more advanced old age. In the meantime, the probability of older females travelling by other modes of transportation does not increase. As a result, older females are more likely to be inactive than older males. In addition, older adults with relatively high household income and better health tend to have higher levels of automobility, even in advance old age.

As the education and working time diminishes in older age, older adults are more likely to engage in social participation, shopping and obtaining services, recreational walking and passive leisure than their middle-age counterpart. Over the life course, car users are more likely to involve in shopping and obtaining services, social participation,

socializing, and active sports than non-car-users, while non-car-users tend to participate more in recreational walking. Among those aged 70 and over, car users are more likely to engage in passive leisure and less likely to spend time on communication.

The results also show that social participation and the participation in shopping and obtaining services become more polarized between people who travel by car and people who do not travel by car in older age. Older car users are over 4 times more likely to shop and obtain services than their non-car-user counterparts. In addition, compared with older non-car-users, older car users are about 3 times more likely to engage in social participation. Moreover, comparing among different generations of the aging populations, the positive associations between car-travel and the engagement in shopping and obtaining services, social participation, socializing, and active sports are stronger in older cohorts, even though the participation rate in car-travel decreases in older age.

6.5.2 Transport-related exclusion in activity participation

The number of seniors is expected to grow significantly in the coming decades, and there is an increasing demand of age-friendly built environment in both urban and rural areas. However, because of the high levels of automobility among a majority of the aging populations and the lack of alternative transportation options that can provide equivalent level of mobility for the aging populations, a decrease of automobility seems to associate with restrained mobility and decreased social participation and engagement in shopping and obtaining services, active sports and socializing.

Shopping and obtaining services stands out as the most car-dependent activity for older adults. This finding resonates with the concept of "system of automobility". Because of the prevalence of car-travel, retailers and service providers prioritize car access in their choice of location and site-design to attract customers. This type of development pattern makes car-travel outcompete other transportation modes, and further creates a car-dependent built environment. Yet shopping and obtaining services are everyday needs, so this car-dependent commercial development pattern can be problematic as older adults turn to advanced old age, their household size gets smaller, and no one in the household continues to drive.

As shown by existing empirical studies (Nelson et al., 2007; Qiu et al., 2010), being inactive or homebound has negative health impacts on older adults. The participation gap between car-users and non-car-users indicates the risk of social exclusion of older adults with relatively low levels of automobility, as the lack of mobility options alternative to private cars inhibits them from participating activities that are accessible to car users (Lucas, 2012). Arguably, the immobility of non-car-users imposed by a car dependent built environment creates social exclusion for a large group of disadvantaged older adults who have relatively low household income and/or poor health, with less driving experience over the life-course (such as females in pre-war cohorts and immigrants from a less car-dependent environment).

Compared with the baby boomer cohorts, transit users in the pre-war cohort are more likely to travel by car. Though previous research finds that the distance travelled by bus does not decrease significantly as the age of population increases (Mercado & Páez, 2009), this analysis indicates that, older transit users may still need to use a car as a supplementary mobility option to fulfill certain travel purposes. Without a vast expansion of public transit services, a potential middle ground is to integrate existing public transportation services with mobility options that offer flexible routes, such as carpooling.

Nevertheless, the results also show that non-car-users are more likely to participate in recreational walking than car users over the life course, and the oldest pre-war cohort who travelled by active modes are even less likely to use a car than their baby-boomer counterparts. These findings indicate that walking is still an important form of physical activity and transportation option for the elderly, even though it may not enable older non-car-users to engage in a level of activity participation comparable to older car users. Based on the existing literature, most of the age-friendly community initiatives are either community-based not-for-profit organizations or city governments, and the agenda of creating age-friendly communities has often been restricted to micro-level interventions, such as improving the safety of streets and sidewalks and expanding transit service. Such approaches do not necessarily address mobility challenges induced by the nation-wide car-depend environment. Based on a detailed analysis of changing mobility patterns and activity patterns of the aging populations, this study proposes that the policy framework of age-

friendly communities also need to engage retailers, service providers and institutional organizers to provide inclusive services or environment for people with restrained automobility.

6.6 Conclusion

This chapter explores the changing patterns of automobility and activity participation over the life course with a multilevel model framework. By estimating the probabilities of car-travel and activity participation by age group, this study explores the differentiated automobility among different social groups, and the variation in activity participation between car users and non-car-users over the life course. The results indicate that despite a decline in automobility in the aging process, the participation gap between car users and non-car-users is even larger in older age, for social participation and the participation in shopping and obtaining services, active sports and socializing. This can be partly explained by the fact that a car-dependent built environment discourages the participation in a range of activities among older adults who have less convenient access to cars, and results in an increased percentage of older adults staying at home or being inactive (e.g. Kim 2011).

