NEIGHBORHOOD BUILT ENVIRONMENT AND TRAJECTORY OF LOWER EXTREMITY FUNCTION AMONG OLDER WOMEN

By

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Abstract

Background

Among older adults, lower-extremity functional decline is strongly associated with risk of future disability. Because regular engagement in physical activity is an effective means of slowing functional decline and preserving functional health, characteristics of the neighborhood built environment associated with physical activity among older adults should result in downstream effects on the trajectory of lower extremity functional decline. However, few studies have explored the relationship between neighborhood built environment and the trajectory of lower-extremity functional decline, and none have examined the effect of change in neighborhood built environment over time on physical function among older adults. The purpose of this study was to describe the association of objectively measured characteristics of the neighborhood built environment with the trajectory of lower-extremity function among older women over a 12-year period in Portland, Oregon.

Methods

This retrospective, cohort study examined the association between objective measures of neighborhood built environment and gait speed, a widely used measure of lower extremity function, among a sample of 1256 community-dwelling older women enrolled in the Portland, Oregon cohort of the Study of Osteoporotic Fractures. Participants' baseline visit occurred between 1986 and 1988, and follow-up visits occurred every two years thereafter. Data from participants first six visits, a follow-up period of approximately 12 years, were used in this analysis. Measures of the neighborhood built

environment corresponding to the time period of the study were constructed from historical data in the Regional Land Information System and linked to participants' residential addresses using geographic information system technology. Measures of public transit accessibility, street connectivity, and land-use mix were combined in an index of neighborhood walkability. Parallel-process, latent growth curve models were constructed to examine the association of baseline neighborhood walkability with baseline gait speed, baseline neighborhood walkability with change in gait speed, and change in neighborhood walkability with change in gait speed. A similar series of models examined the association of distance to parks/green spaces with gait speed. Models were adjusted for age, educational attainment, complex comorbidity, incident fracture, and neighborhood socioeconomic status. A pattern-mixture modeling approach was employed to adjust for attrition.

Results

Advanced age, lower educational attainment, and the presence of complex comorbidity were all significantly associated with lower gait speed at baseline. Advanced age was associated with greater decline in gait speed over time. After controlling for age, education, complex comorbidity, incident fractures, and neighborhood socioeconomic status, baseline neighborhood walkability was not significantly associated with baseline gait speed or change in gait speed over time. There was, however, a statistically significant association between the slope of neighborhood walkability and the slope of gait speed ($b=.024$, $p=.020$). A one-decile increase in walkability over the study period was associated with a .024 m/sec reduction in the rate of gait speed decline. There were no significant associations between neighborhood distance to parks/green space and the trajectory of gait speed.

Conclusions

This study found that change in neighborhood walkability over time was associated with the degree of change in gait speed over time. Women who lived in neighborhoods that became more walkable over the 12-year study period (i.e. increased access to public transit, more diverse land-use mix, and greater street connectivity) had a reduced rate of gait speed decline. These findings indicate that characteristics of the neighborhood built environment are a modifiable determinant of lower-extremity function among older women, and suggest that efforts to promote pedestrian-friendly urban design may be a valuable means of reducing disability among older adults.

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Chapter 1—Introduction

Disability among Older Adults

Disability is a major public health issue among older adults. Broadly defined as substantial limitation in life activities, disability is highly prevalent among adults aged 65 years and older, with one in three older adults reporting at least one functional limitation. Among older adults participating in the 2005 American Community Survey, 30% reported limitation in walking, climbing stairs, or carrying objects, (termed functional disability) and 10% reported limitation in performing activities of daily living (ADL) such as dressing, bathing, or getting around inside the home (Fuller-Thomson, Yu, Nuru-Jeter, Guralnik, & Minkler, 2009). Similarly, among older adults enrolled in the Cardiovascular Health Study, 30% developed mobility disability and 15% developed ADL disability (Chaudhry et al., 2010). Based on an analysis of data from the National Health Interview Survey, Newcomer, Kang, Laplante, and Kaye (2005) estimated that 15.1. million non-institutionalized adults require assistance with either ADL's or instrumental activities of daily living (IADL's). In each of these studies, older women were observed to have higher rates of ADL, functional, and mobility disability than older men. Increased rates of disability and steeper declines in function among older women have also been reported by Beckett et al. (1996) and Seeman, Merkin, Crimmins, & Karlamangla (2010).

The development of disability is associated with increased risk of subsequent institutionalization, morbidity, and mortality among adults aged 65 years and older (Beswick et al., 2008; Greene, 1983; Guralnik, Fried, & Salive, 1996; Jette, Tennstedt, & Crawford, 1995; Ostir et al., 1999). The cost of providing additional medical care and long-term care services to newly disabled older adults is estimated to be $26-30 billion dollars per year (Guralnik, Alecxih, Branch, & Wiener, 2002). Taylor and Hoenig (2006) found that older adults with reported difficulty walking had higher rates of health care utilization higher downstream Medicare costs after controlling for disease burden. Furthermore, there is a well-documented association between functional independence and self-reported quality of life among older adults (Cerniauskaite et al., 2012; Groessl et al., 2007; Vest, Murphy, Araujo, & Pisani, 2011). Given the profound impact that functional impairment and subsequent disability has on the health and well-being of older adults, as well as the substantial costs associated with providing medical care and supportive services to older adults with impaired physical function, identifying the modifiable determinants of functional decline is a critical step in addressing the needs of our aging population. It is particularly important to identify those factors associated with pre-clinical changes in physical performance because timely intervention may minimize or prevent the sequelae associated with functional impairment.

Objective Measures of Lower-Extremity Function Predict Future Disability

Measurement of physical function can be subjective, through self-reported level of difficulty engaging in specific physical tasks (e.g., walking a city block or extending the arms above the shoulders), or objective, by measuring predefined criteria during the performance of standard physical task (e.g., the time it takes to walk 6 meters or upper extremity active range of motion) (Simonsick et al., 2001). There is evidence, however, that objective, performance-based measures of physical function, particularly lower-extremity function, are more sensitive than subjective measures to the pre-clinical changes in physical performance that have been observed to precede functional impairment and future disability (Cooper et al., 2011). Performance-based measures of lower extremity function are consistent predictors of future ADL disability (Guralnik et al., 2000; Wennie Huang, Perera, VanSwearingen, & Studenski, 2010), mobility disability (Cesari et al., 2009; Fried, Bandeen-Roche, Chaves, & Johnson, 2000; Guralnik, Ferrucci, Simonsick, Salive, & Wallace, 1995), falls (Abellan van Kan et al., 2009), hospitalization (Cesari et al., 2005), institutionalization (Giuliani et al., 2008; Montero-Odasso et al., 2005), and mortality (Cooper et al., 2010; Studenski et al., 2011). Guralnik et al. (1995), in a longitudinal study of older adults with no reported disability, found that those who performed in the lowest tertile on three measures of lower extremity function (timed walk, chair stand test, balance test) were 4.2 times more likely that the highest performing tertile to report ADL disability and 4.9 times more likely to report mobility disability at 4-year follow-up. Fried et al. (2000), in a study of 436 older women, found that incident difficulty in walking one-half mile was predicted by reduced gait speed and incident difficulty climbing 10 steps was predicted by reduced stair climb speed. Performance-based measures of lower-extremity function are also reliable indicators of present functional impairment, and can objectively measure the progression of functional decline and disability occurring either through worsening of the precipitating pathology or through the initiation of secondary impairments (Bohannon, 2009; Cesari, 2011; Lan, Melzer, Tom, & Guralnik, 2002; Ostir et al., 2012; Verghese, Wang, & Holtzer, 2011). Thus, objective measures of lower-extremity function can be used both to measure pre-clinical declines in physical performance in older adults who are not experiencing functional limitation and quantify the degree of functional decline in the context of established function impairment.

Physical Activity is a Modifiable Determinant of Function and Disability

Ecological models of both aging and disability suggest that the physical environment is an important determinant of the health and function of older adults (Satariano, 2006). Because the activity space of older adults is largely centered around their local residential environments, the physical, or built, features of their neighborhood environment may play a particularly important role in promoting functional ability or hastening functional decline (Glass & Balfour, 2003). However, little is known about the mechanisms through which neighborhood built environment influences functional health. One potential pathway through which the built environment may influence functional decline and subsequent disability is by facilitating or hindering physical activity (Satariano & McAuley, 2003). Physical activity is one of the most important strategies to preserve function and reduce disability among older adults. Regular engagement in physical activity is associated with preservation of lower-extremity function and decreased risk for the subsequent development of functional limitation (Seeman & Chen, 2002). Furthermore, there is evidence that engagement in physical activity can improve lower-extremity function even among older adults with existing functional impairment (Life Study Investigators et al., 2006; Peterson et al., 2009; Protas & Tissier, 2009). While older adults may participate in a number of types of physical activity, walking is by far the most common (Siegel, Brackbill, & Heath, 1995). According to data from the Behavioral Risk Factor Surveillance System (BRFSS), 45% of women over the age of 65 reporting walking for leisure-time physical activity, and walking was the most frequently reported leisure-time physical activity among older women who met current activity recommendations (Simpson et al., 2003). However, the prevalence of older women who reported engaging in walking for leisure-time physical activity increased only 4.8% between the years of 1987-2000, despite a concerted national campaign to promote leisure-time physical activity (Simpson et al., 2003). In regards to transit-related walking, though it remains the second most popular means of travel among older adults, the proportion of total household trips among older adults made by walking, roughly 9%, was unchanged from 2000 to 2009 (Lynott & Figuerido, 2011). These statistics underscore the potential to improve the functional health of older adults through promoting both leisure time walking and walking for transit.

Neighborhood Built Environment is Associated with Physical Activity Level

A growing body of literature has documented the relationship between neighborhood built environment and physical activity behavior, particularly walking (Ewing & Cervero, 2010; Handy, 2005; Van Cauwenberg et al., 2011). Neighborhood physical features which have been associated with increased levels of physical activity include highly-connected local street networks (Li et al, 2005), diverse land-use mix (Shigematsu et al., 2009; Wang & Lee, 2010), access to public transportation (Borst et al., 2009 ; Su, Schmocker, & Bell, 2009), and distance to parks or green spaces (Michael, Perdue, Orwoll, Stefanick, & Marshall, 2010). Of these, the first three characteristics are considered by urban planners to be the primary influences on active travel, defined as the choice of non-motorized forms of travel such as walking or cycling. The approach taken in the current study was to combine measures of street connectivity, land-use mix, and public transport access in a composite measure of neighborhood walkability, which is generally defined in the urban planning literature as the degree to which neighborhood design promotes or hinders active travel. Similar indices have been used in a number of previous studies examining the relationship between neighborhood walkability and physical activity (Brownson, Hoehner, Day, Forsyth, & Sallis, 2009; Leslie et al., 2007; Van Dyck et al., 2010). Neighborhood distance to park/green space, on the other hand, is largely associated with recreational physical activity, and so was not included in the composite measure of walkability described above. Instead, this study included a single measure of distance to park/green space in order to distinguish between neighborhood influences on active travel and recreational physical activity.

Neighborhood Built Environment and Physical Function

Given the well-established relationship between physical activity and physical function, one could reasonably expect that neighborhood characteristics which promote active travel and/or recreational physical activity would have measurable effects on the trajectory of functional decline among older residents. However, few studies to date have explored the relationship between neighborhood physical environment and physical function (Rosso, Auchincloss, & Michael, 2011). Of those, only four have examined the relationship of neighborhood environment to change in functional ability over time, and no study to date has modeled the association between change in neighborhood environment and the trajectory of functional decline. Consequently, it is unclear whether urban planning initiatives to promote more walkable neighborhoods will improve functional outcomes among the older adults living in those neighborhoods.

During the past several decades, the city of Portland, Oregon, has become nationally renowned for enacting and implementing urban planning policies aimed at managing growth and limiting urban sprawl (Song & Knaap, 2004). Beginning in 1991, the Portland regional government (known as Metro) began working on a comprehensive urban planning strategy, aligned with New Urbanist principles, promoting pedestrian-oriented, walkable neighborhoods. These policies included expanding public transit, encouraging mixed-use development, rehabilitating brown field and industrial use areas, and creating neighborhood park and green spaces (Metro, 2011). In addition, the city of Portland is a national leader in the use of geographic information system (GIS) technology to guide urban planning initiatives, and have been collecting extensive neighborhood-level data since 1988. Thus, it is the ideal setting to examine the effects of neighborhood environment on functional ability over time, particularly the degree to which changes in the neighborhood environment are associated with changes in lower extremity function.

Specific Aims

Therefore, the specific aims of this study are to:

1. Describe the relationship between baseline neighborhood walkability and baseline lower-extremity function among older women.

   Hypothesis: Baseline neighborhood walkability is significantly associated with baseline lower-extremity function. Women who live in more walkable neighborhoods will have higher baseline lower-extremity function.

2. Describe the relationship between baseline neighborhood walkability and change in lower-extremity function among older women.

   Hypothesis: Baseline neighborhood walkability is significantly associated with the magnitude of decline in lower-extremity function over time. Women who live *in more walkable neighborhoods will have less decline in lower-extremity function over time.*

3. Describe the relationship between change in neighborhood walkability and change in lower-extremity function among older women.
   Hypothesis: The magnitude of change in neighborhood walkability is significantly associated with the magnitude of decline in lower-extremity function over time. Improvement in neighborhood walkability over time is associated with a reduced rate of lower-extremity functional decline.
4. Describe the relationship between baseline distance to neighborhood parks/green spaces and baseline lower-extremity function among older women.
   Hypothesis: Baseline distance to neighborhood parks/green spaces is significantly associated with baseline lower-extremity function. Women who live in neighborhoods with greater distance to a park/green space will have higher baseline lower-extremity function.
5. Describe the relationship between baseline distance to neighborhood parks/green spaces and change in lower-extremity function among older women.
   Hypothesis: Baseline distance to neighborhood parks/green spaces is significantly associated with the magnitude of decline in lower-extremity function over time. Women who live in neighborhoods with greater distance to a park/green space will have less decline in lower-extremity function over time.
6. Describe the relationship between change in the distance to neighborhood parks/green spaces and change in lower-extremity function among older women.

Hypothesis: The magnitude of change in the distance to neighborhood parks/green spaces is significantly associated with the magnitude of decline in lower-extremity function over time. A reduction in the distance to a park/green space over time is associated with a reduced rate of lower-extremity functional decline.

Significance to Nursing

Meeting the needs of our aging population is one of the greatest challenges facing public health nursing in the coming decades. Our success in meeting this challenge hinges on developing community-based approaches to reducing the sequelae of institutionalization, morbidity, and mortality associated with functional decline among older adults. Yet, despite the clear need to understand the environmental determinants of functional health among older adults, few studies to date have explored the relationship of neighborhood built environment to the trajectory of functional decline among older adults, and no study to date has examined the effect of change in neighborhood built environment on physical function among older adults. This study addresses that gap in the current science, and the results of this study can inform future policy and planning initiatives to promote healthy aging.

Chapter 2—Background and Significance

Introduction

Understanding the complex dynamics of the relationship between the health and function of older adults and the environments in which they live requires a broad focus, as contributions to this field of inquiry have been made by a variety of disciplines. In this study, both the theoretical framework and the methodological approach draw heavily on work done outside the nursing field. The theoretical framework developed for this study merges classic ecological models of aging and disability with contemporary urban planning theory in an attempt to articulate the mechanisms through which neighborhood built environment influences long-term preservation of function by facilitating active aging in the community. This chapter is divided into several sections. The first section is an overview of the ecological perspective on health. This is followed by a discussion of Lawton and Nahemow's (1973) theory of environmental press, which provides a general framework for understanding how environmental characteristics influence the health and function of older adults, and Verbrugge and Jette's (1994) disablement process model, which articulates the progression of disability in an ecological context. Finally, the urban planning perspective on how neighborhood built environment influences physical activity behavior is reviewed. These approaches are then combined in a conceptual model of the relationship between the neighborhood environment and disability. This chapter concludes with a comprehensive synthesis of the literature to date on the relationship between characteristics of the neighborhood built environment and functional outcomes among older adults.

The Ecological Perspective

The ecological perspective, which emphasizes the interplay of biological, psychological, and socioenvironmental influences on behavior, provides an overarching framework for the study of environmental influences on health behaviors and outcomes. The ecological model of the determinants of health used in the Healthy People 2010 campaign is shown in Figure 2.1 (U.S. Department of Health and Human Services, 2010). This simple model illustrates two key principles of the ecological perspective that inform this study. First, that the health of individuals is influenced by both the physical and social characteristics of their environments, as well as by biological and psychological characteristics. In regards to health behavior, the ecological perspective posits that the physical characteristics of the environment in which a given behavior takes place can have a powerful an influence on that behavior (Sallis & Owen, 2002; van Sluijs et al., 2007). Second, that the various individual and environmental factors which affect health behavior and outcomes are interrelated, and can exert both direct and indirect effects on health and function.

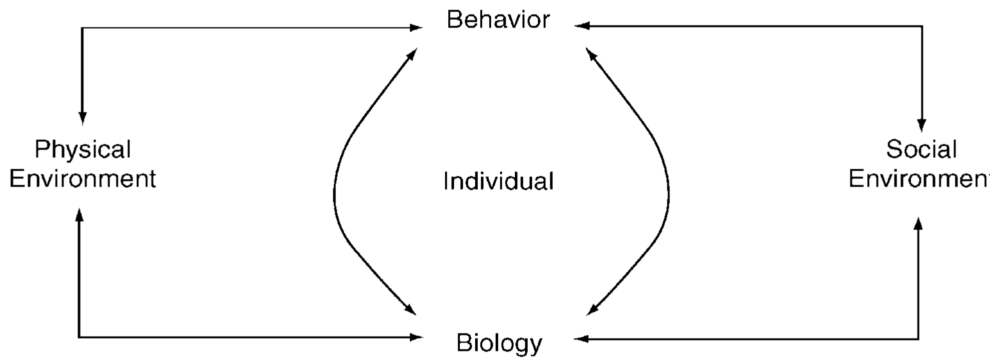


Figure 2.1. An ecological model of the determinants of health. Adapted from *Healthy People 2010: Understanding and Improving Health* (p. 14), U.S. Department of Health and Human Services, 2000 Washington, DC: U.S. Government Printing Office.

Geographic scale is an important consideration in the examination of environmental influences on health and function. (King, Stokols, Talen, Brassington, & Killingsworth, 2002). For example, an individual is geographically situated within a specific residential location, which is located within a larger city, state, and region. Characteristics of the environment at each of these geographic scales may exert important effects on health. In this study, the geographic area of focus is the residential neighborhood environment, which itself can be viewed as consisting of the physical-or built-environment and the social environment (Glass & Balfour, 2003). It is increasingly recognized that the dimensions of the neighborhood environment interact in complex ways to influence the health of residents. This study focuses primarily on the built environment, though it does incorporate a measure of neighborhood SES, which is reflective of the neighborhood social environment.

It is important to note that as a general framework for understanding the determinants of health and behavior, the ecological perspective only suggests a system of relationships; it does not specify the causal mechanisms that are responsible for the effect of a given environmental characteristic. For example, from an ecological perspective it is clearly important to consider the proximity of recreational facilities in a model of individual physical activity, though the ecological perspective provides no theoretical guidance for predicting the direction or magnitude of the relationship between proximity of recreational facilities and engagement in physical activity. Instead, the ecological perspective offers an inclusive framework for synthesizing diverse theoretical models. Three theoretical models that are central to this study are the theory of environmental press, the disablement process model, and demand theory as applied in the field of urban planning to travel behavior.

The Theory of Environmental Press

Lawton and Nahemow (1973) developed an ecological model of human behavior and function known as the theory of environmental press or the press-competence model. Its primary thesis is that behavior is contingent on the dynamic interplay between the competence of the individual and the demands placed on the individual by their environment. This theory defines individual competence broadly, as encompassing any number of measurable characteristics in the domains of biological health, sensorimotor functioning, cognitive skill and ego health. Similarly, environment is broadly conceptualized as including both the social and physical environment. Figure 2.2 illustrates the relationship between individual competence and environmental demands.

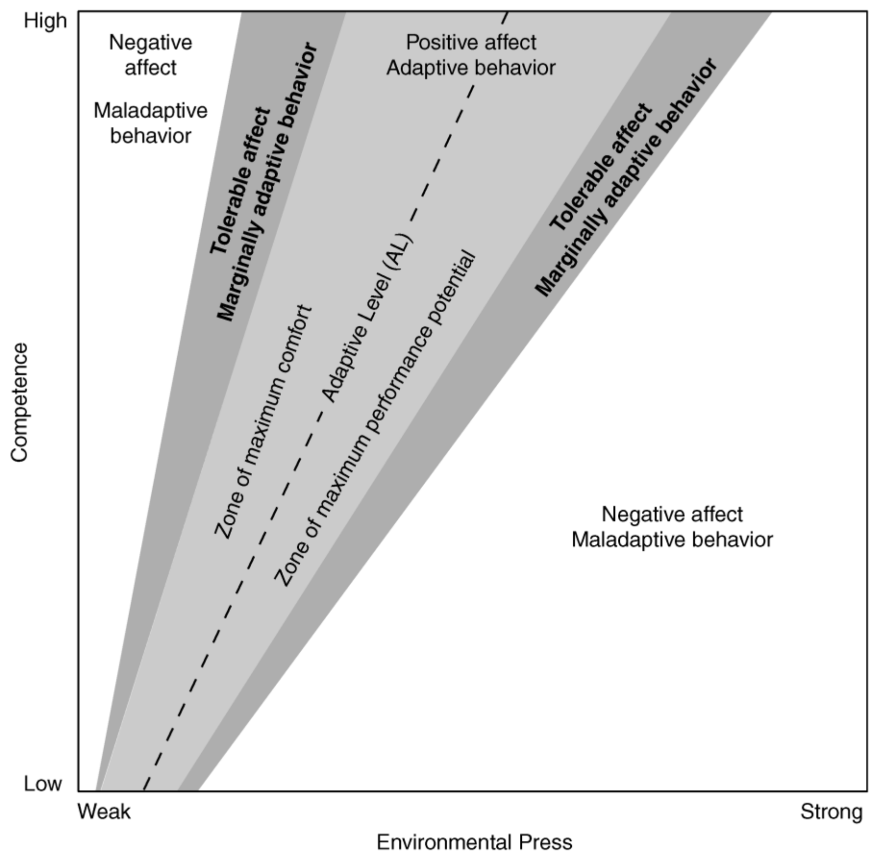


Figure 2.2. The press-competence model. Reprinted from *Ecology and the Aging Process*, MP Lawton, L Nahemow. In C Eisdorfer and MP Lawton (Eds) Psychology of Adult Development and Aging. 1973. APA

Individual competence is shown on the vertical axis, ranging from low to high, while environmental press ranges from weak to strong on the horizontal axis. The line running diagonally across the diagram, designated adaptive level, represents the theoretical point at which the level of individual competence matches the level of environmental press. To the right and left of this line are the zones of maximum performance and maximum comfort. These represent the positive adaptive responses that occur when there is a widening gap between a person's competence and the press of their environment, as on the right of the figure, or a narrowing of that gap, as on the left. For example, when a person is able to meet the challenges posed by either a mild decrease in competence or an increase in environmental press, the result can be a maximization of potential and positive adaptation. However, negative adaption occurs if the decrease in competence is too great or the environmental press too significant, resulting in negative affect and maladaptive behavior. It is the point where the demands of the environment exceed the person’s capacity. Conversely, on the left is the zone of maximum comfort, where the person’s capacity exceeds the demands of the environment, but not to a degree that the lack of stimulation and challenge results in negative adaptation, which is depicted on the far left where the lack of environmental challenge is so pronounced that boredom, passivity, and apathy result.