The findings provide a nuanced understanding of the relationship between active aging and automobility, which have been largely neglected in the literature on age-friendly communities. At a national scale, because a car-dependent development pattern has shaped travel patterns and business models, shopping and obtaining services show the highest level of car-dependency. Organizational activities, such as volunteering, religious gatherings and political/civic activities also tend to be highly car-dependent. However, older adults, especially non-car-users, are more likely to participate in recreational walking. This shows that a walkable environment that enables both active travel and recreational walking can help older adults, especially non-car-users, to stay active. Yet, as walking often happens within a neighbourhood scale, promoting walkable neighbourhoods cannot by itself address the participation gap in various social and physical activities between older car users and non-car-users. Therefore, policies need to take a new perspective and to make the participation in certain types of activity less car dependent. Such improvements require the support from retailers, service providers and institutional organizers. Additionally, this

study discusses the impact of the system of automobility on activity participation from a life course perspective. Based on the findings, future studies can examine the potentially cumulative disadvantage, both in terms of activity participation and health, among social groups with low levels of automobility.

Moving forward, with more survey cycles available, future studies can expand the multilevel model framework adopted in this chapter and examine the period effects and cohort effects of activity participation of aging populations. Particularly, by combining new cycles of survey data and obtaining the actual age of respondents, future studies can conduct more detailed analysis on variations among the oldest-old (aged 80 and over), and to identify the tipping-point of age when the aging population becomes significantly less active, or whether such age threshold changes over time.

Adopting the life-course perspective, this chapter identified an increased participation gap in shopping and obtaining services, social participation, and socializing between car-users and non-car-users in older age. This finding points out future research needs to examine whether transport-related exclusion in activity participation leads to cumulative disadvantages among aging populations.

7 Conclusions

7.1 Key findings

With both the number and the percentage of older adults continuing to increase in the coming decades, there are emerging demands for good places to age in place. However, traditionally, planning theories on good urban form have limited discussions on aging populations (e.g. Talen & Ellis, 2002), while studies on aging populations tend to focus on the non-spatial aspect of individual life experiences, health determinants, and supporting social networks. To build conversations between various disciplines, this dissertation integrated theoretical and conceptual frameworks from gerontology, public health, urban geography, and planning, and analyzed aging in relation to place and mobility, with population-representative survey data in Canada. With multiple cycles of the census and general social survey, this study provided a macro-level understanding of aging-in-place in Canada.

This dissertation explored two sets of questions. First, with a focus on places where people age in place, chapter 3 and chapter 4 examined how different demographic trends shape the spatial pattern of aging simultaneously, how to understand patterns of population aging at a local scale, and whether neighbourhoods with different age structures have distinct characteristics. Second, with a closer look at aging in a largely car-dependent built environment, chapter 5 and chapter 6 analyzed how mobility gaps between gender and cohort groups varies over time, whether the participation in activities becomes more polarized between car users and non-car-users in older age, and what types of activities are more car dependent for older adults.

Among municipalities in Canada, there are only weak correlations between population aging and population decline, yet the weak association is strongly influenced by a few outliers that either have substantially higher growth rates or have experienced sporadic population change during a short period. The spatial pattern of population aging becomes more heterogeneous at a finer geographical scale. To understand the spatial pattern of aging, it is important to include multiple indicators that capture changes in both population size

(such as population counts, and number of movers/non-movers) and population age structure (such as median age, and the percentage of population by age group).

Among all neighbourhoods in Canada, four types of neighbourhoods with distinct age structures can be identified. Above 48% of neighbourhoods in Canada are at the mature-stage (characterized by a household structure of parents in the baby-boomer cohort and teenage children). With high ownership rates and high percentage of non-movers, these neighbourhoods are aging steadily. Mature-stage neighbourhoods tend to have high housing affordability and car-dependent built environments, while aged neighbourhoods tend to have relatively compact built environments and low housing affordability.

At the national level, automobility remains important over the life course of aging populations in Canada. However, there are significant differences in automobility among older males and older females, particularly in advanced old age. Within each cohort, older females are less likely to hold a driver's license, more likely to travel as car-passengers, and are more likely to travel by active modes and by transit than their male counterparts. Although a smaller gender gap in automobility is observed among the baby boomer cohorts, it is not clear whether a smaller gender gap can be observed when they reach advanced old age. Despite an increase of automobility over time, the age effect of being less mobile remains strong among people in advanced old age. For the growing population group of the oldest-old, in which females are about two thirds of the population, there is a potential risk that they face a substantial decrease in automobility and no alternative transportation option is readily available or easily accessible to them.