A key feature of this model is that functional outcomes cannot be solely predicted from either individual characteristics or from environmental features. Rather, they are viewed as a function of the degree of “fit” between the person and the environment; positive adaptation and consequent optimum function result from the equilibrium between capacity and environmental press (Lawton, 1983). For younger adults, maintaining this equilibrium does not generally pose a significant or lasting challenge. However, for older adults, the reduction in competence resulting from acute or chronic health concerns can lead to disequilibrium, magnifying the press exerted by the environment. Accordingly, older adults are regarded by Lawton to disproportionally experience the impact of adverse conditions in the physical environment (Lawton, 1985).

Glass and Balfour (2003) have observed that Lawton and Nehmow’s theory places little emphasis on the characteristics of the environment conducive to function, features they term environmental buoys. They argue that environmental buoys are as important in determining behavioral, functional, and health outcomes as negative environmental pressures. Focusing explicitly on the residential environment, they proposed a model of neighborhood effects on aging that extends Lawton's theory of environmental press to incorporate the concept of environmental buoying (Glass & Balfour, 2003). This model is depicted in Figure 2.3 below.

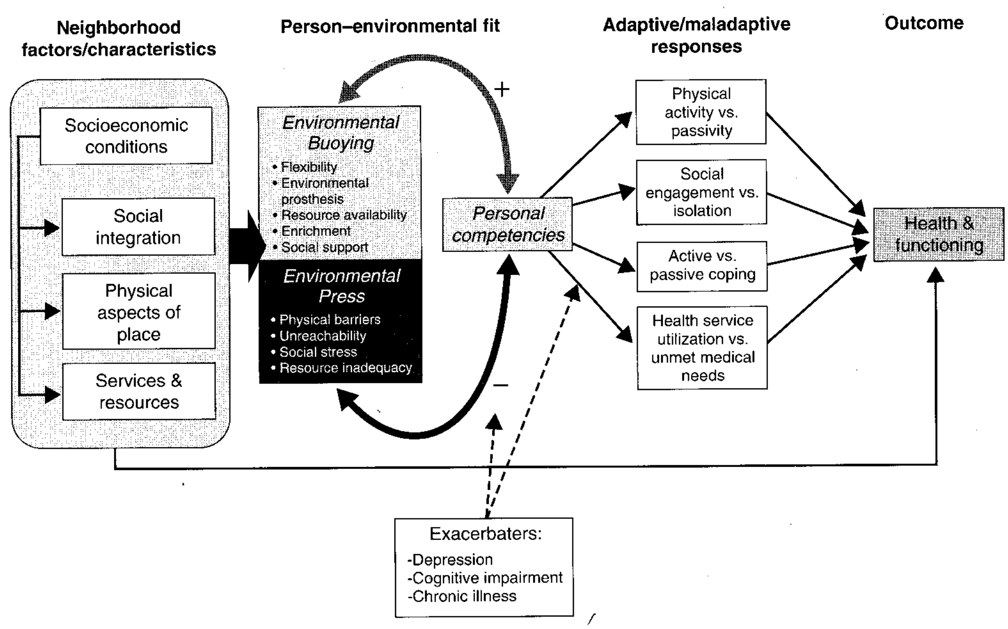


Figure 2.3. Causal model of neighborhood effects on aging. Reprinted from Glass, T., & Balfour, J. L. (2003). Neighborhoods, aging and functional limitation. In I. Kawachi & L. Berkman (Eds.), *Neighborhoods and Health* (pp. 303-334). New York: Oxford University Press.

Balfour and Glass's model presents a theoretical pathway from characteristics of the neighborhood environment to individual functional ability that is mediated by behavioral responses to the level of person-environment fit. This model suggests that modifications to the neighborhood environment can serve as environmental buoys, potentially mitigating the impact of diminishing competence on functional ability. This notion of environmental buoys enhancing the fit between the older adult and their environment is echoed in the Disablement Process model.

The Disablement Process

In the seminal article entitled "The Disablement Process," Verbrugge and Jette (1994), proposed a model of disability describing both "how acute and chronic conditions affect functioning in specific body systems, fundamental physical and mental actions, and activities of daily living and the personal and environmental factors that speed or slow disablement" (p. 1). Building on the work of the sociologist Saad Nagi (1965), Verbrugge and Jette conceptualized disability as a process beginning with the presence of an acute, chronic, or congenital pathology. This pathology can lead to impairment in a specific body system or systems. For example, the development of diabetes can lead to dysfunction of the renal and cardiovascular systems. This impairment can then lead to functional limitation, which refers to a diminished capacity to perform basic functional tasks or activities. These are conceptualized as generic actions which occur in multiple contexts, such as walking, lifting an object, reading standard print, or hearing conversation in a normal tone. Returning to the previous example, cardiovascular impairment may result in a diminished capacity to engage in physical activity such as walking. This stage has also been referred to as preclinical disability (Fried et al., 2000), and is the point at which a person may be unaware of their diminished capacity but have measurable functional decline. The transition from functional limitation to disability occurs when the person begins to experience difficulty in carrying out activities of daily living such as personal care, shopping, employment, household management, hobbies, or social interaction. Disability, then, can be seen as the expression of a functional limitation in a social context (Institute of Medicine, 1991).

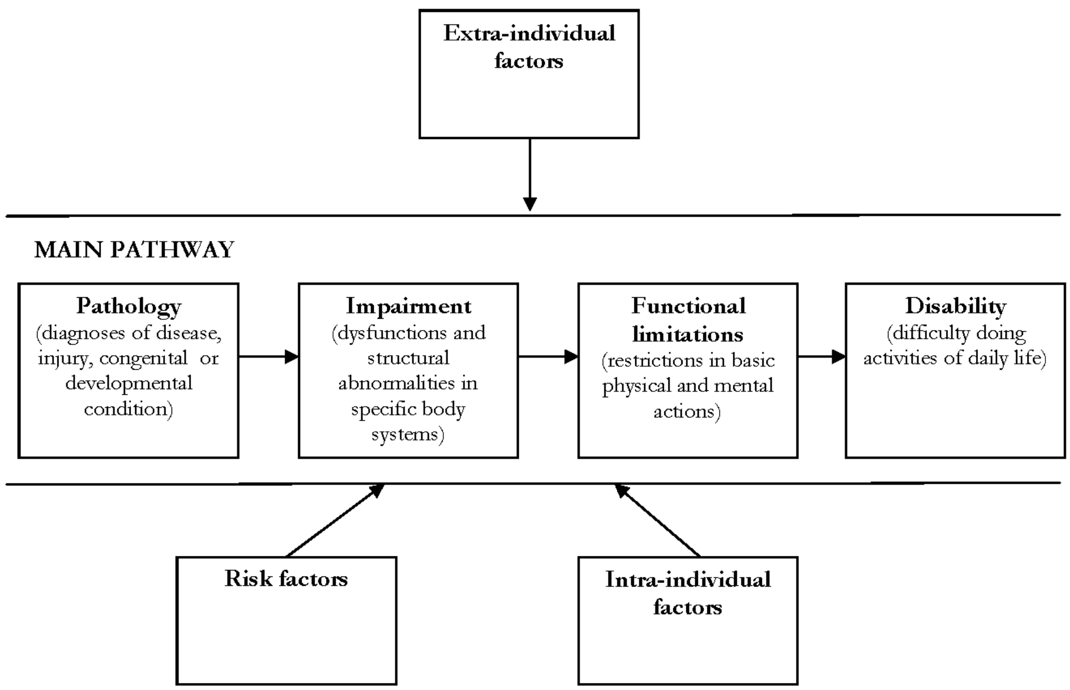


Figure 2.4. The disablement process. Adapted from “The disablement process,” by L. M. Verbrugge and A. M. Jette, 1994, *Social Science and Medicine, 38*(1).

The disablement process model, as originally depicted by Verbrugge and Jette, is shown in Figure 2.4. It must be pointed out, however, that the disablement process is not conceptualized as unidirectional. Rather, the model allows for feedback loops both within a given disablement process and between linked processes (Verbrugge & Jette, 1994).

For example, a person experiencing activity intolerance as a result of cardiovascular disease (functional limitation) may be unable to engage in their usual recreational exercise (disability), which results in musculoskeletal deconditioning (functional limitation) and further limitations on daily activity (disability). This is important feature of the disablement process model, because it implies that functional limitation can be viewed from multiple vantage points; as a precursor of disability, an indicator of disability, and an effect of disability. A depiction of the feedback effects identified by Verbrugge and Jette is given in Figure 2.5.

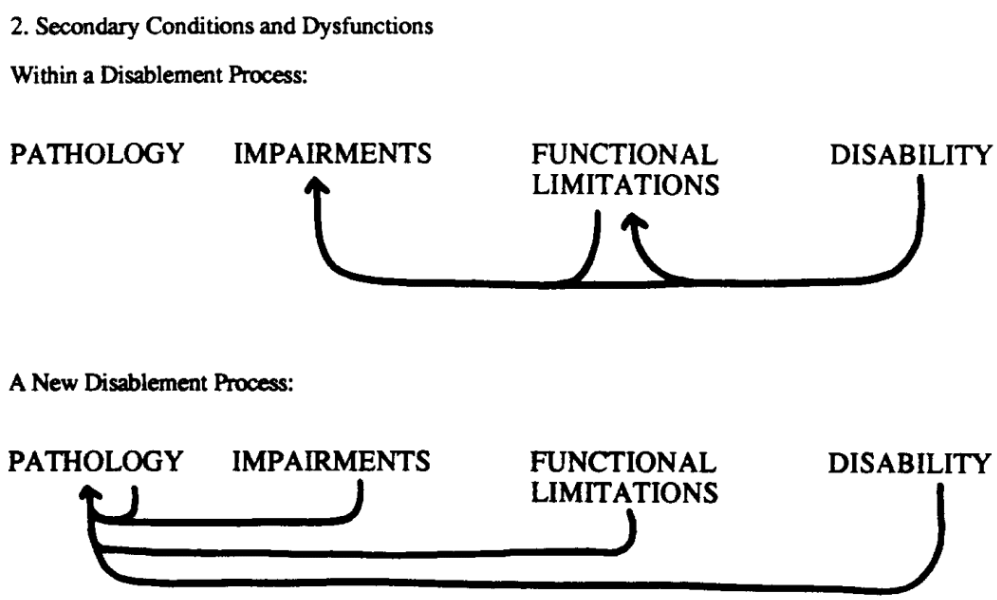


Figure 2.5. Primary and secondary feedback loops in the disablement process. Adapted from “The disablement process,” by L. M. Verbrugge and A. M. Jette, 1994, *Social Science and Medicine, 38*(1).

The disablement process is an explicitly ecological model, in that external factors are viewed as influencing the progression from pathology to disability. Verbrugge and

Jette (1994) hypothesized that extra-individual factors could serve as moderators of the disablement process and identified a number of those potential factors, including medical care and rehabilitation, external supports, and the built and social environment. In fact, they acknowledged that although the model that they developed was “person-centered”, the disablement process was best understood in the context of the relationship between a person and his/her environment. In the following sections we will examine the empirical evidence supporting the disablement process model, and explore the potential determinants of disability among older adults.

Lower-Extremity Physical Performance Predicts Disability

The relationship between functional limitation and disability described in the disablement process model has been well-established. Performance-based measures of lower-extremity function have been shown across multiple studies to predict subsequent mobility disability and ADL disability after controlling for a variety of potential confounders. Guralnik et al. (1995), in a study of 1122 non-disabled adults aged 70 years or greater participating in the Iowa cohort of the Established Populations for the Epidemiological Study of the Elderly (EPESE), found that those older adults with the lowest gait speed scores had a 4.8 increase in the relative risk of subsequent mobility disability at 4 year follow up when compared to those with the highest gait speed scores. A subsequent study pooling data from participants across the EPESE sites (N = 4,488) and from the 1,946 participants in the Hispanic EPESE study reported a similar increase in the relative risk for both mobility and ADL disability among those with the lowest gait speed scores (Guralnik et al., 2000). Results from the 3047 participants in the Health, Aging and Body Composition study found that baseline gait speed of less than 1 meter/sec was associated with a 2.2 increase in the relative risk of reporting persistent lower extremity limitation at 5 year follow up (Cesari et al., 2005). Ostir, Markides, Black, and Goodwin (1998), in a study of 1365 older adults (mean age=73.3), found that those in the lowest quartile of walking speed at baseline had 5.4 increased odds of ADL disability at 2 year follow up compared to those in the highest quartile. Among participants in the Cardiovascular Health Study (N=3156), those with a baseline gait speed of greater than 1.0 m/sec had a significantly reduced hazard (hazard ratio = .88) of developing incident ADL disability during the 8.4 years of follow-up (Rosano, Newman, Katz, Hirsch, & Kuller, 2008). Similarly, in the Women's Health and Aging Study, each increase of .3 meters/sec in participant's gait speed was associated with a .72 relative risk of incident ADL disability and a .57 relative risk of mobility disability at 3 year follow-up (Onder et al., 2005). This significant relationship between gait speed and disability has been replicated in a number of other studies (Abellan van Kan et al., 2009; Vermeulen, Neyens, van Rossum, Spreeuwenberg, & de Witte, 2011).

Individual-Level Determinants of Lower Extremity Function and Disability

The individual-level determinants of functional limitation and disability have been well established in the literature to date. Several demographic characteristics are known to be associated with lower-extremity function and disability. Chronological age is a strong predictor of lower-extremity functional decline (Gill, Allore, Hardy, & Guo, 2006). Guralnik et al. (1993) reported an estimated 2.0 increase in the relative risk of decline for each 10-year increase in age. Similarly, in an analysis of participants in the Health and Retirement Study, Dunlop, Song, Manheim, Daviglus, and Chang (2007) observed that each decade of increased age was associated with double the hazard of

ADL disability. Females have been reported to have higher rates of disability and steeper declines in lower-extremity function than males (Inzitari et al., 2006; Leveille, Penninx, Melzer, Izmirlian, & Guralnik, 2000; Murray et al., 2011; Murtagh & Hubert, 2004) Both income and educational attainment have consistently been found to be related to lower-extremity function and disability (Berkman et al., 1993; Freedman, Martin, Schoeni, & Cornman, 2008; Murray et al., 2011; Nusselder, Looman, & Mackenbach, 2005). Race and ethnicity have been observed to be related to lower-extremity function (Ostchega, Harris, Hirsch, Parsons, & Kington, 2000), although Dunlop et al. (2007) found this relationship was attenuated by controlling for socioeconomic characteristics and health behaviors.

As one would expect, both health status and health behaviors are associated with functional decline. Guralnik et al. (1993) found that the presence of a single chronic condition was a significant predictor of functional decline, and that risk increased with each additional comorbid condition. Of course, the degree of risk associated with specific conditions varies widely (Chaudhry et al., 2010; Freedman, Martin, et al., 2008; Inzitari et al., 2006). In a systematic review by Stuck et al. (1999), cancer, hypertension, arthritis, diabetes, stroke, hypertension, cardiovascular disease, and fracture were reported as the diagnoses most consistently associated with functional decline. Cognitive impairment has been shown to predict lower-extremity functional decline and ADL disability (Kuo, Leveille, Yu, & Milberg, 2007; Mehta, Yaffe, & Covinsky, 2002), as has vision loss (M. Y. Lin et al., 2004). Health behaviors that predict functional impairment include smoking (Liao et al., 2011), overweight (Bruce, Fries, & Hubert, 2008; Chakravarty et al., 2012) and physical inactivity (Reynolds & Silverstein, 2003; Stuck et al., 1999). Of these, the relationship between physical activity and lower-extremity function is the focus of this study and is discussed in detail in the following section.

Physical Activity is a Determinant of Functional Limitation and Disability

Regular engagement in physical activity is significantly associated with functional health and reduced risk of disability, with a clear dose-response relationship between activity intensity and maintenance or improvement in function (Hillsdon, Brunner, Guralnik, & Marmot, 2005; Manini & Pahor, 2009; Peterson et al., 2009). Although engaging in high intensity exercise has been shown to produce the greatest functional and health benefits (Hrobonova, Breeze, & Fletcher, 2011; Paterson & Warburton, 2010), maintaining a consistent regimen of high-intensity exercise can be challenging for many older adults (American College of Sports Medicine et al., 2009). Consequently, public health campaigns during the past decade have largely focused on promoting more reasonable activity goals for older adults, such as the 2008 recommendation by the U.S. Department of Health and Human Services that older adults engage in moderate-intensity aerobic activity for a minimum of 30 minutes per day on five days of the week (U.S. Department of Health and Human Services, 2008). There is consistent evidence that regular engagement in moderate levels of physical activity has beneficial effects on health and function, including maintenance of lower extremity function and reduced risk for lower-extremity functional impairment (Bruce et al., 2008; Paterson & Warburton, 2010). Brach et al. (2003), in a 14-year study of 229 older women, found that women with higher levels of physical activity at baseline had significantly higher gait speed at follow-up than did women with lower baseline levels of physical activity. Among older adults in the Cardiovascular Health Cohort, physical activity, expressed in kilocalories was independently correlated with both gait speed and time to complete 5 chair stands (Hirsch et al., 1997) .Among a cohort of 6398 adults aged 39-63 years old, meeting recommended levels of physical activity at baseline was associated with a 1.63 greater odds of reporting no functional limitations at 8-year follow-up (Hillsdon et al., 2005). The protective effects of moderate physical activity on declines in lower-extremity function, as measured by a series of performance-based tests, was demonstrated by Seeman and Chen (2002), who found that older adults who engaged in regular moderate or strenuous physical activity had reduced odds of functional decline at 3 year follow-up.

While the effects of low intensity physical activity, such as walking at a regular pace, on lower extremity function and disability are not as well established as those of moderate and high intensity physical activity, emerging evidence indicates that even low-intensity activity has beneficial effects on physical function. Nusselder et al. (2008) reported that older adults who engaged in the metabolic equivalent of walking at an average pace for 4-6 hours per week (METS 12-17/wk) had a significant reduction in hazard of mobility or ADL disability (HR = .66) when compared to those with low levels (<12 METS/wk) of physical activity. Calculating the number of years free of disability, they found that engaging in this level of physical activity would result in 4.0 additional years free of disability for women and 3.1 for men, compared to those in the lowest METS group.

Findings from several studies indicate that maintaining or increasing levels of physical activity can slow or reverse established functional decline. Manini et al. (2010) conducted a randomized controlled trial of the effects of a moderate intensity exercise program among a sample of 424 older adults who were sedentary at baseline with low to moderate lower-extremity function as measured by the SPPB. Both at six months and one year, the intervention group had statistically significant increases in their SPPB score and 400-meter walk speed compared to the control group from baseline. In the study previously described by Nusselder et al. (2008), older adults who engaged in the metabolic equivalent of 4-6 hours of normal walking per week had a significantly increased hazard of recovering from disability (HR =1.95). A pilot test of the effects of a 12-week, moderate intensity, function-focused exercise program on performance-based measures of physical function among older adults with functional impairment was conducted by Protas & Tissier (2009). After 12 weeks, participants gait speed improved an average of .36 meters/sec and their SPPB score improved an average of 3.2 points. Participants continued to demonstrate gains in gait speed and improved function at six-moth follow up. These and other studies suggest that promoting physical activity among older adults can result not only in preservation of lower extremity function but can actually reverse functional decline.

Improving the health and function of older adults by increasing physical activity engagement has been a major focus of both public health research and practice for the past two decades. Until recently, this focus has largely been centered on individual-level approaches to increasing leisure-time physical activity, such as educating people on the benefits of physical activity, or developing, testing and piloting exercise interventions. Despite these efforts, over the past ten years the prevalence of leisure-time physical activity participation has not changed (Carlson, Fulton, Schoenborn, & Loustalot, 2010; Troiano et al; 2008). Accordingly, there has been increasing awareness in the public health field of the contribution of non-recreational physical activity to overall activity levels, with the recognition that the long-term trend toward inactive or sedentary lifestyles among US adults is, in part, attributable to declines in active travel (Brownson, Boehmer, & Luke, 2005). For example, between the years of 1960 to 2000, the percent of workers walking to work declined from 10.3% to 2.9% (Federal Highway Administration, 2010). Similarly, the proportion of overall trips taken by waking declined from 9.3% in 1970 to 5.3% in 1995 (Alfonzo, 2005). This is widely considered to be attributable, at least partially, to the decentralized, suburban development patterns that became increasingly common in the last half of the 20th century (Ewing, Schmid, Killingsworth, Zlot, & Raudenbush, 2003). Because individual's activity space tends to constrict with age, older adults may be particularly vulnerable to the deleterious effects of urban "sprawl." As Balfour and Glass (2003) note, the design of many residential neighborhoods is not conducive to meeting the activity needs of older adults with diminishing competence. They suggest that design features such the proximity and concentration of resources and amenities, access to public transportation, and location of parks and other neighborhood resources may promote activity and function among older adults. A shared concern with identifying the features of the built environment that promote an active lifestyle can be found in the field of urban planning, where a significant body of work has examined how features of the neighborhood built environment influence activity and travel decisions.