Between car users and non-car-users, the levels of social participation and the participation in shopping and obtaining services, active sports and socializing are more polarized in older age. Shopping and obtaining services show the highest level of car-dependency. Arguably, a car-dependent built environment discourages the participation in a range of activities among older adults who have less access to cars, and results in an increased percentage of older adults staying at home or being inactive. Nonetheless, older non-car-users are more likely to participate in recreational walking, which implies that a walkable environment can help older non-car-users, to stay active.

7.2 Original contributions and limitations

Aging-in-place has not been widely studied in the planning literature, and existing studies of aging-in-place often focus on local government's age-friendly agenda or membership-based community initiatives (e.g. Lehning, 2012; Lehning, Scharlach, & Wolf, 2012). However, a planning perspective is important for providing age friendly environments that support aging-in-place. To help integrate a planning perspective on this interdisciplinary topic, this dissertation focused explicitly on the places where people age in place, and conducted macro-level analyses to understand a big picture of the expected vast scale aging-in-place phenomenon.

Methodologically, this dissertation explored new approaches to analyze the spatial pattern of aging and neighbourhood contexts of aging at local scales. Demographic research often examines population aging at a national, regional or municipal level, and limited studies focus on aging at a fine-grained spatial scale. At the municipal scale, this dissertation analyzed the spatial pattern of aging by synthesizing multiple demographic trends, and examining relationships between these demographic trends, instead of using a single threshold to understand the spatial pattern of aging (such as the change of median age and the percentage of people 65 years and over). At the neighbourhood-scale, this dissertation categorized neighbourhoods across Canada by their age structures, with cluster analysis. Although this dissertation only adopted a relatively simple k-means clustering method, this approach can be extended by including more census cycles and more comprehensive clustering methods that classifies trajectories of neighbourhood change, which can provide an empirical foundation to theorize the phenomenon of aging-in-place.

Moreover, this dissertation adopted a life-course perspective in the empirical analysis of survey data, and investigated changes in the aging process, instead of a traditional approach of examining older adults (often defined as age 65 and over) as a specific population group. Although the life-course perspective is a long established theory in gerontology (Elder, 1998; Elder, Kirkpatrick Johnson, & Crosnoe, 2003), the application the life-course in empirical studies is often limited to examining individuals' life trajectories or transitions in the aging process with interviews or specially-designed longitudinal survey

data (e.g. Alwin, 2012; Hendricks, 2012). Expanding the methodology to examine aging with a life course perspective, this dissertation applied a multilevel age-period-cohort analysis with multiple cross-sectional survey data. Age-period-cohort analysis with a multilevel framework is at the frontier of demographic research on age, cohort and period effects in relation to social change. Yet most existing studies on the multilevel age-period-cohort analysis have been in the fields of demography, statistics, and public health, and often focused on methodological discussions (e.g. Yang, 2008; Zheng, Yang, and Land, 2011; Bell, 2014; O'Brien, 2017). By applying this methodology to transportation research, this dissertation integrated the empirical analysis with gerontological theories of the life course perspective, and analyzed the differentiated transportation mobility and activity participation between different groups of aging populations.

Conceptually, this dissertation built conversations between the aging-in-place literature that focuses on neighbourhood-scale community initiatives and policies, and studies on residential mobility that examine moving patterns and regional growth and decline. The macro-level empirical analysis in this dissertation provided contextual knowledge for comparing inconsistent empirical findings on good places to age in place, which can help to explain magnitudes of different demographic trends that shape the phenomenon of aging-in-place and patterns of residential mobility simultaneously.

Furthermore, with a macro perspective, this dissertation established conceptual links between aging-in-place and the mobility of aging populations. Mobility is an important yet an under-discussed aspect of aging-in-place. The residential mobility of older adults is related to the extent to which they can choose a good place for them to age in place, and the transportation mobility of older adults is associated with their activity space and the place they interact with on a daily basis in the aging process. By analyzing aging-in-place in relation to residential mobility and transportation mobility, this dissertation pointed out directions to integrate conceptual frameworks of place and mobility in the research on aging-in-place and healthy aging.

Nonetheless, a few limitations in the empirical analysis need to be noted. First, the lack of a spatially detailed moving data by age group undermined the accuracy of analyzing the spatial pattern of aging-in-place. Second, the lack of a spatial data set of institutions,

nursing homes, or senior housing across Canada made it difficult to distinguish naturally occurring retirement communities from the planned aged homes, and both types of neighbourhoods can be classified as aged neighbourhood based on their age structures. Third, the cohort analysis and multilevel models of age-period-cohort analysis can be substantially improved with more cycles of cross sectional survey data or longitudinal data that tracts individuals or neighbourhoods over time.