The Urban Planning Perspective

Demand theory. Demand theory is the most widely used theoretical approach within the disciplines of urban planning and transportation science to explain how characteristics of the built environment predict travel behavior. Broadly speaking, travel can be simply defined as the "movement through space" (Mokhtarian & Salomon, 2001) and encompasses both motorized and non-motorized travel modes. Of the non-motorized forms of travel, the two most common are walking and cycling, which together are grouped under the umbrella of "active travel." From the transportation modeling perspective, travel is generally assumed to be a derived demand, i.e., it is a disutility that is endured for the purpose of arriving at a desired destination (Hoehner, Brennan, Brownson, Handy, & Killingsworth, 2003). Travel occurs because people desire to participate in an activity at their destination. A fundamental concept in the transportation modeling conceptualization of travel behavior is that of utility maximization, which posits that individuals select a particular mode of travel by considering the relative utility of the transportation choices available to them in their environment and making a decision based on a rational calculation of the utility of each potential choice (Handy, 2005). Therefore, urban form influences travel behavior through the range and characteristics of transportation choices that are available within the environment, such as the proximity of public transportation, the presence and condition of sidewalks, and the interconnectedness of street networks (Handy, Boarnet, Ewing, & Killingsworth, 2002). Early models typically focused on predicting travel behavior as a function of the relative cost and duration of each mode, hypothesizing that minimization of travel time and cost would dominate travel decisions. However, as evidence has emerged that other characteristics, such as the "attractiveness" of the destination or the pleasure of the mode, influence persons to choose more distant destinations or to choose more time intensive modes of travel, these early models are being supplanted by activity-based models which also take into account the location and characteristics of travel routes and destinations (Handy, 2005).

The "three d's": Density, diversity, and design. There is no an agreed upon nomenclature for the aspects of the built environment thought to influence travel behavior, though one that is commonly used is the "3D's" of density, diversity and design (Cervero & Kockelman, 1997). *Density* can refer to the number of people, dwelling units, buildings, etc. within a given unit of area, though it is most commonly operationalized as population density. *Diversity* is a measure of land use and refers to the spatial distribution of activities and the physical structures that house those activities. Geographic areas where one type of use (residential, commercial, industrial, etc.) predominates are referred to as single-use. In contrast, mixed-use development is characterized by a diversity of activities located in close geographic proximity. *Design* is a broad term that includes both structural and aesthetic characteristics. The most widely measured structural characteristic is the connectedness of the street grid. This is illustrated in Figure 2.6. The image on the left side depicts a loosely connected suburban network, which would be said to have low connectivity, while the image on the right depicts a tightly connected urban grid network with high connectivity.

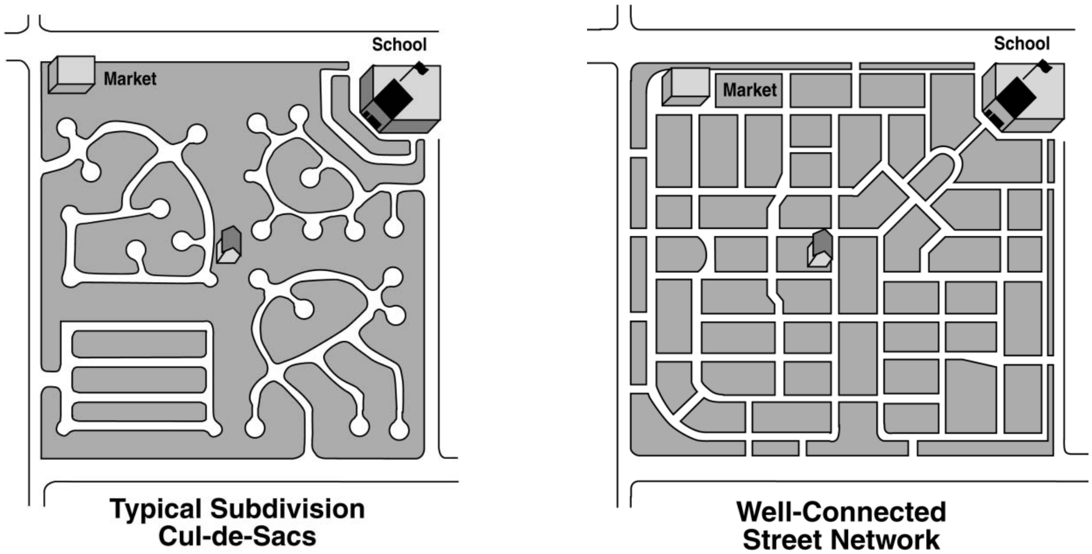


Figure 2.6. Low connectivity and high connectivity street networks. Reprinted from *Neighborhood Street Design Guidelines: An Oregon Guide for Reducing Street Widths*, by Neighborhood Streets Project Stakeholders, 2000, Oregon Department of Transportation and the Department of Land Conservation and Development

Other structural aspects of design that may be of particular importance to older adults include the presence and condition of sidewalks, curb cuts, cross walks, and other pedestrian infrastructure that facilitate safe walking (Cunningham & Michael, 2004; W. Li et al., 2006). The aesthetic aspects of neighborhood design, while widely acknowledged as a potentially critical determinant of the decision to engage in neighborhood activity, have proven somewhat more difficult to operationalize. (Ewing, Handy, Brownson, Clemente, & Winston, 2006), developed an audit tool assessing eight urban design qualities thought to influence an individual’s aesthetic valuation of a given location. These are imageability, legibility, enclosure, human scale, transparency, linkage, complexity, and coherence. However, this tool relies on observer audits of the built environment and has not been widely adopted.

Subsequent authors have employed two additional categories, distance to transit and destination accessibility, which are helpful to further differentiate the aspects of the built environment thought to influence activity (Ewing & Cervero, 2001; Ewing et al., 2009). *Destination accessibility* is the degree to which given resources are locally accessible. As may be evident, destination accessibility can be regarded as a function of both the diversity of choices within a given area and the design of the street network that permits travel between locations. However, it is a helpful category because it allows for the operationalization of measures of accessibility to particular destinations that may be of interest. The last category**,** *Distance to transit* is a measure of the accessibility of a particular class of destinations, public transit resources. Because most public transit trips begin and end with walking, this is seen as an important potential determinant of walking activity. It is typically measured as the distance between the residence and the nearest transit stop, though may also be measured and the number of stops within a defined geographic space (Ewing & Cervero, 2010).

Neighborhood accessibility. The influence of demand theory and utility maximization theory is evident in the assumption that factors such as proximity of resources (e.g., parks, recreational facilities, grocery stores, transit stops) and connectedness of street grids increase the likelihood of walking. This relationship between characteristics off the street network and the availability and characteristics of likely travel destinations has been conceptualized in the urban planning literature as neighborhood accessibility. Handy (1996) defines neighborhood accessibility as "the pattern of activities; their quantity, quality, variety, and proximity; and the connectivity between them as provided by the transportation system" (p. 184). This concept of accessibility is closely related to ideas of neighborhood walkability. Thus, in the urban planning literature, pedestrian-oriented neighborhoods are most commonly thought to be characterized by high density of development; mixed land-use; highly connective, human-scale street networks; and desirable aesthetic qualities (Agrawal, Schlossberg, & Irvin, 2008; Handy et al., 2002; Pedestrian Transit Program, 1998). This conceptualization of pedestrian-oriented neighborhoods, or 'walkability', guided the selection of neighborhood built environment variables chosen in the proposed study.

Empirical evidence. How features of the neighborhood environment influence physical activity has been a subject of intense interest to public health researchers in the past decade, as the failure to achieve substantial gains in population levels of physical activity reveals the limitations of individual-level approaches to activity promotion (Carlson et al., 2010). To date, over 200 studies, most conducted in the last decade, have examined the relationship between various forms of physical activity, primarily walking, and the social and physical characteristics of neighborhoods in which those activities largely occur (Ewing & Cervero, 2010). The preponderance of evidence indicates that physical activity, particularly walking, is associated with characteristics of the neighborhood built environment (Sallis et al; 2009). For example, studies have found associations between walking and measures of land-use mix (Frank, Kerr, Rosenberg, & King, 2010; Berke, Koepsell, Moudon, Hoskins, & Larson 2007; Nagel, Carlson, Bosworth, & Michael, 2008) intersection density (Li, Fisher, Brownson, and Bosworth, 2005) public transportation access (Su, Schmocker, & Bell, 2009), and proximity of parks/green spaces (Michael et al., 2010; F. Li et al., 2005). However, within this literature there is no clear consensus on precisely which characteristics of the built environment are associated with physical activity. Largely, this is a result of the methodological diversity, both in how neighborhood built environment and physical activity are defined and measured, that characterizes this field of study. For example, neighborhood environment may be measured objectively or subjectively, which is an important distinction because residents' subjective perceptions of neighborhood characteristics have generally been found to differ from objectively measured characteristics (Ball, Crawford, Roberts, Salmon, & Timperio, 2008; Boehmer, Hoehner, Wyrwich, Brennan Ramirez, & Brownson, 2006), and previous studies indicate that perceived features of the neighborhood environment and objectively measured features have differential effects on physical activity (Gebel, Bauman, & Petticrew, 2007; Hoehner, Brennan Ramirez, Elliott, Handy, & Brownson, 2005; L. Lin & Moudon, 2010). Objective measures of the built environment, which are the focus of this study, can be derived from aggregate-census data at the tract, or block levels; calculated using GIS-based measures at various geographic scales; or collected during observer audits of micro-scale design features (Brownson et al., 2009). Further, there are typically multiple approaches to operationalizing and measuring the same underlying variable, such as land-use mix (Handy, 2005). Similarly, the studies to date have focused on a number of distinct types of physical activity, and they have employed a variety of measurement approaches, further complicating cross-study comparison of findings. The result is that there is no characteristic of the built environment which has been unambiguously associated with physical activity--there are conflicting findings regarding the relationship between neighborhood built environment and physical activity for every major characteristic. Lastly, there have been relatively few studies which have examined the relationship between neighborhood built environment and physical activity among older adults. With this in mind, the variables measured in this study were chosen both on the basis of evidence to support their relationship with physical activity among older adults and their congruence with established urban planning theory.

Conceptual Model

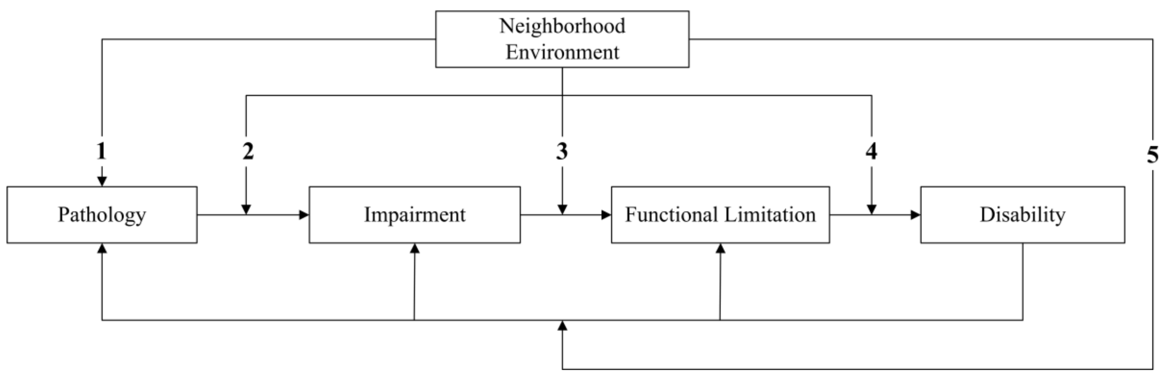


Figure 2.7. Conceptual model of the influence of neighborhood environment on the disablement process

The conceptual model presented in Figure 2.7 incorporates the theoretical approaches discussed in the preceding sections in order to describe the mechanisms through which neighborhood environment may impact functional limitation and disability. First, as indicated in the path labeled with the number 1 in the diagram, the neighborhood environment can be related, either directly or indirectly, to the risk of developing a given pathology. In the first instance, the development of the pathology can be directly linked to neighborhood conditions. Examples of direct effects include neighborhood levels of air pollutants increasing the risk for respiratory disease and sidewalks in disrepair increasing risk for injurious falls. An indirect relationship is one in which the link between neighborhood characteristics and the development of a given pathology is mediated by another event or process. For example, if residing in a walkable neighborhood increases the likelihood of engaging in physical activity, and, as a consequence, decreases the likelihood of developing cardiovascular disease, then it could be said that neighborhood walkability had an indirect effect on cardiovascular disease risk.

In the paths labeled 2 and 3, neighborhood characteristics moderate the steps in the pathway from pathology to impairment and from impairment to functional limitation. For example, physical activity and dietary choice play a significant role in the trajectory of many chronic diseases, and are common targets of secondary prevention efforts. Both physical activity and dietary choices take place in the context of the neighborhood environment, which may facilitate or hinder adoption and maintenance of healthy behaviors, and thus moderate the progression from pathology to impairment and functional limitation.

In path 4, the neighborhood environment is depicted as moderating the relationship between functional limitation and disability. This is the relationship that has received the most attention in the literature on the environment and disability, because it clearly reflects the notion of disability as a contextual phenomenon. In other words, a reduction in lower extremity function is disabling to the degree that the neighborhood environment supports or impedes carrying out activities of daily living. For example, characteristics such as convenience of locations or access to transit may allow persons experiencing declines in lower extremity function to continue to maintain acceptable levels of activity and mobility in their neighborhood environment despite those declines, thus moderating the relationship between declining function and disability (Glass & Balfour, 2003).

Lastly, in path 5, the feedback loops hypothesized by Verbrugge and Jette (1994) are moderated by environmental factors. The underlying mechanisms involved in this moderation are likely similar to those of the primary disablement process, though in this case characteristics of the neighborhood environment may buffer or exacerbate the primary disability and thus influence both the course of the primary disability and the development of secondary disabilities.

This conceptual model illustrates complex relationship of neighborhood environment to the disablement process. This study does not attempt to isolate any one of these potential causal pathways; rather, it is a broad examination of the relationship between neighborhood characteristics and lower extremity function. Implicit in the choice of neighborhood measures, however, is the hypothesis that residing in a walkable neighborhood results in increased rates of physical activity, which in turn reduces disease risk and promotes lower extremity function. Similarly, local accessible park/green space as sites for engagement in recreational physical activity should result in maintenance of lower extremity function. Additionally, as participant's competence declines over the 10-year period during which this study was conducted, the theory of Environmental Press suggests that changes that occur during that time which reduce the environmental pressure will promote maintenance of function. Because a walkable neighborhood is one which provides ease of access to local community resources, improvements in neighborhood walkability should reduce the level of environmental press for those with declining capacity, slowing the reduction in lower extremity function.

Built Environment as a Determinant of Functional Limitation and Disability

A review of the literature on the relationship between neighborhood built environment and lower extremity function or disability was conducted by searching the Medline database with the keywords: neighborhood, environment, disability, function, aging, and mobility. Nine studies were available that examined the relationship between physical characteristics of the neighborhood environment and a functional outcome. They are summarized below and a critical analysis of the literature follows.

Balfour and Kaplan (2002), in a study of 883 persons aged 55 years and older in Alameda County, California found that functional loss was related to self-reported problems with neighborhoods, including excessive noise, inadequate lighting at night, and heavy traffic. Notably, limited public transportation was not associated with increased risk of functional loss. Participants who reported multiple neighborhood problems at baseline were at 2.23 times the risk of decline in general physical function and 3.12 times the risk of decline in lower-extremity function at one-year follow-up when compared with those who reported no neighborhood problems.

Clarke and George (2005) retrospectively linked survey data from 4154 adults aged 65 years and older from central North Carolina to census-tract level measures of land-use diversity and housing density. They found that older adults reported greater independence in instrumental activities of daily living (e.g., shopping, managing money, household chores) when they lived in environments with more land use diversity. Among those participants with functional limitations, housing density was inversely related to self-care disability.

Schootman et al., (2006) retrospectively examined the risk of onset of lower body limitations among 563 middle-aged African Americans around St. Louis, Missouri. Surveyors' assessed participant's blocks of residence and assigned a composite score based on five characteristics: condition of houses, amount of noise, air quality, condition of streets, and condition of yards and sidewalks. Lower-extremity function was measured at baseline and three-year follow-up using the Nagi performance scale. The authors found that people living in areas with fair/poor conditions were over three times more likely to develop a lower body limitation than those living in good/excellent neighborhoods.

Bowling and Stafford (2007) conducted a cross sectional study of the cross-sectional relationship between ADL disability and perceptions of neighborhood quality (including "closeness to shops" and "somewhere nice to go for a walk") and neighborhood problems ("including traffic volume") among 786 older adults in the United Kingdom. After adjusting for individual-level covariates, they did not find any of the perceived neighborhood characteristics to be associated with ADL disability.

Freedman, Grafova, Schoeni, & Rogowski (2008) examined the association of street connectivity, density of population and establishments, air pollution, and access to health care with lower body, IADL, and ADL limitation. They found that, for men, living in a more connected area was associated with a lower risk of IADL limitations (OR = 0.88), though this association was not significant for older women. They found no association between any measures of neighborhood environment and lower-body function.

Using data from 1195 participants in the Chicago Community Adult Heath Study, Clarke et al. (2008), examined the cross-sectional relationships between self-reported mobility disability and observer-rated measures of sidewalk and street condition, physical disorder, and residential security in a four block radius around each participant's residence. None of the built environment measures were associated with the probability of mobility disability among those participants without any physical impairment. They did find that the condition of sidewalks and streets was significantly associated with the degree of mobility disability among those participants with reported impairment, indicating that the built environment modified the relationship between functional limitation and impairment.

Clarke et al. (2009), in a sample of 1821 adults, examined the relationship of trajectory of self-reported mobility disability over 15 years to census-tract measures of population density and proportion of workers who commute by public transit or walking. They found that older adults aged 75 or more who lived in a census tract with a low proportion of commuters who walked or used public transit had 1.5 greater odds of developing mobility disability than older adults who lived in a tract with a high proportion of commuters who walked or used public transit. This association was not significant for younger adults and they did not find a significant association between population density and mobility disability.

Beard et al. (2009) performed a cross-sectional analysis linking census-level disability data ("physical disability" and "going outside the home disability") to census-level measures of land-use mix, neighborhood decay, and street characteristics among the 937,857 respondents to the US Census in New York City. A composite measure of “street characteristics” (specifically low density of intersections, low number of street trees, and greater distance to a bus stop) was significantly associated with the prevalence of both disability types. A measure of land-use mix was not associated with the prevalence of disability in this study.

Michael, Gold, Perrin, and Hillier (2011) conducted a longitudinal study of the associations between performance-based measures of lower-extremity function and census-tract level measures of street connectivity and street density among older women enrolled in the Portland, Oregon cohort of the Study of Osteoporotic Fractures. Among women who reported walking at baseline, they found that both street connectivity and street density were significantly associated with change in chair rise time but not with baseline chair rise time. Women who lived in census tracts with greater street connectivity or greater street density had less of an increase in chair rise time over the study period. This association was not significant for the women who reported not walking at baseline, and there were no significant associations observed between the built environment measures and trajectory of gait speed.

Similar to the literature on the relationship between the built environment and physical activity, there is little methodological consistency in the above studies. Aspects of the physical environment assessed include street characteristics, connectivity, noise, air quality, condition of houses, population density, land-use mix, and sidewalk condition. One study used factor analysis to create composite measures of neighborhood characteristics such as ‘neighborhood decay’ (Beard et al., 2009). This strategy, however, makes it difficult to understand the relationship of specific neighborhood characteristics to the outcome, and it limits our ability to compare results across studies. Furthermore, this wide array of characteristics results in there being very few which have more than a single study to support observed associations.

These studies utilize several different geographic scales within which neighborhood characteristics are measured. The majority used census tract measures, although these are generally regarded as less robust than measures derived from GIS data in geographic areas centered around participants residential addresses. To date, no study of the relationship between neighborhood environment and functional decline has employed GIS technology to construct measures of the objective features of the neighborhood built environment around participants' residential addresses. This is particularly salient among older adults with potential functional limitation or disability, because both aging and disability are associated with a reduction in the spatial range of one's daily functional activities (Guralnik et al., 1996). Studies of neighborhood effects have increasingly favored objective measurement, though there are potential differences between the objective neighborhood environment and the perceived neighborhood environment that could have differential effects on health and behavior (L. Lin & Moudon, 2010; Weden, Carpiano, & Robert, 2008; Wen, Hawkley, & Cacioppo, 2006). Thus, while one study found that both objective characteristics and perceived neighborhood problems were associated with functional difficulty (Balfour & Kaplan, 2002) another only found objective characteristics to be associated with functional limitation (Schootman et al., 2006).

The studies cited utilized a variety of measures of function and disability, including subjective measures of lower body function or mobility, self-reported ability to perform ADLs and IADLs, and performance based measures of physical function. As with the neighborhood environment measures, the diversity of outcome variables and the lack of consistency in measurement across studies limits comparison. In regards to physical environment, for example, Freedman et al. (2008) found that greater street connectivity was associated with increased ability to perform IADLs among older men. However, connectivity was not associated with the performance of ADLs or with lower body limitations, a finding supported by Beard et al. (2009) who found no associations between a measure of connectivity and either physical disability or 'going outside the home' disability. They also found that a composite measure of neighborhood decay was not significantly associated with their measures of disability, a finding which conflicts with that of Schootman et al. (2006), who reported a significant association between a similar measure and lower-body functional limitation.

Generally speaking, however, these studies provide tentative support for the general hypothesis that neighborhood characteristics play a role in the development and progression of functional impairment and disability among older adults. All but one found a significant association between at least one of the neighborhood characteristics and the outcome being measured, though the specific results are mixed and difficult to compare across studies due to their methodological variation. Both studies examining the physical environment as a moderator of the relationship between physical impairment and disability reported significant findings. Clarke and George (2005) report housing density to be a modifier of ADL ability and land-use diversity to be a modifier of IADL ability among those with reported lower extremity impairment. Similarly, condition of streets was found to be a significant modifier of mobility disability among functionally impaired adults (Clarke et al., 2008).

While these previous studies laid the groundwork for understanding the effects of the neighborhood built environment on the disablement process, the review of literature revealed significant gaps in our understanding that were addressed by this study. First, the majority of studies were cross-sectional and thus unable to examine changes in function or disability over time. Only four studies examined change in lower extremity function or functional ability over time (Balfour et al., 2002; Clarke et al., 2009; Michael et al., 2011; Schootman et al., 2006). Second, previous studies typically employed either subjective measures of neighborhood environment which are subject to bias, or imprecise objective measures of the built environment at the level of census tract or counties, which may not accurately reflect the local neighborhood characteristics experienced by participants (Flowerdew, Manley, & Sabel, 2008). Similarly, these studies largely relied upon a variety of self-reported functional status measures, including measures of ADL performance, IADL, performance, and lower-extremity function. Lastly, though all of the samples in these studies contained older adults, only four consisted solely of adults aged 65 years or older (Beard et al., 2009; Bowling et al., 2007; Clarke & George, 2005; Michael et al., 2011). This limits the degree to which the findings from these studies are generalizable to older adults. Most importantly, no study to date has been designed to examine concurrent change in neighborhood built environment and lower-extremity function, an important first step in establishing the causal pathway between changes to the built environment and trajectory of functional decline. This study addressed these gaps in the literature by examining the association of objectively measured characteristics of the neighborhood built environment to change in a performance-based measure of lower extremity function over time.

Chapter 3—Research Design and Methods

Overview and Design

The purpose of this study was to determine whether the trajectory of lower extremity function among older women is influenced by the physical characteristics of the neighborhoods in which they live. As discussed in chapter 2, neighborhood walkability is a dimension of the built environment that is both theoretically and empirically related to lower-extremity function among older adults. Similarly, previous studies have found that neighborhood distance to parks and green space is associated with recreational physical activity. However, no previous studies have examined how change in neighborhood walkability or neighborhood distance to park/green space impacts the functional ability of the older adults living in those neighborhoods. Consequently, an area of particular interest in this study was to examine whether living in a neighborhood that became more walkable over time or had improved distance to park/green space was associated with a less steep decline in lower extremity function.

Therefore, the specific aims of this study were to:

1. Describe the relationship between baseline neighborhood walkability and baseline lower-extremity function among older women.
   Hypothesis: Baseline neighborhood walkability is significantly associated with baseline lower-extremity function. Women who live in more walkable neighborhoods will have higher baseline lower-extremity function.
2. Describe the relationship between baseline neighborhood walkability and change in lower-extremity function among older women.

Hypothesis: Baseline neighborhood walkability is significantly associated with the magnitude of decline in lower-extremity function over time. Women who live in more walkable neighborhoods will have less decline in lower-extremity function over time.

3. Describe the relationship between change in neighborhood walkability and change in lower-extremity function among older women.

   Hypothesis: The magnitude of change in neighborhood walkability is significantly associated with the magnitude of decline in lower-extremity function over time. Improvement in neighborhood walkability over time is associated with a reduced rate of lower-extremity functional decline.

4. Describe the relationship between baseline distance to neighborhood parks/green spaces and baseline lower-extremity function among older women.

   Hypothesis: Baseline distance to neighborhood parks/green spaces is significantly associated with baseline lower-extremity function. Women who live in neighborhoods with greater distance to a park/green space will have higher baseline lower-extremity function.

5. Describe the relationship between baseline distance to neighborhood parks/green spaces and change in lower-extremity function among older women.

   Hypothesis: Baseline distance to neighborhood parks/green spaces is significantly associated with the magnitude of decline in lower-extremity function over time. Women who live in neighborhoods with greater distance to a park/green space will have less decline in lower-extremity function over time.

6. Describe the relationship between change in the distance to neighborhood parks/green spaces and change in lower-extremity function among older women. *Hypothesis: The magnitude of change in the distance to neighborhood parks/green spaces is significantly associated with the magnitude of decline in lower-extremity function over time. A reduction in the distance to a park/green space over time is associated with a reduced rate of lower-extremity functional decline.*

To address these specific aims and test the above hypotheses, this study employed a retrospective, cohort design examining concurrent change in gait speed and neighborhood walkability over a twelve-year period among a sample of older women living in Portland, Oregon. This study utilized a novel approach to the retrospective, longitudinal design, using a geographic information system (GIS) to merge individual-level and neighborhood data from several sources. Parallel-process growth curve models of neighborhood walkability and gait speed were adjusted for age, education, complex comorbidity, and neighborhood SES. These models were subsequently adjusted for participant attrition using a pattern-mixture modeling approach. Because some of these methods, notably the use of GIS to derive measures of the built environment and the latent variable approach to modeling change, are not commonly employed in nursing science and thus may be unfamiliar to readers, a significant portion of this chapter is devoted to providing a requisite foundation in these areas to evaluate the current study.

Sample/Setting

Participant data were collected from the Portland, Oregon cohort of the Study for Osteoporotic Fractures (SOF) in women. Briefly, the SOF study was a longitudinal, multi-site study with the primary purpose of describing the risk factors for osteoporotic fractures among women (Cummings et al., 1990). The study began in 1986 with the enrollment of 9,704 women > 65 years old who were recruited from four metropolitan areas: Baltimore, Pittsburgh, Minneapolis, and Portland. The exclusion criteria for the study were: 1) African-American (the reason cited was low incidence of hip fracture among African American women), 2) Unable to walk unaided and, 3) Past bilateral hip replacement. Membership lists for the Kaiser Permanente Northwest (KPNW) health plan were used to recruit women in Portland (Cummings et al., 1990). Due to the inclusion of Medicaid patients in the KPNW health plan, the Portland participants were representative, in regards to socioeconomic status, of the metropolitan population (Greenlick, Freeborn, & Pope, 1988). At baseline, there were 2,422 white, non-Hispanic women in the Portland cohort, distributed between 55 ZIP codes in the Portland metropolitan region. Figure 3.1 displays the geographic distribution of study participants.

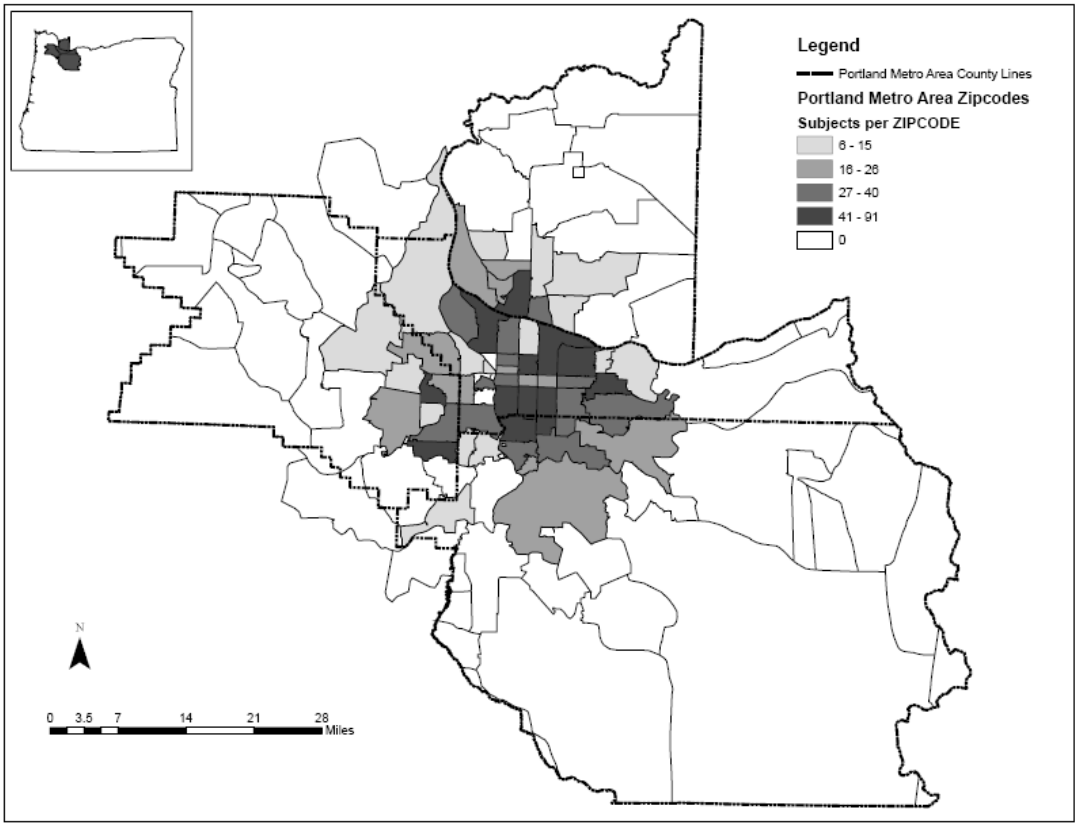


Figure 3.1. Geographic distribution of Portland, Oregon cohort of the Study of Osteoporotic Fractures

This study utilized data from participant's first six visits, which occurred between the years of 1986-1998. 4% of the Portland cohort had their baseline visit in 1986, 43% had their first visit in 1987, and 53% had their visit in 1988. At the first visit and approximately every two years thereafter through visit six, the women enrolled in the study participated in a series of structured interviews and clinical examinations. A detailed description of the data collection procedures at each visit is available on the study website (Study of Osteoporotic Fractures, 2011). The outcome in this study, gait speed, was measured at each visit with the exception of visit 5. Health history was collected at each visit, and demographic information was collected at baseline. The timeline for the collection of individual-level variables used in this study are presented in Figure 3.2. On average, participants contributed 6.4 years of follow-up data on the outcome measure. Although data from subsequent visits was available, the rate of attrition from the study increased sharply after the sixth visit. Between the sixth and seventh visit, 24% of the baseline sample were lost to attrition, leaving only 22% of the baseline sample for analysis. Such a large proportion of missing data would have led to considerable difficulty in estimating the statistical models, and given the long period of follow-up data between visits one through six, the decision was made not to include subsequent waves in the analysis.

1986-1988	1989-1990	1991-1992	1993-1994	1995-1996	1997-1998
VISIT 1	**VISIT 2**	**VISIT 3**	**VISIT 4**	**VISIT 5**	**VISIT 6**
Gait Speed	Gait Speed	Gait Speed	Gait Speed	------	Gait Speed
Age	------	------	------	------	------
Education	------	------	------	------	------
Cognitive Impairment	------	------	Cognitive Impairment	Cognitive Impairment	Cognitive Impairment
Diabetes	------	Diabetes	Diabetes	Diabetes	Diabetes
Hypertension	------	Hypertension	Hypertension	-------	Hypertension
Incident Fracture	Incident Fracture	Incident Fracture	Incident Fracture	Incident Fracture	Incident Fracture
Stroke	Stroke	Stroke	Stroke	Stroke	Stroke
------	MI	MI	MI	MI	MI
------	CHF	------	CHF	CHF	CHF
------	COPD	------	COPD	COPD	COPD
------	Depression	------	Depression	------	Depression
------	------	Cancer	Cancer	Cancer	------
Residential Address	*Residential Address*	*Residential Address*	*Residential Address*	*Residential Address*	*Residential Address*
Marital Status					
Living Alone					
Blocks Walked per Week					
Self-Reported Health					

Figure 3.2. Timeline of data collection in Study of Osteoporotic Fractures

Exclusion criteria. A total of 2422 participants in the Portland, OR cohort of the SOF study were initially considered for inclusion in this analysis. Potential participants were excluded from the analysis if they did not meet the following criteria.

1) Successfully geocoded and linked to a valid address/coordinates in the Regional Land Information System (RLIS) database.
2) Reside within the Portland Urban Growth Boundary (UGB) at baseline.
3) Remain at the same residential location during the study period or until point of attrition.

The first and second criteria were technical preconditions for calculating the measures of neighborhood built environment for a given participant. Of the 2422 participants in the Portland cohort at baseline, 72 were unable to be geocoded and were excluded. Because accurate neighborhood data were only available for participants residing within the Urban Growth Boundary (UGB), a municipally-defined three-county area managed by the Portland Regional Government, members of the Portland cohort residing outside of the UGB boundaries (N= 347) were not included in the proposed analysis. The third criteria, that only participants who did not change residences during the study period were included in the analysis, was imposed in order to ensure that the measurement of change in the neighborhood built environment only reflected the actual modifications in urban design (e.g. improved access to public transportation, mixed-use development, etc.) that occurred in participant's neighborhoods during the study period. To assess whether these exclusion criteria introduced selection bias, participants who moved during the study period and participants who remained at their baseline residential address were compared on age, education, baseline self-reported health, and baseline gait speed. After imposition of all exclusion criteria, 1256 women remained in the baseline sample and were included in the analysis. Although the precise calculation of statistical power of latent growth curve models is exceedingly difficult, simulation studies indicate that a sample this large was sufficient to avoid problems with model estimation and convergence (Hertzog, von Oertzen, Ghisletta, & Lindenberger, 2008). A diagram depicting the steps in sample selection is presented in Figure 3.3.

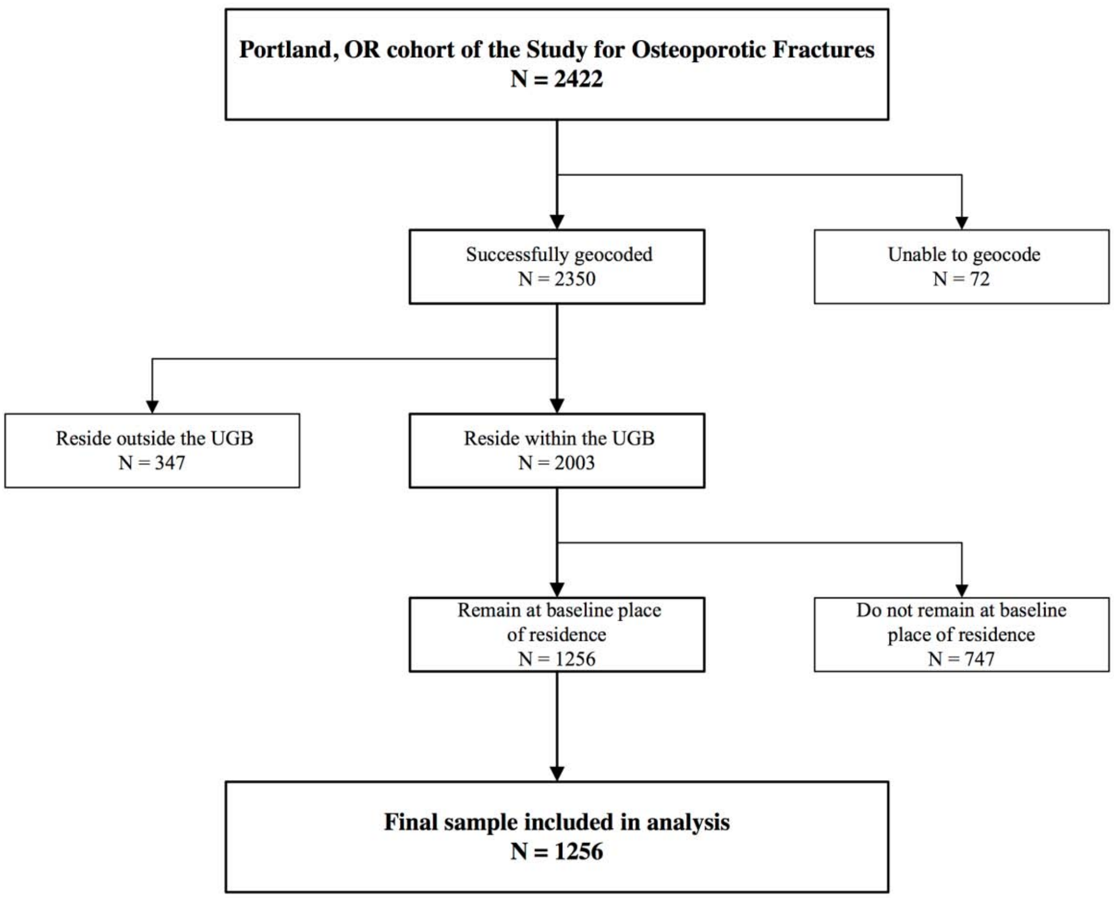


Figure 3.3. Steps in sample selection, SOF Neighborhood Study, 1986 -1998

Informed consent procedures. This study was part of a larger, ongoing R01 examining the relationship of neighborhood built environment to changes in physical activity, BMI, and function among older women. It received full IRB approval at both Oregon Health and Science University (OHSU) and the Kaiser Permanente Center for Health Research (KPCHR). Informed consent procedures for the proposed study were conducted as part of the main SOF project. Before the study began, informed consent interviews were conducted with each potential study participant in accord with study protocols. The SOF written informed consent form indicated that investigators affiliated with SOF could be given access to coded data and that the information collected during the study may be used indefinitely. The OHSU and KPCHR IRB's have confirmed that the original consents allow for the use of data collected from the SOF participants for the current analysis. For purposes of linking participant address data to Metro GIS data, the OHSU IRB and CHR IRB have verified that additional consent to create the neighborhood design characteristics was not required, because the Metro government met the definition of a business associate under HIPAA regulations.

Individual-Level Variables

As stated above, the measures of the individual-level variables used in this study were collected from the Portland, Oregon cohort of the Study of Osteoporotic Fractures. Table 3.1 provides the scale and coding of each individual-level measure included in the analyses. They are discussed in detail below.

Table 3.1

Scale and Coding of Individual-Level Variables, SOF Neighborhood Study, 1986 -1998

Variable	Scale	Value
Gait speed	Continuous	Number of meters per second
Age	Continuous	Age in years
Educational attainment	Categorical	0= less than high school 1=high school graduate 2=≤ 3 years college 3=≥ 4 years of college.
Complex comorbidity	Categorical	0=<2 comorbid conditions 1=≥2 comorbid conditions
Incident fracture	Categorical	0=No incident fracture 1=Incident fracture

Measurement of lower-extremity function. Measurement of lower-extremity function can be broadly divided into objective and subjective approaches. Subjective measurement of lower-extremity function is typically accomplished by asking respondents to rate the level of difficulty they experience engaging in tasks such as walking or climbing stairs. Thus, a commonly utilized set of questions to subjectively assess lower-extremity function are a) “by yourself, that is, without help from another person or special equipment, do you have any difficulty walking up 10 steps without resting?" and b) "by yourself, that is, without help from another person or special equipment, do you have difficulty walking one-quarter mile?" (McDermott, Fried, Simonsick, Ling, & Guralnik, 2000). While subjective measures of lower extremity function have generally been found to correlate with objective measures, the subjective approach does have its limitations (Guralnik, Branch, Cummings, & Curb, 1989). If the measure does not clearly define the activity being measured or the response categories, respondents may have difficulty accurately or consistently reporting their level of difficulty, a source of measurement error that is compounded in longitudinal studies (Bontempo, Frederick, & Hofer, 2012). Similarly, because these measures ask respondents to rate their difficulty in performing activities that occur in environmental contexts, they are sensitive to both intra-individual and inter-individual environmental differences. For example, a given response to the question “do you have any difficulty walking up 10 steps without resting” is implicitly related to characteristics of the stairs that the respondent typically climbs. This suggests that subjective approaches may be better thought of as indicators of disability than of functional ability. Lastly, responses to subjective measures of function are influenced by language, culture, and education, and degree of cognitive function (Guralnik et al., 1989; Linn, Hunter, & Linn, 1980).

Objective measures of lower-extremity function offer several advantages to subjective approaches. They have clear face validity for the task they are assessing and are relatively uninfluenced by environmental characteristics because they are conducted in a standardized fashion (Guralnik et al., 1989) Thus, the score does not directly reflect intra-individual and inter-individual differences in the environments where respondents typically perform the task. Though training effects have been observed in some studies, objective measures are a reliable approach to measuring change in lower extremity function over time, as indicated by high inter-rater and test-reliability reported in previous studies (Perera, Mody, Woodman, & Studenski, 2006; Steffen, Hacker, & Mollinger, 2002) Lastly, they are likely to be less affected by language, culture, education, and cognitive function than subjective measures (Guralnik et al., 1989).

Objective measurement of lower-extremity function is accomplished by asking subjects to complete one or more standardized tasks and evaluating their performance according to predetermined criteria. Most commonly these are tests of gait speed, chair rising, and standing balance (Gill, 2010). Gait speed is measured by asking participants to walk a short distance, 4-10 meters, typically at usual pace. The test is timed and results are given as the number of meters per second. Often, two trials are conducted and the average across trials is reported. Slower gait speed indicates impaired lower extremity function (Gill, 2010). Chair rising is measured in the chair stand test, in which subjects begin in a sitting position and, with arms folded across their chest, are asked to stand up and sit down five times. The test is timed and the results reported as the total time in seconds to complete the test (Gill, 2010). Standing balance can be assessed by asking subjects to maintain side-by side, semi-tandem, and tandem standing positions for 10 seconds. Scoring is based on the duration for which subjects can maintain each position (Gill, 2010). These three tests have been combined in the Short Performance Physical Performance Battery (SPPB), one of the most widely used tools to assess lower extremity function (Gill, 2010; Life Study Investigators et al., 2006). The SPPB has been consistently found to be to be a strong predictor of the onset of both mobility and general ADL disability (Cesari et al., 2009; Cooper et al., 2011; Guralnik et al., 1995; Wennie Huang et al., 2010).

Results from chair stand and gait speed tests conducted at visits 1, 2, 3, 4, and 6 were available of each of the SOF participants, while results from tandem stand and tandem walk tests were only available at visits 1, 2 and 3. This precluded combining these measures in a manner similar to the SPPB. Furthermore, a preliminary examination of the chair stand results revealed potential systematic error at wave 2, possibly reflecting a change in the testing protocol. As a result, the decision was made to limit the current analysis to the measure of gait speed, as previous studies have found that the gait speed test alone performs nearly or as well as the full SPPB in predicting functional decline, morbidity, and mortality (Studenski et al., 2003). A recent International Academy on Nutrition and Aging (IANA) Task Force found gait speed to be as useful as composite measures of physical performance in predicting adverse outcomes including future mobility and ADL disability (Abellan van Kan et al., 2009).

Gait speed. The dependent variable in this study was lower extremity function, which was operationalized as gait speed measured at usual walking pace. Specifically, participants were asked to walk a six-meter course at their usual pace, using an assistive device (e.g. cane or walker) if needed. The time from starting the course to when the first foot crosses the six-meter line was measured to the nearest one-tenth second. This was repeated and the results averaged to provide a gait speed value in meters per second. Previous studies have reported both high test-retest reliability (ICC > .9) and inter-rater reliability (ICC > 9) for the timed six-meter walk test (Steffen et al., 2002; Studenski et al., 2003).

Age. Age in years was calculated at the baseline visit and included in the analysis as a continuous variable.

Educational attainment. Educational attainment was assessed at baseline by asking participants the highest year of education they had completed. This was recorded as a continuous variable and subsequently categorized as less than high school, high school graduate, ≤ 3 years college, and ≥ 4 years of college.