7.3 Insights for planning policy and directions for future research

With a focus on the built environment, the main findings inform conceptualizations of aging-in-place from a planning perspective. Policies supporting aging-in-place often emphasize helping older people to obtain social services and care in the "community" outside of institutions, facilities and nursing homes. From a planning perspective, aging-in-place means planning for the place where older adults age "outside the walls" - in an age-integrated society (Rosenberg & Everitt, 2001).

However, there are limited evidence-based discussions on planning tools/strategies to accommodate the emerging demands of aging populations and to enhance their quality of life. On the one hand, most existing influential policy frameworks of aging-in-place and age friendly cities focus on aging in highly developed urban environments, such as New York city, while discussions on contextual differences are limited (e.g. WHO, 2007; Plouffe & Kalache, 2010). On the other hand, context-specific empirical studies on aging-in-place and age-friendly communities often acknowledge contextual differences without explaining how different the analyzed local environment is from others (e.g. Boldy, Grenade, Lewin, Karol, & Burton, 2011; Garon, Paris, Beaulieu, Veil, & Laliberté, 2014). Because of limited (and often inevitably biased) sample of aging populations and incomparable contexts, the existing evidence tends to point to different policy directions. For example, some studies argue for the need to help older adults to keep driving as long as they are able to, while other studies on age-friendly communities advocate for providing alternative travel options to driving.

In response to the conflicting evidence-based policy suggestions, this dissertation challenges some preconceptions that are commonly found in discussions on planning for

population aging and aging-in-place. Firstly, different from an assumption that population aging is associated with population decline, the empirical analysis shows that overall, population aging and population decline has weak associations, and planning for aging-in-place is not necessarily about managing decline. However, as the weak association is strongly influenced by a few outliers, future studies need to examine characteristics of these outliers, and articulate conditions that will lead to stagnation - structural population aging and decline.

Secondly, though concept of aging-in-place is often interpreted as policies that should help older adults staying in their own homes or neighbourhoods as long as possible, the empirical analysis highlights the need to understand how the meaning of aging in place varies in different neighbourhood contexts. Though policy frameworks for age-friendly cities often imply that a more compact built environment is more age-friendly, the analysis points out that decreasing affordability is observed in both young and aged neighbourhoods that tend to have relatively compact built environment and good access to amenities. While younger populations continue to locate at urban centres, older adults may not choose to or may not be able to locate or relocate to places with compact built environments. The residential mobility among older adults remains low compared to their younger counterparts. Yet the low residential mobility among older adults can be attributed to the lack of affordable housing options in the good places to age in place. Although previous research suggests that with the aging of population there are increasing demands for more compact built environment (Myers & Ryu, 2008), the empirical analysis indicates that relatively compact neighbourhoods continue to attract younger populations and become increasingly unaffordable. Therefore, planning policy needs to consider how to prevent the potential displacement of vulnerable older adults, especially older renters, while promoting compact built environment for aging-in-place. Arguably, planning for aging-in-place is not primarily about supporting older residents not to move. Instead, it needs to examine to what extent the local environment can support the changing needs of the older residents over the life-course.

Thirdly, in vast areas of car-dependent urban form, car-use remains important for activity participation among older adults, and the importance of automobility is likely to increase among aging baby boomers. On average, the baby boomer generations are often

reported to be healthier, wealthier and more accustomed to the car culture than previous generations (Schwanen & Paez, 2010). However, the aging population is a highly diverse group. An overemphasis on the car-preference among the older adults and the support for membership-based aging-in-place initiatives are likely to divert policy incentives away from the subgroups of older adults who need most mobility support and housing support. Given that automobility is differentiated by gender gap, income and health status over the life course, a car-dependent built environment may lead to cumulative disadvantage, both in terms of activity participation and health, for those who had limited car-access or stopped driving at a relatively early life-stage. Therefore, future studies need to examine the long-term impact of a car-dependent built environment and the potential (cumulative) disadvantage it causes to people who have less car access.