Complex comorbidity. Comorbid conditions were assessed with a combination of self-report measures and screening tests. Participants were asked to report physician diagnosis of cancer (categories: breast, cervix, colon, lung, ovary, rectum, skin, other), chronic obstructive pulmonary disease, congestive heart failure, diabetes, hypertension, myocardial infarction, or stroke. Unfortunately, there was variability both in how these questions were asked and at which visits specific conditions were assessed. Cancer, chronic obstructive pulmonary disease, congestive heart failure, and diabetes were assessed by asking the question "has your physician ever told you that you have . . .?" at each visit. In contrast, myocardial infarction and stroke were assessed using this question only the first time they were assessed, at subsequent visits participants were asked if they had been told they had a stroke or a "heart attack" since their last visit. The timing of when each condition was assessed is presented in figure 3.2 above. Variability in assessment of comorbid conditions at each wave limited the manner in which this information could be incorporated into this analysis. For example, there was no consistent way to distinguish comorbid conditions present at baseline from those which developed during the study. With this in mind, a relatively simple approach was taken to collapse all of the information available for these conditions into a single, binary indicator of complex comorbidity, defined as self-reported diagnosis of two or more of the abovementioned conditions at any point during the study period. In addition to these self-reported comorbid conditions, cognitive impairment was assessed with the Mini-Mental State Exam (MMSE) and depression was assessed with the Geriatric Depression Scale (GDS). The MMSE was administered during visits 1, 4, 5 and 6. A score of less than 21, indicating moderate to severe cognitive impairment, was used as the threshold for cognitive impairment in this current study (Folstein, Folstein, & McHugh, 1975). The 15 item GDS-SF was administered during visits 2, 4, and 6. A score greater than 5 was used as the threshold for depression in this study (Sheikh & Yesavage, 1986)

Incident fracture. The incidence of hip, spinal, and vertebral fractures was assessed via self-report and confirmed by review of medical records and radiological tests. In addition to these adjudicated fractures, participants were asked the question, “since your last visit has a doctor told you that you have fractured or broken a bone. Incident adjudicated and non-adjudicated fractures were collapsed into a binary indicator of incident fracture during the study period.

Neighborhood-Level Variables

Objective measures of land-use mix, public transit access, street connectivity, and park/green space access were derived from historical data sources and linked to participants’ addresses using a geographic information system (GIS). Geographic information systems are computer systems capable of capturing, storing, analyzing, and displaying geographically referenced information (Thornton, Pearce, & Kavanagh, 2011). GIS systems allow the researcher to include multiple geographically referenced variables as data layers on a single map, facilitating the analysis of complex spatial data (Harmon & Anderson, 2003). In the process known as geocoding, a set of spatial coordinates-for example, a residential address- is entered into a GIS database containing additional geographically referenced data such as sidewalk coverage or location of recreation facilities. These can then be linked with other data sources and the relationships between these linked data can be statistically analyzed and graphically displayed in map form (Parker & Asencio, 2008). Because GIS technology allows for the calculation of disaggregated neighborhood measures centered on each participant's place of residence, it avoids the potential bias resulting from the use of aggregate data sources (Brownson et al., 2009).

Data sources. Neighborhood built environment data were provided by the Data Resource Center of METRO, Portland's regional government. These data were primarily collected from the Regional Land Information System (RLIS), a GIS database created by the regional government in 1988 to support transportation modeling and regional planning applications. RLIS data layers include: tax lots, aerial photography, developed land, land use, zoning, transportation, parks and open space, tree canopy, steep slopes, places (e.g., hospitals, city halls, etc.), building permit records, along with Census and other demographic data. Because the RLIS data did not provide complete historical data covering each time point in the study, it was supplemented with additional data sources, including Metro Transportation Analysis Zones (TAZ) and data (households and employment), Trimet (the regional transit agency) archives, Landsat TM data (used to produce a 1991-based land cover map), and US Census TIGER/Line and block group data from 1990. Drawing on multiple data sources allowed for the construction of built environment measures for the years 1988, 1994, and 1998, corresponding to visits 1, 4, and 6 of the SOF study.

The neighborhood built environment variables measured in this study were land-use mix, public transit access, street connectivity, and park/green space access. Land-use mix, public transit access, and street connectivity were combined into an index of neighborhood walkability. Distance to park/green space was retained as a distinct variable. The construction of each variable is discussed in detail below. A summary table of the built environment measures used in the current analysis is presented in Table 3.2.

Land-use mix. Land-use mix was operationalized as the distance from a participant's residential address to the nearest area zoned for commercial use. RLIS zoning data from the years 1990, 1994, and 1998 were used to construct this variable. All areas designated with the general commercial zoning class were included, with the exception of those areas designated as industrial or institutional. The Euclidian (straight-line) distance from the geocoded residential address to the nearest edge of the closest commercial area was measured in feet. A graphical example of this is presented in figure 3.4. An alternative approach to distance calculation is the network distance, which is a measure of the actual distance from point to point when traveling over the street network. While this method of calculating distance is generally regarded as more accurate (Oliver, Schuurman, & Hall, 2007), the computational demands are much greater. Due to the large sample size and multiple time-points in this study, calculation of the variables using the network distance was not done

Table 3.2

Built Environment Variables used in the Study, SOF Neighborhood Study, 1986 -1998

Variable	Measure	Data source/years available
Walkability Index		
Public Transit Access	Distance to the nearest transit stop (bus and light rail)	Trimet archival data 1988 RLIS transit data 1998
	Bus-stop density (Quarter-mile radius)	Trimet archival data 1988 RLIS transit data 1998
Land Use Mix	Distance to the nearest commercial area	RLIS zoning and tax lots 1990, 1994, 1998
Street Connectivity	Intersection Density (Quarter-mile Radius)	TIGER/Line file 1990 RLIS street data 1994, 1998
Park and Green Space Access	Distance to the nearest park/green space	RLIS parks data 1988, 1994, 1998
Neighborhood Socioeconomic Status	Composite measure • % unemployment • % occupation in managerial or professional roles • % poverty • % education • Median home price • Median household income	US Census, American Community Survey, 1990

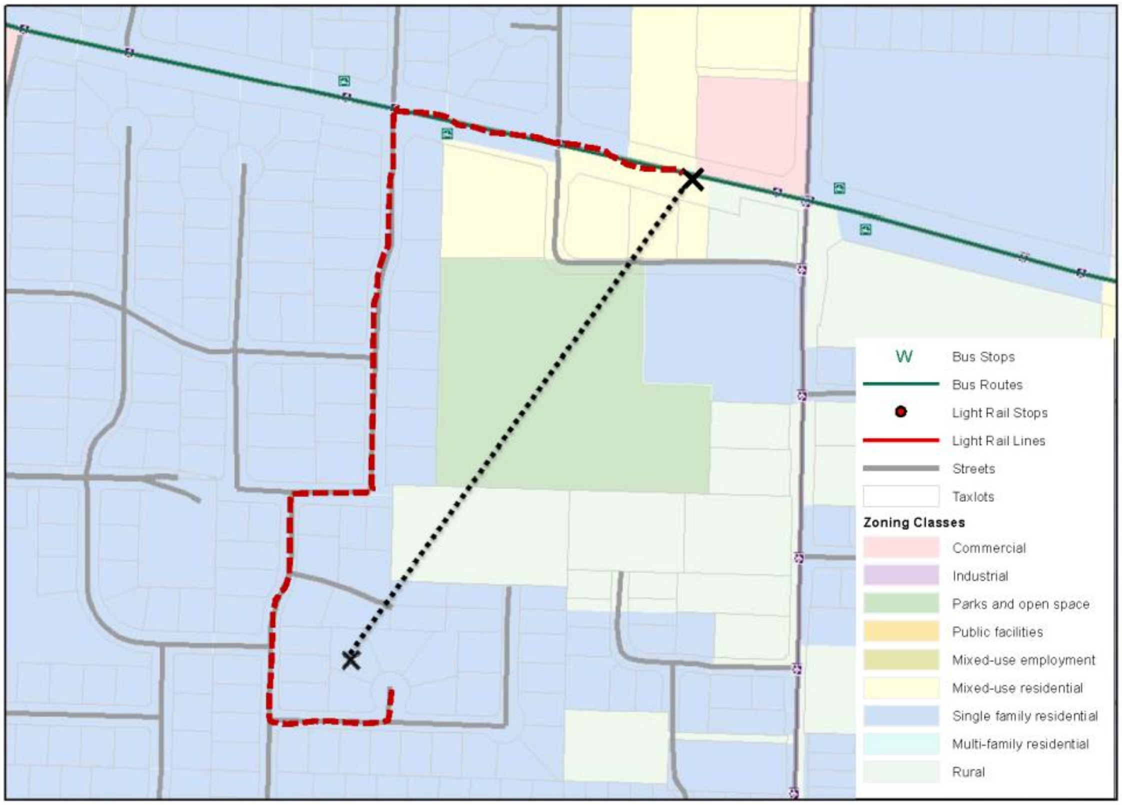
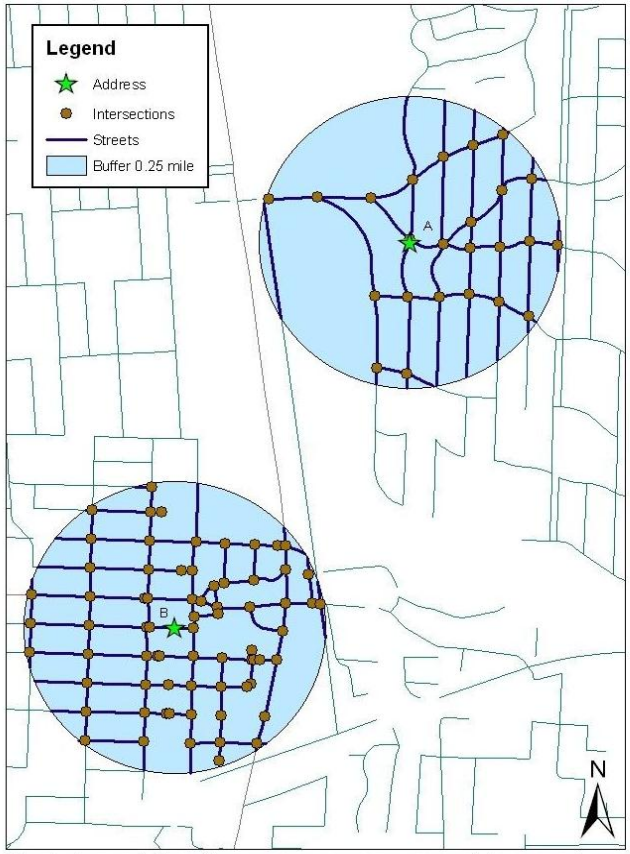


Figure 3.4. Measurement of distance from participant's residential address to the nearest commercial area.

Street connectivity. Street connectivity was operationalized as the density of intersections in a quarter-mile radius around each participant's residential address. TIGER/Line data from 1990 and RLIS streets layer data from 1994 and 1998 were used to calculate this variable. A quarter-mile, circular buffer was generated around each participant's residential address. A quarter-mile buffer was chosen because previous studies have demonstrated that that is the geographic scale most influential on walking behavior. Intersection density was calculated by dividing the number of intersections within the buffer zone by the total area of the buffer. Figure 3.5 depicts the method used to count intersections within the buffer zone around participants’ residential addresses.



Participant A has fewer street segments and intersections within the quarter-mile buffer than Participant B

*Figure 3.5.*Measurement of intersection density in a quarter-mile radius around participant’s residential address

Public transit access. Public transit access was operationalized as the distance to the nearest transit stop from the participant’s residence and the density of bus stops within a quarter mile buffer around each participant’s residence. This reflects that access can be regarded as a function of both proximity and diversity of choice (Ewing & Cervero, 2010). For both measures, data were used from Trimet (the Portland public transit authority) archives from 1988 and RLIS transit data from 1998. The 1994 values were imputed from the 1988 and 1998 data using linear interpolation, because the creation of the walkability index required data on each variable at each time point. While linear interpolation does rely on the untreatable assumption that growth in this measure was linear across the study, alternative approaches such as carrying the last observation forward also made assumptions about the shape of the growth in this measure. Linear interpolation was chosen with the recognition that the assumption of linear growth was closest to the statistical assumptions that would be made if the data were analyzed as missing using one of the robust estimation procedures (i.e. maximum likelihood). The distance to the nearest transit stop was measured as Euclidian distance to a bus or light-rail stop. Figure 3.6 demonstrates the method used to generate this measure. The density of bus stops was measured as the number of bus stops servicing unique routes within a quarter-mile, circular buffer. Consequently, a single stop was counted once for each route that it served, resulting in a measure that reflected the availability of public transit choices within the buffer. Aside from this, the approach is comparable to that used to calculate intersection density, as depicted in figure 3.4.

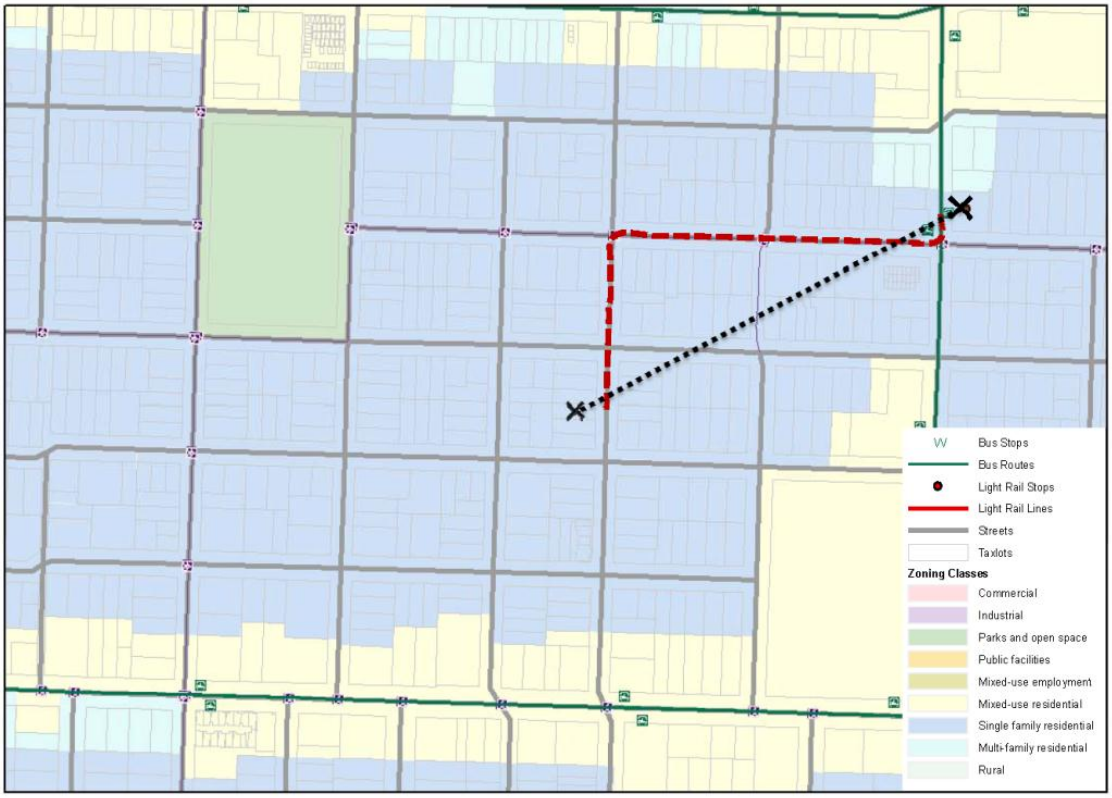


Figure 3.6. Measurement of distance from participant's residential address to the nearest transit stop.

Walkability. To construct a general index of walkability, the deciles of each built environment measure at visit one were calculated and each participant's raw score was converted to a decile score. Because the general trend was increasing walkability, the subsequent raw scores were ranked according to the visit one deciles in order to reflect the degree of change from baseline over time. These decile scores were coded so that a higher score (range 0-9) indicated increasing density (intersection, bus stop) or proximity (public transit stop, commercial area, park/green space). The public transit accessibility, intersection density, and proximity of commercial zoning scores at each wave were averaged to create an index of walkability based on the theoretical framework described in Chapter Two. Proximity to park/green space was not included in this index of walkability but was included in subsequent analyses as a separate variable.

Park/green space access. Park or green space access was operationalized as the Euclidian distance from a participant's residential address to the closest edge of the nearest park or green space. RLIS parks data from 1988, 1994, and 1998 were used to create this measure. This method was similar to the calculation of distance to the nearest commercial area depicted in figure 3.4. Only publicly accessible areas categorized as 'park', 'open space', 'greenway', or 'trail' were included in this measure. Forest Park, the largest urban forest reserve in the United States, covers roughly 6000 acres in the Portland Metro area but has relatively few access points. To address this, only distances to those access points were included in this measure. Lastly, areas smaller than 650 square feet were not included in this measure because they would not likely be useful for exercise purposes and in order to filter out spaces inappropriately categorized as a park or green space.

Neighborhood socioeconomic status. A summary measure of baseline neighborhood socioeconomic status (NSES) was constructed by geocoding participants residential address at visit one to the corresponding 1990 block group census measures of unemployment, occupation in managerial or professional roles, poverty, education, median home price, and median household income. These measures were combined into a standardized z score as described by Krieger et al. (2002), with a higher score indicating higher NSES.

Data Security

A unique, sequential identification number was assigned to each study participant and this was used in the GIS linkage and to distinguish individual records. The SOF participant addresses linked to the identification number and the records were stripped of all additional identifying information. A dataset consisting of only a list of addresses and corresponding identification numbers was transferred to Metro on password-protected CD-ROM disks by SOF personnel. After Metro calculated the built environment variables for each address, they linked those variables to the identification number and destroyed the address file. This was then linked, via the identification number, to the de-identified participant data. One dataset with identification numbers linked to residential addresses has been retained as a password-protected file on an encrypted hard drive.

Data Analysis

After the initial data cleaning, merging, and recoding of variables described above, data analysis occurred in several stages. First, basic statistical procedures were conducted to describe the data, to assess whether participants who moved during the study period differed systematically from those who did not, and to characterize patterns of missing data. Next, a series of unconditional latent growth curve models were constructed to describe the trajectory of neighborhood walkability, the trajectory of neighborhood distance to park/green space, and the trajectory of gait speed over time. Parallel-process latent growth curve models were then constructed to examine the relationship between gait speed and neighborhood walkability and gait speed and neighborhood distance to park/green space. Lastly, because there was significant mortality-related attrition during the study period, growth curve models were adjusted for non-ignorable missing data by using a pattern-mixture modeling approach. As recommended by Muthen (2010), sensitivity analyses were conducted by comparing models estimated under full information maximum likelihood (FIML) estimation procedures to pattern mixture-models fit with varying identifying restrictions. Data cleaning and descriptive analyses were performed with SAS version 9.2 and growth modeling was performed with MPlus version 6. Below is a more detailed explanation of each stage in the data analysis.

Descriptive statistics. Descriptive statistics were calculated for each of the variables included in the analysis. The distribution of gait speed at each time point and the built environment variables at each time point were assessed by calculating the skew and kurtosis statistics and visual examination of histograms. Correlation matrices of gait speed at each time point, of the built environment variables at each time point, and between the covariates were constructed both to inform specification of the residual structures in subsequent growth models and to assess for the presence of multicollinearity. T-tests for continuous variables and chi-square tests for categorical variables were used to determine whether there were significant differences between participants who moved and those who did not move in age, education, comorbidity, average self-reported health, neighborhood SES, and gait speed. The frequency and pattern of missing data was identified for each participant, with particular attention paid to patterns of missing data indicative of attrition. In order to calculate the proportion of attrition at each wave, a participant was classified as having dropped out of the study from the time-point at which all of their subsequent outcome data was logged as missing. Because attrition due to mortality was recorded during the SOF study, the proportion of attrition at each wave due to mortality was also calculated. The high rate of mortality-related attrition observed during the study period suggested that the drop-out mechanism could be related to the outcome and should thus be modeled as non-ignorable attrition. This will be discussed in more detail in a following section.

Overview of latent growth curve modeling. Latent growth curve modeling (LGCM) is a special application of the broad class of latent variable models to the analysis of longitudinal data (Jones, 2012). Similar to the multilevel approach to growth curve analysis, LGCM treats the parameters in the growth curve model as random coefficients, allowing for estimation of their means, variances, and covariances. Keeping in mind that notation varies widely between authors, an unconditional linear growth curve model can be expressed in the following series of regression equations (Singer & Willett, 2003).

$$y_{it} = \eta_{0i} + \eta_{1i}\lambda_t + \varepsilon_{it} \tag{3.1}$$

$$\eta_{0i} = \alpha_0 + \zeta_{0i} \tag{3.2}$$

$$\eta_{1i} = \alpha_1 + \zeta_{1i} \tag{3.3}$$

In multilevel terms, Equation 3.1, represents the level-one, or within-person, change in the outcome, where y=outcome, i=individual participant, t=time point, η_0=baseline (intercept) level of growth, η_1=rate (linear slope) of growth over time, λ=time score, and ε=residual error. From this equation we see that for a given individual, the estimated value of the outcome variable at a specific point in time can be expressed as a function of their individual growth parameters and some degree of residual variance. Individual variability in the growth parameters is modeled in Equations 3.2 and 3.3, where α_0 is the group mean of the intercept parameter and α_1 is the group mean of the slope parameter. ζ_{0i} and ζ_{1i} represent the individual deviations from those means, which have residual variances of ψ_{00} and ψ_{11}, respectively, and a covariance ψ_{01}. There are several important assumptions underlying this model. First, it is assumed that $\Sigma(\varepsilon_{it}) = 0$, $\mathrm{COV}(\eta_{0i}, \varepsilon_{it}) = 0$, and $\mathrm{COV}(\eta_{1i}, \varepsilon_{it}) = 0$. Another common model assumption is that the residual variance terms are uncorrelated over time, though this assumption can be relaxed in the LGCM framework in order to test models with alternative residual structures. Lastly, in the multilevel framework the residual variance is held equal across time points, though in the LGCM framework this can be relaxed to allow for time-specific variance estimates.

Because the LGCM approach and the multi-level approach are, in most respects, functionally equivalent, the framework presented above is adequate to present most features of LGCM modeling. Nevertheless, there are important differences between the two approaches that warrant discussion. Strictly speaking, the LGCM is not a multi-level model at all. Rather, it is a multivariate, single-level, model in which η_0 and η_1 are viewed as latent variables rather than random parameters. In fact, as we see in Equations 3.4 and 3.5, the LGCM can be understood as a highly parameterized structural equation model with the measurement model corresponding to level-1 and the structural model corresponding to level-2 of the multilevel framework (Preacher, Wichman, MacCallum, & Briggs, 2008).

$$\boldsymbol{y} = \boldsymbol{\nu} + \boldsymbol{\Lambda}\boldsymbol{\eta} + \boldsymbol{\varepsilon} \tag{3.4}$$

$$\boldsymbol{\eta} = \boldsymbol{\alpha} + \mathbf{B} + \boldsymbol{\zeta} \tag{3.5}$$

In Equation 3.4, the observed variables are stacked in vector $\boldsymbol{y}$, $\boldsymbol{\nu}$ is vector of measurement intercepts, $\boldsymbol{\Lambda}$ is a matrix of measurement slopes, the latent growth factors are combined in vector $\boldsymbol{\eta}$, and $\boldsymbol{\varepsilon}$ is vector of measurement residuals with a covariance matrix denoted as $\boldsymbol{\Theta}$. As we can see, this equation is essentially a factor analysis model relating the observed values of the variable y to the latent growth factors. The structural relations of these growth factors are given in Equation 3.5, where $\boldsymbol{\alpha}$ and $\mathbf{B}$ vectors of structural intercepts and slopes, and $\boldsymbol{\zeta}$ is vector of residuals with a covariance denoted as$\boldsymbol{\Psi}$.