With spatially detailed macro-level analyses, this dissertation shows a big picture of diverse contexts of aging-in-place, which helps to build conversations between studies that examine aging and place at various scales and in different disciplines. In the existing literature, both driving and active travel are identified as positively associated with health outcomes for aging populations (e.g. Choi & Mezuk, 2013; Annear et al., 2012). Results from this dissertation indicate that within a car-depend built environment, promoting walkable neighbourhoods alone cannot address the participation gap in various social and physical activities between older car users and non-car-users. However, future studies need to analyze and compare long-term health effects of both active travel and automobility in different built environment contexts, and synthesize the built environment characteristics of good places to age in place. In addition, by analyzing the participation in a variety of daily activities over the life course, this dissertation identified accessing services and retail to be a most car-dependent activity among older adults. The development pattern of retail and commercial services has been long influenced by "the system of automobility" – with large-scale retail or service outlets choosing locations that prioritize car use. Though policy frameworks of age-friendly communities have not emphasized older adults' access to retail, land-use and transportation planning policies can address this neglected aspect of an age-friendly built environment.

Building on findings of the scoping study (Chapter 2), this dissertation addresses two clear directions for future planning research on aging-in-place. At a macro scale, studies need to analyze how different sets of planning tools/strategies are suitable for creating age-friendly communities in distinct types of aging-in-place contexts. At a micro scale, studies on aging-in-place need to integrate both concepts of place and mobility, and to analyze older adults' activity spaces and how they change in the aging process.

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Appendix A. List of reviewed articles

Author	Title	Date	Journal
Barnett et al.	Associations between the neighbourhood environment characteristics and physical activity in older adults with specific types of chronic conditions	2016	International Journal of behavior nutrition and Physical Activity
Calrson et al	Walking mediates associations between neighborhood activity supportiveness and BMI	2016	Health&Place
Cerin E. et al.	Associations of objectively-assessed neighborhood characteristics with older adults' total physical activity and sedentary time in an ultra-dense urban environment: Findings from the ALECS study	2016	Health&Place
Chaudhury et al	Neighbourhood environment and physical activity in older adults	2016	Social Science & Medicine
Hand, C	Associations between neighbourhood characteristics and community mobility in older adults with chronic health conditions	2016	Disability and Rehabilitation
Hsueh, MC; Liao, Y; Chang, SH	Perceived Neighborhood and Home Environmental Factors Associated with Television Viewing among Taiwanese Older Adults	2016	International Journal of Environmental Research and Public Health
Smith, AR; et al.	Trajectories of Outdoor Mobility in Vulnerable Community-Dwelling Elderly: The Role of Individual and Environmental Factors	2016	Journal Of Aging And Health
Todd M., et al.	GIS-measured walkability, transit, and recreation environments in relation to older Adults' physical activity: A latent profile analysis	2016	Preventive Medicine
van Cauwenberg	Neighborhood walkability and health outcomes among older adults: The mediating role of physical activity	2016	Health&Place
Van Holle et al	interactions between neighborhood social environment and walkability to explain Belgian older adults' physical activity and sedentary time.	2016	International Journal of Environmental Research and Public Health

Barnett et al.	Neighbourhood environment, sitting time and motorised transport in older adults: A cross-sectional study in Hong Kong	2015	BMJ
Christine et al.	Longitudinal associations between neighborhood physical and social environments and incident type 2 diabetes mellitus: The Multi-Ethnic Study of Atherosclerosis (MESA)	2015	JAMA internal medicine
Clarke et al.	Cognitive decline and the neighborhood environment	2015	Annals of epidemiology
Curl et al	The effectiveness of 'shared space' residential street interventions on self-reported activity levels and quality of life for older people	2015	Landscape and Planning
Gao et al	Association between social and built environments and leisure-time physical activity among Chinese older	2015	BMC public health
Gell et al.	Built environment attributes related to GPS measured active trips in mid-life and older adults with mobility disabilities	2015	Disability and Health Journal
Koble-alexandral et al	The relationship between the built environment and habitual levels of physical activity in South African older adults: a pilot study	2015	BMC public health
Lu Z. et al.	Environmental influences on indoor walking behaviours of assisted living residents	2015	Building Research and Information
Merom et al	Neighborhood walkability, fear and risk of falling and response to walking promotion: The Easy Steps to Health 12-month randomized controlled trial	2015	Preventive Medicine Report
Nyunt et al.	Objective and subjective measures of neighborhood environment (NE): Relationships with transportation physical activity among older persons	2015	International Journal of behavior nutrition and Physical Activity
Ribeiro et al	Distance to parks and non-residential destinations influences physical activity of older people, but crime doesn't: A cross-sectional study in a southern European city	2015	BMC public health