Perhaps the most important difference between the two approaches is in their treatment of time. In the multi-level approach, time is incorporated as a variable in the model, while in LGCM it is a fixed parameter. More precisely, specification of the shape of the growth curve in the LGCM framework is accomplished through the $\boldsymbol{\Lambda}$ matrix, which contains the factor loadings of the growth factors on the outcome at each time point. The columns in is this matrix are known as basis curves, or latent growth vectors (Singer & Willett, 2003). In a linear model, change is modeled as a function of two latent growth vectors, corresponding to the intercept and the slope factors. Typically, the value of the intercept factor loadings are all fixed at a value of 1 to reflect that the value of the intercept remains constant across time points. In a linear model, the factor loadings can be any value as long as the intervals between them linearly correspond to the intervals between measurement occasions. For example, given a model with five annual measurement occasions, the vectors of factor loadings depicted in Equation 3.6 specify equivalent linear models.

$$\boldsymbol{\Lambda} = \begin{bmatrix} 1 & 0 \\ 1 & 1 \\ 1 & 2 \\ 1 & 3 \\ 1 & 4 \end{bmatrix} \qquad \boldsymbol{\Lambda} = \begin{bmatrix} 1 & 0 \\ 1 & .25 \\ 1 & .50 \\ 1 & .75 \\ 1 & 1 \end{bmatrix} \qquad \boldsymbol{\Lambda} = \begin{bmatrix} 1 & -4 \\ 1 & -3 \\ 1 & -2 \\ 1 & -1 \\ 1 & 0 \end{bmatrix} \tag{3.6}$$

What differs in each of these coding schemas is the location of the intercept and the choice of loading values for the slope factor. The location of the intercept is determined by coding its corresponding factor loading with a value of 0. This is most commonly set at the first measurement occasion, as in the first two matrices above, resulting in the interpretation of the intercept parameter as the average value of the outcome at baseline and the slope parameter as change from that baseline value over time. However, there may be instances when the last measurement occasion is of more substantive interest, a situation which is easily accommodated in the LGCM framework by setting the final measurement occasion at the value of 0, as depicted in third matrix above. The choice of loading values for the slope factor can have a substantive impact on the interpretation of the slope parameter, even when differing coding schemes represent the same functional form. In a linear model, the slope parameter represents the degree of change between the values of 0 and 1. Consequently, in Equation 3.6, the slope factor loadings in the matrix on the left specify a parameter estimate interpreted as the average change between the first and second time points, in the center matrix the resultant slope parameter estimate is interpreted as the average change from the first to the last time point, and the matrix on the right it is the average change between time points four and five.

We can specify the unconditional latent growth curve model described above using standard SEM path diagrams. By convention, rectangles denote measured variables, circles denote latent variables, triangles denote constants, single-headed arrows denote regression paths with the arrow pointing toward the dependent variable, and double-headed arrows denote variances or covariances. Figure 3.7 is a representation of an unconditional, linear growth model with 5 time points. The factor loadings from the latent intercept factor are all fixed at 1, as described above, and the slope loadings specify a linear trajectory with the intercept set at baseline and equal intervals between measurement occasions. The residuals are uncorrelated and constrained to be equal across time points.

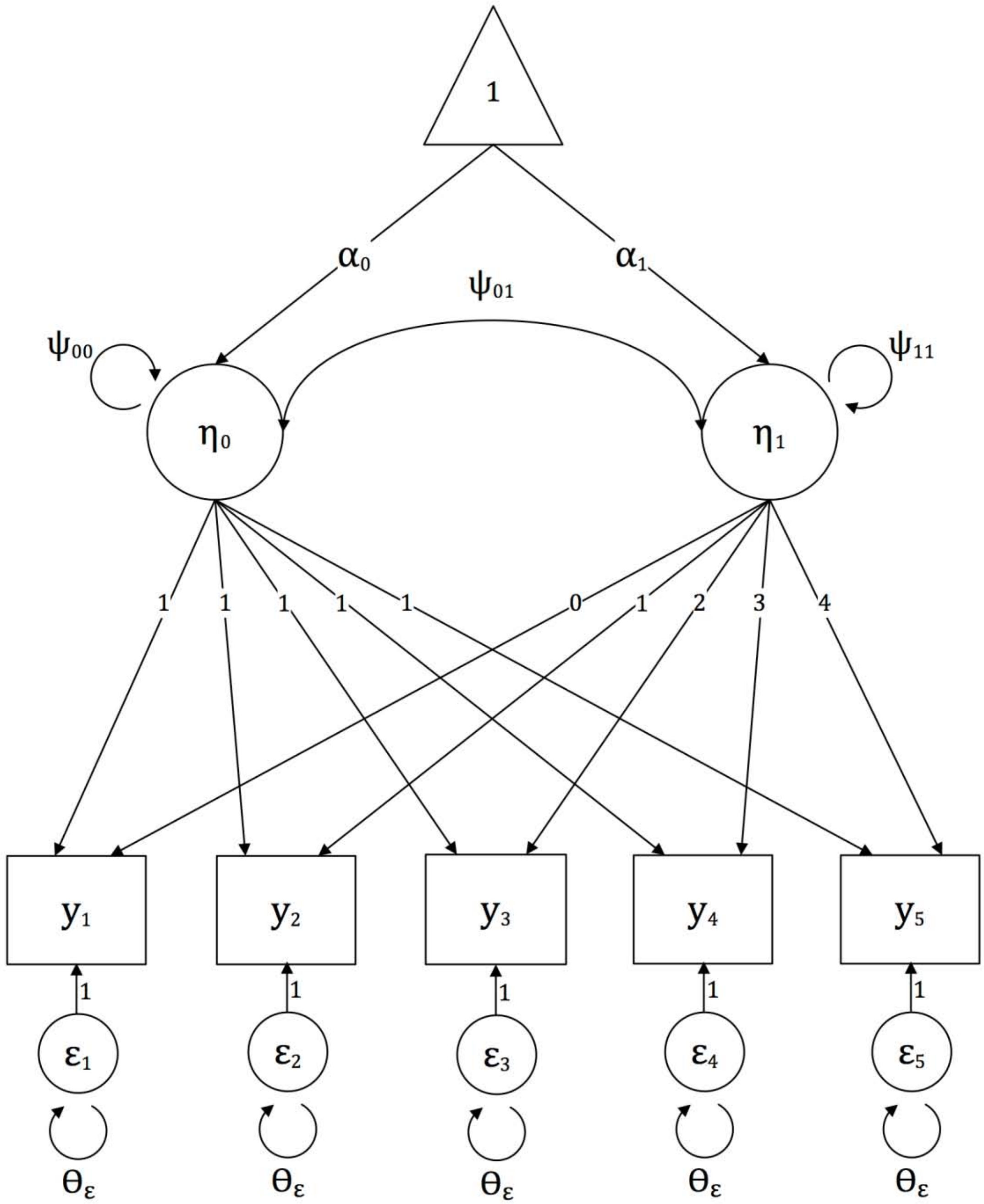


Figure 3.7. Path diagram of unconditional latent growth curve model.

Conditional latent growth models. Because the intercept (η_0) and slope (η_1) parameters are modeled as random coefficients, the unconditional model is easily extended to incorporate the inclusion of both time-invariant and time-varying covariates. The simplest conditional model is that incorporating a single, time-invariant covariate, which is depicted in Equations 3.7, 3.8, and 3.9 below. For consistency, I have returned to the general growth modeling notation introduced at the beginning of this section.

$$y_{it} = \eta_{0i} + \eta_{1i}\lambda_t + \varepsilon_{it} \tag{3.7}$$

$$\eta_{0i} = \alpha_0 + \gamma_0 x_i + \zeta_{0i} \tag{3.8}$$

$$\eta_{1i} = \alpha_1 + \gamma_1 x_i + \zeta_{1i} \tag{3.9}$$

We note that the level-one equation given in 3.7 has remained the same as that presented in Equation 3.1. However, Equations 3.8 and 3.9 extend the level-two equations of the unconditional model by regressing the growth factors on a single, time-invariant covariate x_i. These covariate coefficients can, in the linear model, be interpreted in the same fashion as OLS regression coefficients. Thus, $\gamma_0$is the amount of change in the intercept of the growth curve given a one unit change in the covariate, and γ_1 is the degree of change in the slope of the growth curve given a one unit change in the covariate. Figure 3.8 presents a diagram of this model. (Note: in order to simplify the model diagrams, non-essential notation and model elements are not depicted in this and subsequent models).

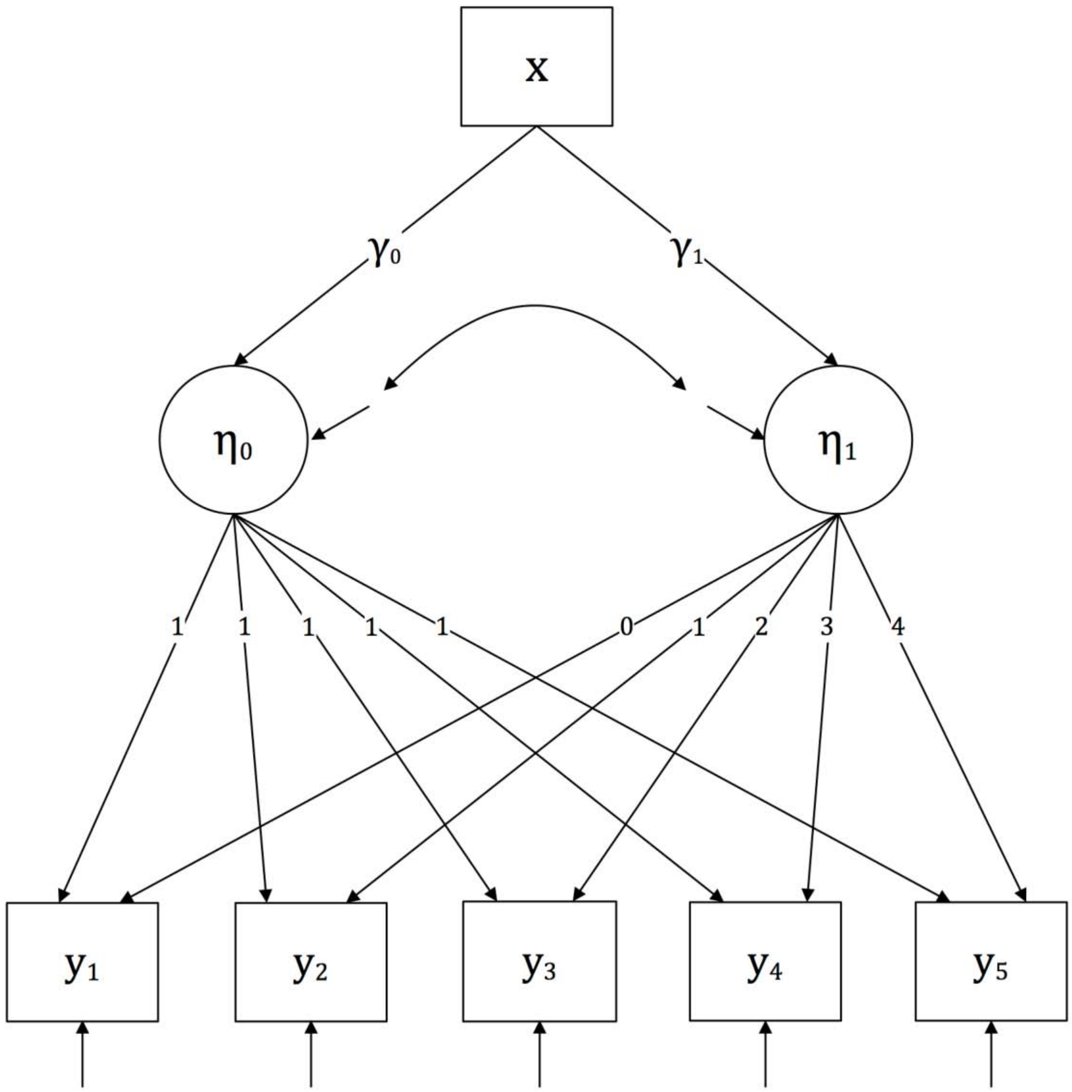


Figure 3.8. Path diagram of latent growth curve model with the inclusion of a time-invariant covariate.

The inclusion of time-varying covariates in the LGCM is typically accomplished by regressing them directly on the outcome variables at the corresponding measurement occasion. In the mathematical formulation of the model, this is accomplished at level-one of the model, as represented in the Equation 3.10 where v_{it} denote the value of a time-varying covariate and γ_t is the associated regression coefficient at time point t. No modifications are made to the level-two models.

$$y_{it} = \eta_{0i} + \eta_{1i}\lambda_t + \gamma_t v_{it} + \varepsilon_{it} \tag{3.10}$$

Because there are no time-varying covariates included in the current analysis, the path diagram depicting the inclusion of time varying covariates is not presented.

Parallel-process growth models. Broadly speaking, both the inclusion of time-invariant and time-varying covariates are examples of regressing the latent growth factors on exogenous, fixed effects. By further extending the LGCM framework we can model the relationship between random effects, which opens the door to understanding the relationship between two growth processes occurring simultaneously. In the parallel-process growth model, two or more growth curves are modeled, each with a corresponding set of latent growth factors which can be correlated with or regressed on one another (Preacher et al., 2008). In the simplest case, modeling the correlation of the unconditional linear growth curve for process y with the unconditional linear growth curve for process w, the model is expressed in the two sets of equations given below.

$$\begin{aligned} y_{it} &= \eta_{0iy} + \eta_{1iy}\lambda_t + \varepsilon_{yit} \\ \eta_{0iy} &= \alpha_{0y} + \zeta_{0yi} \\ \eta_{1iy} &= \alpha_{1y} + \zeta_{1yi} \end{aligned} \tag{3.11}$$

$$w_{it} = \eta_{0iw} + \eta_{1iw}\lambda_t + \varepsilon_{wit}$$
$$\eta_{0iw} = \alpha_{0w} + \zeta_{0wi} \tag{3.12}$$
$$\eta_{1iw} = \alpha_{1w} + \zeta_{1wi}$$

In this simple example of an unconditional parallel-process model, the first growth process is represented in the set of equations given in 3.11, and the second growth process is represented in the set of equations given in 3.12. The relationship between the two growth processes is expressed in the covariance structure of the level-2 residuals, defined as the matrix given in Equation 3.13.

$$\mathbf{\Psi} = \begin{pmatrix} \mathbf{\Psi}_{\eta_y\eta_y} & \mathbf{\Psi}_{\eta_y\eta_w} \\ \mathbf{\Psi}_{\eta_w\eta_y} & \mathbf{\Psi}_{\eta_w\eta_w} \end{pmatrix} \tag{3.13}$$

Typically, these covariances between the latent growth factors are transformed into correlations, which are interpreted according to standard convention. For example, a positive correlation between the intercept factors for y and w indicates that at baseline, high values on one are associated with high values on the other, and vice versa. Similarly, a negative correlation between the slope factors reflects that, over time, a declining score on outcome w is associated with an increasing score on outcome y and vice versa. A further extension of this approach is to model regression paths between one or more of the latent growth factors. This can be used to address theoretical models which posit that the growth parameters of one process predict the parameters of another. An example of such a model is given in figure 3.9.

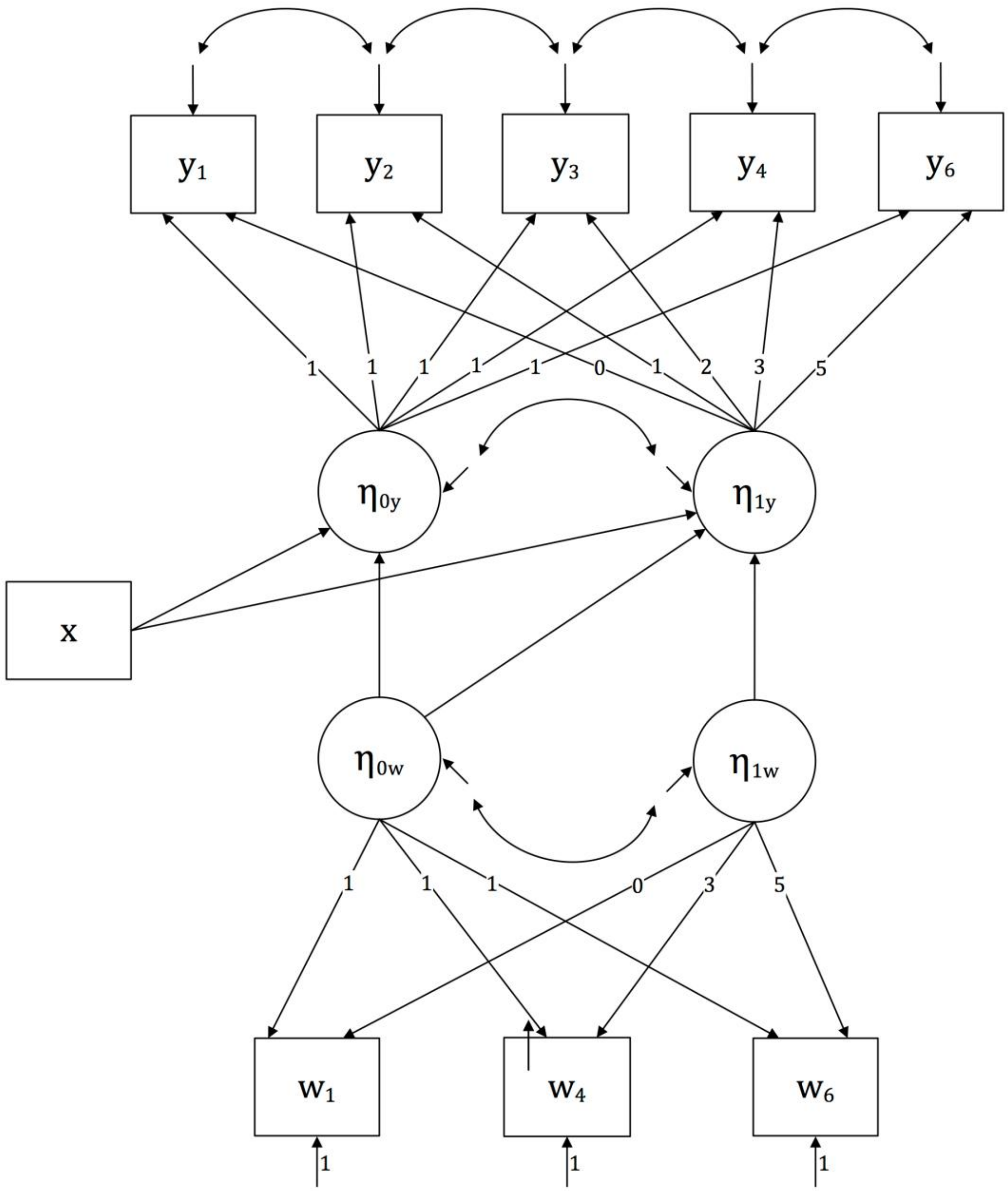


Figure 3.9. Path diagram of parallel-process latent growth curve model with the inclusion of a time-invariant covariate.

The parallel-process model presented in Figure 3.9 is a close approximation of the model tested in the current study, in which the growth parameters of the process w are modeled as independent variables which predict, along with several time varying covariates, the growth parameters of the process y. Specifically, the baseline value of y is predicted by the value of x and is correlated with the baseline value of w, while change in y is predicted by the value of x, the baseline value of w, and change in w. There are two important features of this model which should be pointed out. First, the number of measurement occasions for each process is not equal, which is an acceptable condition, though having only three measurement occasions for neighborhood walkability w does place significant constraints on the model due to identification issues. Second, the measurement occasions for each process are not evenly spaced, which is accommodated by changing the coding of the factor loadings to reflect the uneven intervals.

Non-linear growth models. While the preceding discussion has been limited to modeling change as a linear process, there are many processes which are best modeled using a non-linear function. The LGCM framework readily accommodates modeling non-linear change, which is accomplished by recoding the factor loadings in the $\mathbf{\Lambda}$ matrix and, if necessary, adding additional latent growth parameters (Grimm & Ram, 2009). This study tested two non-linear models, the quadratic model and the latent basis model. The quadratic model is a fairly straightforward extension of the linear model, in which an additional growth factor is added to the level-one equation to represent the curvature of the trajectory, as shown in Equation 3.14, a third column of squared factor loadings is added to the $\mathbf{\Lambda}$ matrix, shown in Equation 3.15, and an additional equation describing the latent quadratic factor is added to level-two of the model (not shown).

$$y_{it} = \eta_{0i} + \eta_{1i}\lambda_t + \eta_{2i}\lambda_t^2 + \varepsilon_{it} \tag{3.14}$$

$$\boldsymbol{\Lambda} = \begin{bmatrix} 1 & 0 & 0 \\ 1 & 1 & 1 \\ 1 & 2 & 4 \\ 1 & 3 & 9 \\ 1 & 4 & 16 \end{bmatrix} \tag{3.15}$$

An alternative approach to a priori specification of the shape of the growth curve is to allow one or more factor loadings to be freely estimated from the model data. This so-called latent basis approach is capable of modeling a variety of non-linear forms, and can typically be accomplished with just two latent growth parameters, which requires estimation of fewer parameters than higher-order polynomial functions (Grimm & Ram, 2009). A minimum of two factor loadings must be fixed in order to produce an estimable model, and, as is the case with the linear model, the choice of factor loadings determines the interpretation of the slope factor. For example, Equations 3.16 and 3.17 illustrate the two most common coding schemas employed in latent basis models.

$$\boldsymbol{\Lambda} = \begin{bmatrix} 1 & 0 \\ 1 & 1 \\ 1 & \lambda_3 \\ 1 & \lambda_4 \\ 1 & \lambda_5 \end{bmatrix} \tag{3.16}$$

In the first, the factor loadings are fixed for the first two time points and the remaining factor loadings are freely estimated. This results in a slope parameter which is interpreted as the degree of change between the first and second measurement occasion. However, as a model of non-linear change, that parameter estimate does not hold for the degree of change between any subsequent visits. An alternative coding is presented in Equation 3.18 which fixes the first and last measurement occasions and allows the intervening occasions to be freely estimated.

$$\boldsymbol{\Lambda} = \begin{bmatrix} 1 & 0 \\ 1 & \lambda_2 \\ 1 & \lambda_3 \\ 1 & \lambda_4 \\ 1 & 1 \end{bmatrix} \tag{3.17}$$

In this schema, which is the one used in the present analysis, the slope parameter is interpreted as the degree of change between the first and last measurement occasion. This schema has the additional benefit of estimating factor loadings which represent the proportion of overall change in the outcome that occurred by each measurement occasion.