Shibata et al	perceived neighbourhood environmental attributes and prospective changes in TA viewing time among older Australian adults.	2015	International Journal of Behavioral Nutrition and Physical Activity
van Holle et al.	Do psychosocial factors moderate the association between objective neighborhood walkability and older adults' physical activity?	2015	Health&Place
Winters et al.	Older adults' outdoor walking and the built environment: Does income matter?	2015	BMC public health
Clarke	The Role of the Built Environment and Assistive Devices for Outdoor Mobility in Later Life	2014	The journals of Gerontology
Ding et al	neighborhood environment and physical activity among older adults: do the relationships differ by driving status?	2014	Journal of Aging and Physical Activity
Gong et al	Neighbourhood green space, physical function and participation in physical activities among elderly men: The Caerphilly Prospective study	2014	International Journal of behavior nutrition and Physical Activity
Hirsch et al.	Changes in the built environment and changes in the amount of walking over time: longitudinal results from the multi-ethnic study of atherosclerosis	2014	American journal of epidemiology
Thompson et al.	Do changes to the local street environment alter behaviour and quality of life of older adults? the 'DIY Streets' intervention	2014	British Journal of Sports Medicine
Troped P.J., et al.	Relationships between the built environment and walking and weight status among older women in three u.s. states	2014	Journal of Aging and Physical Activity
Zhang et al.	The Built Environment and Walking Activity of the Elderly: An Empirical Analysis in the Zhongshan Metropolitan Area, China	2014	Sustainability
Zhang et al.	Household, Personal and Environmental Correlates of Rural Elderly's Cycling Activity: Evidence from Zhongshan Metropolitan Area, China	2014	Sustainability
Cerin et al	Walking for Recreation and Perceptions of the Neighborhood Environment in Older Chinese Urban Dwellers	2013	Journal of Urban Health

Cerin et al.	walking for transportation in Hong Kong Chinese urban elders: a cross-sectional study on what destinations matter and when.	2013	International Journal of Behavioral Nutrition and Physical Activity
Perry et al.	does neighborhood walkability moderate the effects of intrapersonal characteristics on amount of walking in post-menopausal women?	2013	Health&Place
Ribeiro, AI et al.	Physical activity-friendly neighbourhood among older adults from a medium size urban setting in Southern Europe	2013	Preventive Medicine
Rosso, AL et al.	Neighborhood Amenities and Mobility in Older Adults	2013	American Journal of Epidemiology
Stahl et al.	A five-year follow-up among older people after an outdoor environment intervention	2013	Transport Policy
Van Cauwenberg et al	Older adults' transportation walking: a cross-sectional study on the cumulative influence of physical environmental factors	2013	International Journal of Health Geographics
Adams et al	Neighborhood Environment Profiles for Physical Activity Among Older Adults	2012	American journal of health behavior
Carlson et al	Interactions between psychosocial and built environment factors in explaining older adults' physical activity	2012	Preventative medicine
Giehl et al	Physical activity and environment perception among older adults: a population study in Florianópolis, Brazil	2012	Revista de Saúde Pública
Lotfi & Koohsari	Neighborhood Walkability in a City within a Developing Country	2012	Journal of urban planning and development
Murayama et al	Contextual effect of neighborhood environment on homebound elderly in a Japanese community	2012	Archives of Gerontology and Geriatrics
Nathan et al	Access to commercial destinations within the neighbourhood and walking among Australian older adults	2012	International Journal of behavior nutrition and Physical Activity
Pelclova et al.	Neighborhood environment and walking for transport and recreation in central European older adults	2012	Acta Gymnica

Strath et al.	Measured and perceived environmental characteristics are related to accelerometer defined physical activity in older adults	2012	International Journal of behavior nutrition and Physical Activity
Takahashi et al	A cross-sectional survey of the relationship between walking, biking, and the built environment for adults aged over 70 years	2012	Risk management and healthcare policy
Tsunoda et al.	Associations of physical activity with neighborhood environments and transportation modes in older Japanese adults	2012	Preventative medicine
Van Cauwenberg et al	Physical environmental factors related to walking and cycling in older adults: The Belgian aging studies	2012	BMC public Health
Clarke et al	Participation among adults with disability: The role of the urban environment	2011	Social Science and Medicine
Inoue et al.	Perceived neighborhood environment and walking for specific purposes among elderly Japanese.	2011	Journal of epidemiology
King et al	Aging in neighborhoods differing in walkability and income: Associations with physical activity and obesity in older adults	2011	Social Science and Medicine
Levasseur et al	Associations Between Perceived Proximity to Neighborhood Resources, Disability, and Social Participation Among Community-Dwelling Older Adults: Results From the VoisiNuAge Study	2011	Archive of physical medicine and rehabilitation
Shin et al.	The distance effects of environmental variables on older African American women's physical activity in Texas	2011	Landscape and urban planning
Frank et al	Healthy aging and where you live: Community design relationships with physical activity and body weight in older Americans	2010	Journal of Physical Activity and health
Gómez et al	Built Environment Attributes and Walking Patterns Among the Elderly Population in Bogotá	2010	American Journal of preventative medicine
Parra et al	Built environment characteristics and perceived active park use among older adults: Results from a multilevel study in Bogotá	2010	Health&Place

Salvador et al	Practice of walking and its association with perceived environment among elderly Brazilians living in a region of low socioeconomic level	2010	International Journal of behavior nutrition and Physical Activity
Bird et al	The influence of the built environment and other factors on the physical activity of older women from different ethnic communities	2009	Journal of Women & Aging
Kemperman A., Timmerman H.	Influences of built environment on walking and cycling by latent segments of aging population	2009	Transportation Research Record
Li et al.	Built environment and changes in blood pressure in middle aged and older adults	2009	Preventive Medicine
Li et al.	Built environment and 1-year change in weight and waist circumference in middle-aged and older adults: Portland neighborhood environment and health study	2009	American Journal of Epidemiology
Michael and Carlson	Analysis of individual social-ecological mediators and moderators and their ability to explain effect of a randomized neighborhood walking intervention	2009	International Journal of behavior nutrition and Physical Activity
Li et al	built environment, adiposity, and physical activity in adults aged 50-75.	2008	American Journal of Preventive Medicine
Morris et al	Self-efficacy and environmental correlates of physical activity among older women and women with multiple sclerosis	2008	Health education research
Nagel et al	The Relation between Neighborhood Built Environment and Walking Activity among Older Adults	2008	American Journal of Epidemiology
Richard et al.	Staying Connected: Neighbourhood Correlates of Social Participation among Older Adults Living in an Urban Environmental in Montreal, Quebec	2008	Health Promotion International
Sugiyama et al.	Associations between characteristics of neighbourhood open space and older people's walking	2008	Urban forestry and urban greening
Berke et al	Protective Association Between Neighborhood Walkability and Depression in Older Men	2007	Journal of American Geriatric society

Berke et al	Association of the Built Environment With Physical Activity and Obesity in Older Persons	2007	American journal of public health
Hovbrandt et al.	Very old people's use of the pedestrian environment: functional limitations, frequency of activity and environmental demands	2007	European journal of aging
Mowen et al	'The role of park proximity and social support in shaping park visitation, physical activity, and perceived health among older adults	2007	Journal of Physical Activity and Health
Michael et al	Measuring the influence of built neighborhood environments on walking in older adults	2006	Journal of aging and physical activity
King et al.	Objective Measures of Neighborhood Environment and Physical Activity in Older Women	2005	American journal of preventive medicine
Li et al.	Multilevel modelling of built environment characteristics related to neighbourhood walking activity in older adults	2005	Journal of epidemiology and community health
King et al	The Relationship between Convenience of Destinations and Walking Levels in Older Women	2003	American Journal of Health Promotion
Balfour & Kaplan	Neighborhood Environment and Loss of Physical Function in Older Adults: Evidence from the Alameda County Study	2002	American journal of epidemiology

Appendix B. Summary of selected review articles

Authors (year of publication) *Source*	**Objective**	**Type of review** *Method / Inclusion or exclusion criteria*	**No. of articles included** *(Type of articles)*	**Conclusion and/or Recommendation**
Haselwandter et al. (2015) *Journal of Aging and Physical Activity*	To identify (1) the relationships between the BE and PA in older adults; (2) barriers or enablers in senior-specific housing; (3) research gaps	**State of the science review/ rapid review** *Included studies with participants aged 65+, excluded studies that were not conducted in the United States, focused on methodology, or did not contain relevant variables, associations, or outcomes.*	Not clearly stated	Emphasized the lack of research on institutionalized settings such as assisted living facilities.
Levasseur et al. (2015) *BMC public health*	To understand how the neighborhood environment is associated with mobility and social participation in older adults	**Scoping study** *Excluded studies that only focused on narrow concepts, reported expert opinions or conference proceedings, or concerned only specific subgroups of population.*	50 *(English articles published Jan. 1980 - Sept. 2013)*	Emphasized the need to consider proximity to resources and to recreational facilities, social support; transportation, and neighborhood security and user-friendliness of the walking environment. Suggested future studies to include both mobility and social participation, and investigate how they are associated with older adults' attitudes.
Annear, M. et al. (2014) *Aging & Society*	To overview environmental influences on healthy and active aging	**Systematic review** *Included studies that (1) sampled community-dwelling adults aged 50+; (2) assessed health-related issues or aspects of the WHO's active aging concept, in relation to environment; and (3) adopted qualitative, quantitative or mixed-methods*	83 *(peer-reviewed geronto-logical primary studies in English published 1985-2010)*	Emphasized the need for: innovative research methods; research-collaboration with older adults; examining broad aspects of the active aging concept; in-depth assessment of environmental characteristics in different localities; theory development; and understanding the pathways leading from environment to health and activity participation.
Moran M., et al. (2014) *International Journal of Behavioral Nutrition and Physical Activity*	To overview qualitative studies to understand the relationships between BE and physical activity in older adults	**Systematic review** *Included studies that (1) with participants' average age 65+, (2) explored the participants' experiences of PA and/or the physical environment, (3) used qualitative methodologies for data collection and analysis, and (4) provided data that can be evaluated*	31 *(qualitative studies in English, published 1996-2012)*	Suggested that the variations in quality might explain previously observed inconsistencies between quantitative studies. Interventions on BE should provide high-quality pedestrian infrastructure; improve safety from crime and traffic; provide easy access to exercise opportunities, daily destinations and rest areas; provide aesthetically appealing and pleasant conditions.