Model fitting procedure. In accordance with the process recommended by Muthen (2010), model-fitting proceeded as follows:

(1) Unconditional growth models of gait speed, walkability score, and access to park/green space score were constructed in order to determine the shape of the growth curve. Linear, quadratic, and latent basis models were fit to the gait speed variable. In each model, the factor loadings were scored so that the first measurement occasion was set as the intercept. The loading of the last measurement occasion on the slope factor was set to the value of one in both the linear and quadratic models in order to facilitate comparison with the latent basis model, which had the first and last time points fixed at 0

and 1, respectively. Initially, each of these models was fit with the residual variance uncorrelated and freed to vary across time-points. The fit of these models was assessed by visually examining plots of estimated vs. observed values and calculation and comparison of relative and absolute fit statistics.

For gait speed, the final unconditional model with uncorrelated residuals was compared to a model with the adjacent residual variances correlated. With only three measurement occasions, fitting an appropriate model to the walkability score and park score variables proved challenging. A quadratic model was not estimable, and the latent basis model was just-identified (df=0), precluding evaluation of model fit and introducing estimation difficulties (negative residual variance). To remedy this, the residual variance was held equal across measurement occasions.

(2) After determining the appropriate shape of each growth curve in unconditional models, parallel-process models of gait speed with walkability score and gait speed with distance to park/green space score were constructed. Each model was specified identically in accord with the specific aims of the study. The models were specified as follows:

a. The intercept growth factor of gait speed was regressed on the intercept growth factor of the built environment variable.
b. The slope growth factor of gait speed was regressed on the intercept growth factor of the built environment variable.
c. The slope growth factor of gait speed was regressed on the slope growth factor of the built environment variable.

.

(3) The model described in step 2 was adjusted for covariates. The intercept and slope growth factors for gait speed were regressed on age, education, complex comorbidity, and baseline neighborhood SES. Incident fracture was only regressed on the slope growth factor. Because the covariates were selected for inclusion in the model based on a priori theoretical concerns, they were retained in the final model whether or not they were found to be statically significant. A path diagram of the final model is presented in Figure 3.10

Assessment of model fit and statistical significance. The fit of the latent growth curve models was determined by evaluating several fit statistics. These include the chi-square test of model fit, the Comparative Fit Index (CFI), the Tucker-Lewis Index (TLI), the Root Mean Square Error of Approximation (RMSEA), and the Standardized Root Mean Square Residual (SRMR). A significant chi-square test generally indicates poor-model fit, though this test is sensitive to sample size and is nearly always significant when sample size exceeds ~400 cases (Kenny & McCoach, 2003). Thus, it was not viewed as a reliable indicator of model fit in the present analysis. For both the CFI and TLI, a value 1.0 indicates perfect fit, with a value > .95 indicating good model fit. Conversely, an RMSEA value of 0 indicates perfect model fit, with a value of ≤ .05 indicating good model fit and a value of ≤ .08 indicating acceptable model fit. Similarly, an SRMR of 0 indicates perfect model fit, with a value ≤ .05 indicating good model fit (Hu & Bentler, 1999; Iacobucci, 2010). The significance level for all statistical tests was set at α=.05.

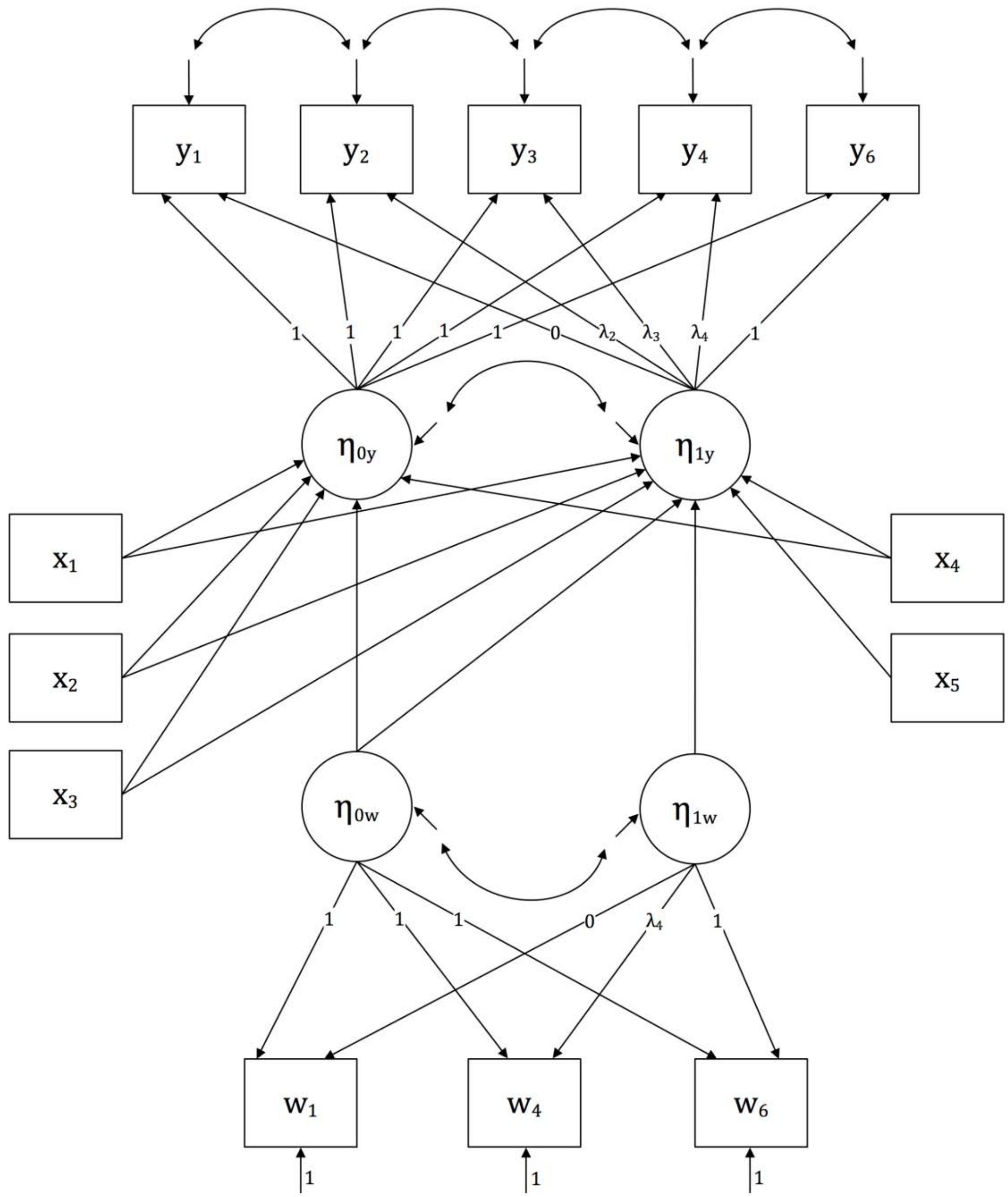


Figure 3.10. Path diagram of the covariate-adjusted parallel-process latent growth curve model tested in the study.

Overview of missing data handling. As noted in the descriptive analysis section above, the amount of missing data for each variable was calculated and the missing data patterns tabulated prior to the LGCM analysis. Defining attrition as a consecutive pattern of missingness from a given measurement occasion to the final measurement occasion, patterns of missing data can be broadly grouped into the two categories of intermittent missingness and attrition (Enders, 2010). It should be noted that the built environment variables were defined as missing from the point that a participant was defined as having dropped out of the study. As Yang, Li, and Shoptaw (2008) have observed, a conservative assumption is that there are different missing data mechanisms underlying these two categories, an assumption which has important implications for the choice of analytic approach.

According to Rubin (1976), there are three mechanisms relating the probability of missingness on a given variable to the observed and missing values in the dataset (a missing value is considered, in Rubin's framework, to have some unknown unobserved value). Missing completely at random (MCAR) refers the situation where the probability of missingness is unrelated to either the observed or missing values in the data, as we see, using notation from Enders (2011) in the following conditional probability distribution,

$$p(R|\phi) \tag{3.18}$$

where R is a binary indicator of missingness and ϕ is a parameter that describes the missing data process. When data are MCAR, incomplete cases may simply be removed from the analysis , as in the practice of listwise deletion, without introducing bias because they are a randomly distributed in the larger sample. The second category of missing data mechanisms is termed missing at random (MAR), which is when

$$p(R|Y_{obs}, \phi) \tag{3.19}$$

where Y_{obs} is the observed data. In other words, the probability of missing data is related to the observed data via the parameter ϕ, but it is not related to the unobserved, missing values. In the case of MAR, removal of incomplete cases may result in bias because these cases differ systematically from the cases with complete data. However, maximum likelihood estimation and Bayesian multiple imputation procedures are robust to data missing under the MAR mechanism, particularly if the covariates that predict missingness are incorporated in the analysis (Baraldi & Enders, 2010). Thus, these mechanisms have together termed “ignorable missingness” since they are generally well handled with current modeling techniques. In this dissertation study, intermittently missing data were assumed to be MAR or MCAR. Consequently, cases with intermittently missing data were retained in the analysis, which was conducted using a full-information maximum likelihood (FIML) estimation procedure that produces unbiased estimates when data are MCAR or MAR.

The third category of missing data is known as missing not at random, or MNAR, which has the probability distribution

$$p(R|Y_{obs}, Y_{mis}, \phi) \tag{3.20}$$

where Y_{mis} is the unobserved, missing data. Here, the probability of missingness is related either to the observed or missing data in the data set. Put another way, the probability of missingness and the variable with missing values have a joint distribution. An alternative way of expressing this joint probability distribution is

$$p(Y_i, R_i|\theta, \phi) \tag{3.21}$$

where Y_i is the value of the outcome variable for individual i, R_i is the indicator of missingness on Y for individual i, θ is a set of parameters describing the distribution of Y, and ϕ is a set of parameters predicting R (Enders). Rubin demonstrated that when data are MNAR, the missing data parameters ϕ hold important information about the outcome parameters θ and not including that information in the model describing Y can result in substantial bias. Thus, MNAR is sometimes referred to as non-ignorable missingness, because it is necessary to incorporate a model of R into the model of Y in order to produce valid estimates. The two primary approaches to this are selection modeling and pattern-mixture modeling (Michiels, Molenberghs, Bijnens, Vangeneugden, & Thijs, 2002; Muthen, Asparouhov, Hunter, & Leuchter, 2011).

Pattern-mixture modeling. The pattern-mixture approach, which is employed in this study, factors the joint distribution presented in Equation 3.21 into the product of two separate distributions (Enders, 2011; Pauler, McCoy, & Moinpour, 2003). Returning to the notation above, the pattern-mixture model is specified as

$$p(Y_i, R_i|\theta, \phi) = p(Y_i|R_i, \theta)p(R_i|\phi) \tag{3.22}$$

where $p(Y_i|R_i, \theta)$ is the conditional distribution of Y given a particular value of R and $(R_i|\phi)$ is the marginal distribution of R. In practical terms, $p(Y_i|R_i, \theta)$ is given as the estimated parameters of Y for each missing data pattern and $(R_i|\phi)$ is the proportion of participants with each missing data pattern. The mean parameter estimates for Y are thus a mixture of parameter estimates specific to each pattern of missing data and are generically calculated as

$$\hat{\hat{\eta}} = \hat{\pi}^{p1}\hat{\eta}^{p1} + \hat{\pi}^{p2}\hat{\eta}^{p2} + \cdots + \hat{\pi}^{pN}\hat{\eta}^{pN} \tag{3.23}$$

where $\hat{\hat{\eta}}$ is the mean parameter estimate, $\hat{\pi}$ is the proportion of participants with missing data pattern p, $\hat{\eta}$ is the pattern-specific parameter estimate for pattern p, and N is the number of patterns. The standard errors of the mean parameter estimates are calculated using the so-called delta method (equations not shown).

An important consideration in the specification of pattern-mixture models is that they are often under-identified, because some of the pattern-specific parameters are inherently inestimable. For example, if some participants only contribute data on the first measurement occasion, calculation of a slope parameter for that group is not possible. Similarly, in a quadratic model the patterns corresponding to attrition at time two and time three would contain inestimable parameters. Incorporating patterns with inestimable parameters requires making explicit assumptions about the value of those parameters. These assumptions are termed identifying restrictions, and are implemented by fixing the inestimable parameter at some determined value. For example, in the neighboring-case restriction, the inestimable parameter is held equal to the value of the nearest group for which that parameter is identified. Because identifying restrictions are essentially untestable assumptions, it is recommended that a sensitivity analyses be conducted by comparing the results from models with different identifying restrictions (Enders, 2011; Thijs, Molenberghs, Michiels, Verbeke, & Curran, 2002).

Determining the mechanism underlying attrition from a longitudinal study, and thus the choice of analytic approach used to account for attrition is a subjective decision. This is because the relationship between ϕ and θ is unknown and inestimable (ref). Consequently, there is no way to test whether data are MAR or MCAR. There is, however, growing discussion about how best to account for attrition in longitudinal studies of older adults, as attrition in these studies is commonly attributable to declining health or mortality, and the assumption of MAR is often not justified (Diehr & Johnson, 2005; Hardy, Allore, & Studenski, 2009). For example, in this study, 615 (48.9%) participants were lost to follow-up due to attrition during the study, of those 356 (28.3%) were lost due to death. It is plausible that, among those participants lost to attrition, the probability of missingness was related to the unobserved value of gait speed. In order to account for any potential bias resulting from misspecification of the mechanism underlying participant attrition, a pattern-mixture modeling approach was employed to adjust each model for attrition-related missing data. Figure 3.11 presents a path diagram of an unconditional LGCM of gait speed incorporating a pattern-mixture model of attrition analogous to the one used in this study.

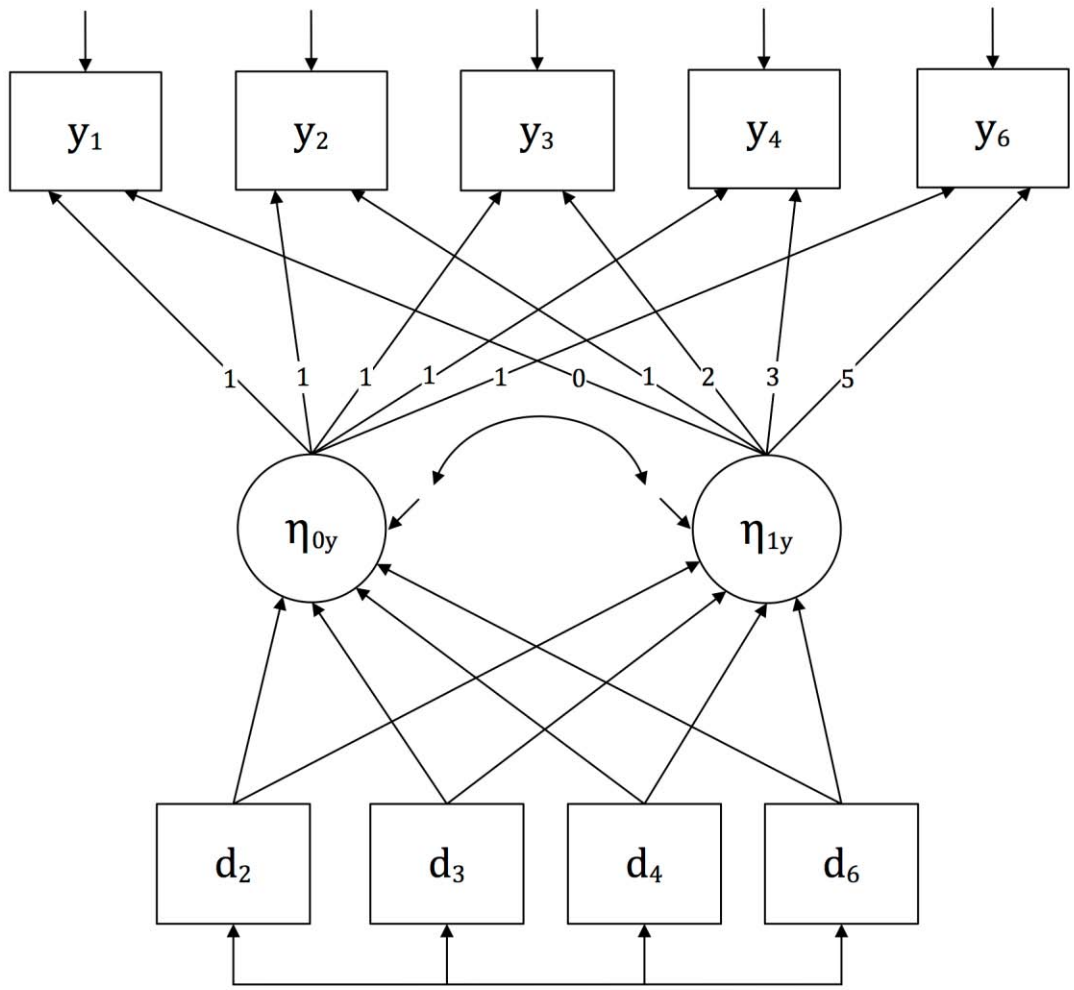


Figure 3.11. Path diagram of a pattern-mixture model with 4 patterns of attrition.

As this model illustrates, there were four patterns of attrition—attrition at visit two, three four or six. This required the calculation of five sets of parameter estimates for each model, one for each pattern of missingness and one for the sub-group of the participants who did not drop-out. Because attrition was defined as a pattern of consecutive missingess on the outcome variable, it was not defined for visit five. Participants who were lost to follow up due to attrition at visit five were therefore classified as attrition at visit 6. This is not an uncommon practice and likely had a negligible impact on the estimation of the models (Muthen et al., 2011). For each model, one pattern-mixture model was fit with a neighboring-case identifying restriction as described above and one was fit with a complete-case identifying restriction, in which the inestimable parameters are fixed at those of the complete cases. The mean intercept and slope parameters of each model were calculated as specified in equation 3.23 and the standard errors were calculated using the delta method. Sensitivity analyses were conducted by comparing the parameter estimates, standard errors, and plots of the estimated growth curves from models estimated using FIML under a MAR assumption to pattern-mixture models with competing identifying restrictions.

Summary

This study employed a parallel-process LGCM approach to examine change in gait speed and change in neighborhood built environment over a 12-year period. The specific aims of the study are addressed by the statistical methods as follows.

1. Describe the relationship between baseline neighborhood walkability and baseline lower-extremity function among older women.

   This is accomplished by regressing the gait speed intercept factor on the neighborhood walkability intercept factor.

2. Describe the relationship between baseline neighborhood walkability and change in lower-extremity function among older women.

   This is accomplished by regressing the gait speed slope factor on the neighborhood walkability intercept factor.

3. Describe the relationship between change in neighborhood walkability and change in lower-extremity function among older women.

This is accomplished by regressing the gait speed slope factor on the neighborhood walkability slope factor.

4. Describe the relationship between baseline distance to neighborhood parks/green spaces and baseline lower-extremity function among older women.

   This is accomplished by regressing the gait speed intercept factor on the distance to park/green space intercept factor.

5. Describe the relationship between baseline distance to neighborhood parks/green spaces and change in lower-extremity function among older women.

   This is accomplished by regressing the gait speed slope factor on the distance to park/green space intercept factor.

6. Describe the relationship between change in distance to neighborhood parks/green spaces and change in lower-extremity function among older women.

   This is accomplished by regressing the gait speed slope factor on the distance to park/green space slope factor.

Chapter 4—Results

Descriptive Statistics

Sample characteristics. Table 4.1 presents demographic and health characteristics of the sample. The average age of participants at baseline was 72.3 (SD=5.21), with the youngest being 65 years of age and the oldest being 99 years of age. The majority (53%) were married, living with a spouse or other person (63%), and had an average of 12.6 years of education. Most of the participants reported themselves to be in good or excellent health at baseline (82%), and only 21% reported a diagnosis of two or more of the following medical conditions (diabetes, stroke, MI, CHF, COPD, cancer). However, because some conditions were not assessed for until the second (MI, CHF) or third visit (cancer), people who dropped out prior due to declining health would not be included in the respondents. Thus, this is likely a slight underestimation of the true rate of comorbid conditions in the sample. The frequency of the specific conditions is given in the table below. At baseline, roughly 90% of the sample reporting walking some amount in the past week, though only 57% reported walking for exercise. The average number of blocks walked in a day for all purposes (exercise and travel) was 12.87.

Table 4.1
Characteristics of the Study Participants, SOF Neighborhood Study, 1986 -1998

Characteristic	Mean ± SD or N (%)
Age (years)	72.27 ± 5.21
Education	
Less than high school	269 (21.42)
High school	474 (37.74)
At least 1 year of college	513 (40.84)
Marital status	
Married	665 (52.94)
Widowed	450 (35.83)
Separated	4 (0.32)
Divorced	93 (7.4)
Never married	44 (3.5)
Live alone	
No	786 (62.58)
Yes	470 (37.42)
Comorbid conditions	
Cancer	275 (25.82)
Chronic obstructive pulmonary disease	202 (17.19)
Congestive heart failure	141 (12.24)
Cognitive impairment	92 (7.35)
Depression	250 (22.73)
Diabetes	137 (10.91)
Hypertension	762 (60.67)
Myocardial infarction	157 (13.60)
Stroke	167 (13.30)
Complex comorbidity (≥ 2 comorbid conditions)	
No	610 (48.73)
Yes	644 (51.27)
Incident fracture	
No	960 (76.43)
Yes	296 (23.57)
Baseline self-rated health	
Excellent	393 (31.29)
Good	634 (50.48)
Fair	205 (16.32)
Poor/Very poor	24 (1.91)
Total walking (blocks per day)	12.87 ± 12.51
Walk for exercise	
Yes	718 (57.17)
No	538 (42.83)

The average gait speed of the sample at each wave is presented in table 4.2. There is a clear pattern of decline as well as substantial variability around the mean. Additionally, the pattern does not appear to be one of linear decline; rather, the mean values indicate that the sample declines more steeply between visits 1-4 and then leveled off somewhat in the period between visits 4-6. The skew and kurtosis statistics indicate that it is approximately normally distributed, a finding which was confirmed by visual inspection of histograms of gait speed at each wave (not shown).