Yen et al. (2014) *Journal of aging and health*	To understand how any of the BE contexts were related to outdoor mobility in older adults.	**Realist synthesis with a scoping review** *Included studies with participants aged 50+, excluded articles with no data or content to contribute to the ecological model*	123 *(English articles published1 991–2011)*	Emphasized safety as a key factor and one of the bridges between environmental components and decisions about mobility, while population density, sidewalk presence, and park proximity did not appear to be key factors.
Kerr J., Rosenberg D., Frank L. (2012) *Journal of Planning Literature*	To review studies on the relationship between the BE, walking, and health in older adults.	**Traditional/ narrative review**	Not clearly stated	Suggested that walkable communities can reduce the risk of chronic disease. The design of the BE in residential neighborhoods and the level of access to transit service determined the level of accessibility to important destinations such as shops, services, and places to recreate.
Hand et al. (2012) *Occupation, Participation and Health*	To review studies concerning neighborhood influences on participation in older adults with chronic health conditions.	**Scoping Review** *Included articles that (1) reported on neighborhood characteristics that affect participation; (2) at least half the sample aged 55+; and (3) the sample included participants with a chronic condition*	15 (*English articles published 1990 to early 2011)*	Suggested that (1) neighborhood economic status, services/resources, mobility resources/barriers, physical problems, cohesion, and safety are associated with older adults' participation; (2) social support needs to be considered as a covariate in studying the levels or limitations of participation.
Van Cauwenberg J., et al. (2011) *Health & Place*	To review the literature on the relationship between the physical environment and PA in older adults.	**Systematic review** *Included non-intervention-based studies with a sample mean age 65+; studied the total or recreational PA/ walking /cycling, or active travel. Excluded studies that narrowly focused on work/ household-related PA, socio-cultural, economic or policy environment, or unhealthy, overweight, disabled or institutionalized participants.*	31 *(quantita-tive studies in English, published Jan.2000 - March 2010)*	Inconsistent results were found, and most of the BE features were not related to PA in the reviewed studies. Identified the need for: (1) studies in different contexts; (2) longitudinal research, standardized, reliable and validated PA and environmental measurements; and (3) studies on possible moderating effects are definitely warranted.
Clarke and Nieuwenhuijs en (2009) *Maturitas*	To review the current state of the health literature on physical environments for healthy aging.	**Traditional/ narrative review** *Used the International Classification of Functioning Disability and Health as a framework.*	Not clearly stated	Identified the need for (1) theoretical and empirical studies on the mechanisms behind the person–environment relationship; (2) studies with nationally representative samples; (3) longitudinal studies; (4) better definition and measurement of person-centred environments.
Sugiyama T. and Ward	To conceptualize	**Traditional/ narrative review**	Not clearly stated	Identified three foci to conceptualize environmental support: (1) personally meaningful

Thompson C. (2007) *Environment and Planning A*	environmental support			outdoor activities, (2) environmental attributes found relevant to people's activities, and (3) unmet needs for daily activities.
Cunningham G.O., Michael Y.L. (2004) *American Journal of Health Promotion*	To identify theoretical models and key concepts used to predict the association between BE and PA in older adults.	**Systematic review** *Included primary research that assessed physical activity or overall health of a community-based population with theoretical models and concepts applicable to seniors.*	27 *(English articles published 1966 - 2002)*	Identified (1) inconsistent findings; (2) the selection of concepts and variables was driven by the choice of theoretical model, but safety, micro urban design features, aesthetics, and convenience of facilities were consistently studied; and (3) few validated instruments were developed and tested to measure the BE.