Table 4.2.
Gait Speed of Sample at Each Visit, SOF Neighborhood Study, 1986 -1998

	N	Mean (SD)	Range	Skew	Kurtosis
Visit 1	1255	1.02 (0.25)	0.13-1.88	-0.09	0.49
Visit 2	1050	0.96 (0.20)	0.30-1.73	-0.25	0.21
Visit 3	929	0.92 (0.21)	0.19-1.58	-0.29	0.63
Visit 4	793	0.85 (0.18)	0.06-1.41	-0.37	1.31
Visit 6	589	0.83 (0.19)	0.22-1.54	-0.03	0.14

Comparison of movers to non-movers. Table 4.3 compares the members of the Portland, Oregon SOF cohort who moved during the study period to those who did not move. Those participants who moved, and were thus not included in the present analysis, on average were 1 year older ($p<.001$), had a higher average number of comorbidities ($p<.001$), were more likely to have two or more comorbid conditions, were more likely to experience an incident fracture during the study period ($p<0.02$), and had a lower baseline gait speed ($p<0.001$). These significant differences between movers and non-movers suggest that poor or declining health may have been associated with the decision to move, although the absolute differences on these measures were small.

Table 4.3
Comparison of Baseline Characteristics by Residential Move Status, SOF Neighborhood Study, 1986-1998

	No Move	Move	
Characteristic	Mean (SD)	Mean (SD)	p value
Gait speed (m/sec)	1.02(0.25)	0.98(0.25)	<.001
Age	72.27(5.21)	73.26(5.80)	<.001
Self-reported health	3.11(0.73)	3.12(0.70)	.84
Count of comorbid conditions	1.74 (1.32)	2.01 (1.48)	<.001
Years of education	12.63(2.70)	12.52(2.72)	.38
Blocks walked per day	12.86(12.51)	12.03(12.18)	.14
Walkability index	4.44 (2.18)	4.63(2.27)	.06
Park score	4.67(2.95)	4.65(2.94)	.86
Neighborhood SES	0.01(4.84)	-0.10(4.79)	.63
	N (%)	N (%)	p value
Complex comorbidity			<.001
Yes	644 (51.27)	427 (57.32)	
No	612 (48.73)	318 (42.68)	
Incident fracture			.02
Yes	296 (23.57)	211 (28.32)	
No	960 (76.43)	534 (71.68)	

Missing data and attrition. The patterns of missing data are presented in table 4.4 and the amount of both attrition and intermittent missing data at each wave is depicted in table 4.5. 49% (N=615) of the participants were lost to attrition during the study period. 51% (N=356) of that attrition was attributable to mortality. The proportion of attrition at each visit attributable to mortality increases over time, from 37% at visit 2 to 81% at visit 6. In addition to attrition-related missingess, there is a fairly constant amount of intermittently missing data from visits 2-6.

Table 4.4
Frequency of Missing Data Patterns, SOF Neighborhood Study, 1986 -1998

N (%)	Visit 1	Visit 2	Visit 3	Visit 4	Visit 6
512 (40.8)					
204 (16.2)					M
153 (12.2)				M	M
153 (12.2)		M	M	M	M
105 (8.4)			M	M	M
26 (2.1)				M	
20 (1.6)			M		
19 (1.5)			M		M
12 (1.0)		M	M		M
11 (0.9)		M			M
11 (0.9)		M		M	M
10 (0.8)			M	M	
9 (0.7)		M			
5 (0.4)		M	M		
4 (0.3)		M	M	M	
2 (0.2)		M		M	

Table 4.5

Attrition and Missing Data, SOF Neighborhood Study, 1986 -1998

	Visit 1	Visit 2	Visit 3	Visit 4	Visit 6
Cumulative attrition:					
N (% of baseline sample)					
Death	0	58 (4.6)	108 (8.6)	190 (15.1)	356 (28.3)
Other	0	95 (7.6)	150 (11.9)	221 (17.6)	259 (20.6)
Total	0	153 (12.2)	258 (20.5)	411 (32.7)	615 (48.9)
Intermittent missing					
N (% of baseline sample)	1 (.01%)	54 (4.3)	70 (5.6)	53 (4.2)	53 (4.2)
Complete data					
N (% of baseline sample)	1255 (99.9)	1049 (83.5)	928 (73.9)	792 (63.1)	588 (46.8)

Neighborhood characteristics. Table 4.6 presents descriptive statistics for the neighborhood environment variables at each wave. On average, participants lived in neighborhoods with moderately interconnected street grids and in fairly close proximity to transit, commercial areas, and parks or green spaces. At baseline, participants had an average of 32.9 bus stops within a quarter mile of their home, and the mean distance to the nearest transit stop was .19 miles. The mean distance to the nearest commercial area was .21 miles, and the mean distance to the nearest park or green spaces was .28 miles. The average intersection density was 202.9. There was, however, a great deal of individual variability in the neighborhood built environment measures. For example, the distance to the nearest transit stop at baseline ranged from 40 feet to 3 miles, and the distance to the nearest commercial area ranged from 0 (indicating the participant lived in a mixed land-use development) to 1.5 miles. There were moderate correlations between all of the measures of neighborhood walkability, such that increased walkability on any one given measure was correlated with increased walkability on all of the other measures. Weak negative correlations were observed between distance to park/green space, intersection density, distance to commercial area, and bus stop density, and weak positive correlations were observed between distance to park/green space and distance to transit. Notably, there was a pattern of weak to moderate correlations between neighborhood SES and neighborhood walkability, such that lower SES tended to score higher on every measure of neighborhood walkability. This inverse relationship between neighborhood walkability and SES has been observed in previous studies in Portland (Michael et al. 2010; Nagel et al., 2008).Table 4.7 presents the correlation matrix of neighborhood built environment measures

Table 4.6
Neighborhood Characteristics by Year, SOF Neighborhood Study, 1986 -1998

Variable	Year	Mean (SD)	Min-Max
Bus stop density (qm)			
	1988	32.9 (30.1)	0-152.0
	1994	37.2 (32.7)	0-180.0
	1998	40.0 (34.9)	0-183.9
Distance to transit stop (ft)			
	1988	980.4 (1703.8)	39.52-1600.0
	1994	862.6 (1155.6)	36.09-1165.0
	1998	769.2 (826.8)	19.63-7110.0
Intersection density (qm)			
	1990	202.9 (92.5)	10.2-590.8
	1994	201.1 (94.6)	10.2-590.8
	1998	205.3 (90.8)	10.2-583.1
Distance to commercial area (ft)			
	1990	1137.0(1283.1)	0-8000.0
	1994	1126.1(1254.9)	0-8010.0
	1998	969.3(875.8)	0-5300.0
Distance to park/green space (ft)			
	1988	1491.8 (1084.9)	0-6864.0
	1994	1345.1 (821.9)	0-5000.0
	1998	1116.4 (696.8)	0-4500.0
Walkability score			
	1988-90	4.44 (2.19)	0-9
	1994	4.53 (2.2)	0-9
	1998	4.67 (2.17)	0-9
Park score			
	1988	4.7 (2.9)	0-9
	1994	4.9 (2.8)	0-9
	1998	5.7 (2.6)	0-9
Neighborhood socioeconomic status			
	1990	0.01 (4.84)	-17.34-17.83

Table 4.7
Correlation Matrix of Neighborhood Built Environment Measures, SOF Neighborhood Study, 1986 -1998

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1. Bus stop density 1988	–														
2. Bus stop density 1994	.98**	–													
3. Bus stop density 1998	.94**	.99**	–												
4. Transit distance 1988	-.38**	-.36**	-.35**	–											
5. Transit distance 1994	-.46**	-.46**	-.45**	.95**	–										
6. Transit distance 1998	-.52**	-.54**	-.54**	.69**	.88**	–									
7. Int. density 1990	.35**	.38**	.39**	-.28**	-.32**	-.33**	–								
8. Int. density 1994	.36**	.39**	.39**	-.29**	-.32**	-.32**	.99**	–							
9. Int. density 1998	.36**	.38**	.39**	-.28**	-.31**	-.31**	.99**	.99**	–						
10. Comm. distance 1990	-.31**	-.32**	-.32**	.29**	.38**	.44**	-.34**	-.34**	-.31**	–					
11. Comm. distance 1994	-.31**	-.33**	-.33**	.30**	.39**	.45**	-.34**	-.34**	-.32**	.99**	–				
12. Comm. distance 1998	-.37**	-.38**	-.37**	.37**	.46**	.50**	-.31**	-.31**	-.30**	.74**	.75**	–			
13. Park distance 1988	-.12**	-.11**	-.11**	.17**	.18**	.17**	-.24**	-.25**	-.26**	-.02	-.02	.05	–		
14. Park distance 1994	-.06*	-.06*	-.05**	.10**	.12**	.13**	-.14**	-.15**	-.16**	-.04	-.04	-.01	0.78**	–	
15. Park distance 1998	-.01	.00	.00	.13**	.16**	.16**	-.10**	-.10**	-.11**	-.08*	-.07*	-.05	0.62**	0.77**	–
16. NSES 1990	-.15**	-.18**	-.19**	.14**	.17**	.20**	-.30**	-.31**	-.31**	.36**	.36**	.37**	-.02	-.07*	-.08**

Note:
**p* < .05, ***p* < .001

Overall, each of the neighborhood built environment variables changed in the direction of increased walkability during the study period, although the magnitude of that change varied considerably among the various measures. The average number of bus stops in a quarter mile radius around participants' homes increased by 18% during the study period and the average distance to transit from participants' homes decreased by 22%. The average distance to the nearest commercial area decreased by 15%, while the distance to the nearest park or green space decreased by 25%. Mean intersection density increased only 1% during the study period, reflecting the relative stability of the street grid over time.

The magnitude of change in the neighborhood built environment over the study period varied by the level of neighborhood walkability at baseline, with the least walkable neighborhoods at baseline exhibiting the greatest change over time. Table 4.8 shows the average 10-year change in built environment score by degree of neighborhood walkability at baseline. This was calculated for each participant as the difference between the 1988 score and the 1998 score (refer to chapter 3 for description of how decile scores were calculated). Participants were grouped according to baseline walkability score: those in the bottom quartile for walkability were categorized as low, the top quartile were categorized as high, and the middle 50% were categorized as medium. These difference scores for participants in each category were averaged to calculate the mean change in score of each variable. The most substantial improvement in all of the variables over time occurs in the low walkability neighborhoods, with the exception of bus density. Very little change in distance to commercial areas, distance to public transit, or intersection density occurred in the high baseline walkability neighborhoods.

Table 4.8
Change in Built Environment Characteristic by Neighborhood Walkability
SOF Neighborhood Study, 1986 -1998

	Walkability		
	Low (N=)	Medium (N=)	High (N=)
Variable	Mean (SD)	Mean (SD)	Mean (SD)
Bus density	0.44 (1.22)	0.67 (1.06)	0.49 (0.87)
Distance to commercial	0.33 (1.16)	0.16 (1.11)	-0.03 (0.99)
Intersection density	0.10 (0.68)	0.06 (0.53)	-0.08 (0.43)
Distance to park	1.31 (2.47)	0.10 (2.29)	0.62 (1.61)
Distance to public transit	0.44 (1.49)	0.11 (0.83)	0.02 (0.85)
Walkability score	0.32 (0.70)	0.25 (0.51)	0.10 (0.44)

Unconditional Growth Models

Gait speed. Figure 4.1 displays the gait speed trajectories of 25 randomly sampled individuals. From this figure we can see that there is a great deal of variability in gait speed at baseline, as well as in the trajectory of gait speed over time. This is reflected in the results of the unconditional linear, quadratic, and latent basis models of gait speed, presented in table 4.9.

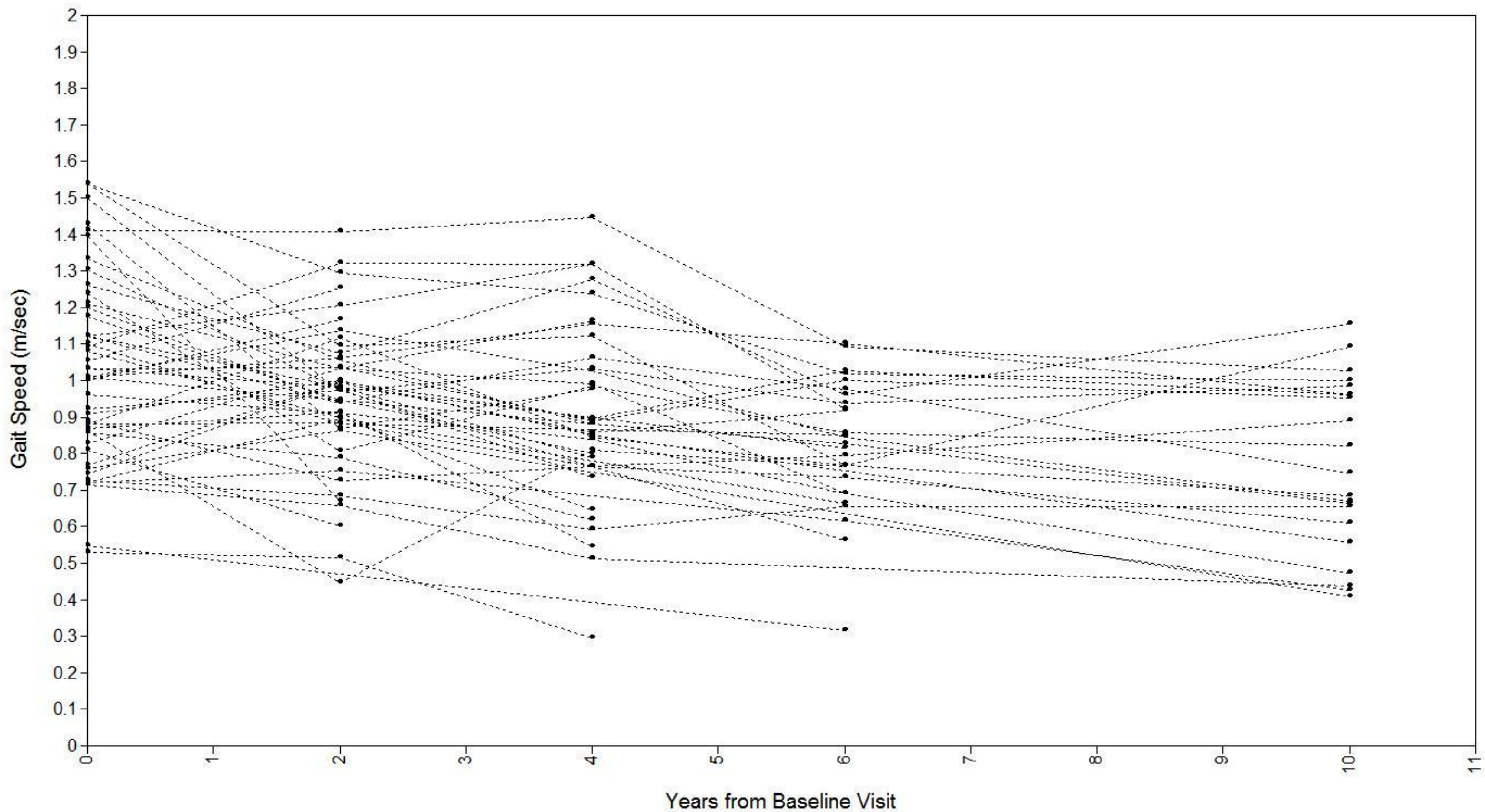


Figure 4.1. Gait speed trajectory of 25 randomly selected participants.

Table 4.9
Unconditional Models of Gait Speed (m/sec), SOF Neighborhood Study, 1986 -1998

Model Parameters		Linear	Quadratic	Latent basis	Latent basis with correlated residuals
η_{0y}	Intercept (SE)	1.004 (.006)**	1.032 (.007)**	1.022 (.007)**	1.022 (.007)**
η_{1y}	Slope (SE)	-.266 (.008)**	-.463*	-.242 (.008)**	-.234 (.008)**
η_{2y}	Quadratic (SE)	NA	.208 (.022)*	NA	NA
ψ_{01}	slope with intercept (SE)	-.001 (.002)	-.013 (.008)	-.004 (.002)*	-.018 (.004)**
ψ_{02}	Quadratic with intercept (SE)	NA	.007 (.007)	NA	NA
ψ_{12}	Quadratic with slope (SE)	NA	-.086 (.030)*	NA	NA
ψ_{00}	Intercept variance (SE)	.029 (.002)**	.032 (.003)**	.032 (.002)**	.041 (.004)**
ψ_{11}	Slope variance (SE)	.003 (.003)	.095 (.032)*	.007 (.002)*	.028 (.005)**
ψ_{22}	Quadratic variance (SE)	NA	.089 (.033)*	NA	NA
Fit Statistics					
Chi-square		182.532(10)**	54.826(2)**	48.859(7)**	15.275(3)*
CFI		.910	.963	.978	.994
TLI		.910	.938	.969	.979
RMSEA		.117	.097	.069	.057
SRMR		..137	.067	.095	.037

Note: parameter estimates are unstandardized
*$p < .05$, **$p < .001$

The intercept of the linear model was 1.004 and the slope estimate was -.266, indicating that the average baseline gait speed was estimated to be 1.004 and that over the study period participants declined an average of .266 m/sec. The intercept variance was significant, indicating that there was significant inter –individual variability in initial gait speed. The slope variance was not significant in this model. However, the fit statistics (CFI=.910, TLI=910, RMSEA=.117, SRMR=.137) suggesting that the linear model was a poor fit to the data. This was evident in the graph of the empirical and model- estimated means presented in figure 4.2.

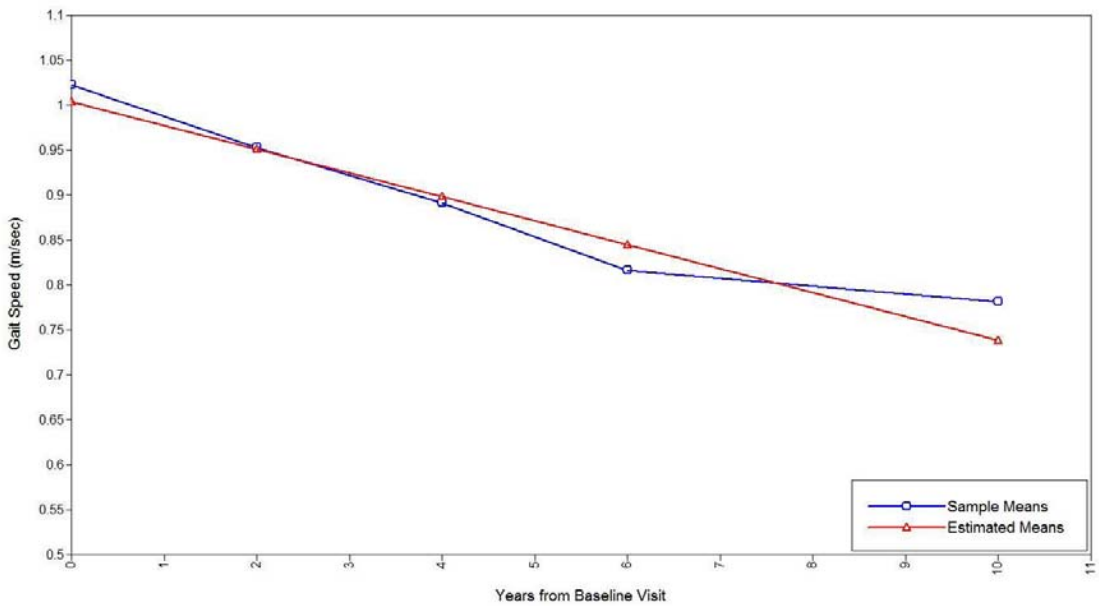


*Figure 4.2.*Empirical and model-estimated trajectories of mean gait speed: Linear model

It was apparent from the empirical gait speed trajectory that a non-linear model would be a better fit to the data. When a quadratic model was fit to the data, the fit improved substantially, though the fit statistics indicated that the fit could be improved further (CFI=.963, TLI=938, RMSEA=.097, SRMR=.067). Figure 4.3 depicts the empirical and model-estimated means for the quadratic model.

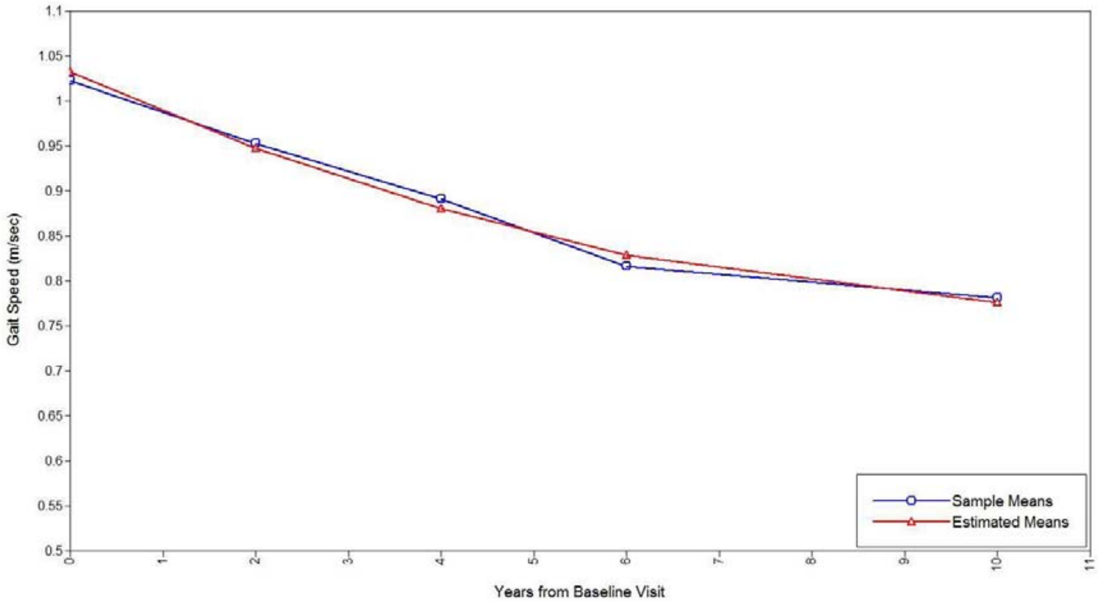


Figure 4.3 .Empirical and model-estimated trajectories of mean gait speed: Quadratic model

Next, a latent basis model was fit to the data (figure 4.4), allowing the time scores between visits one and six to be freely estimated. The fit of this model was acceptable (CFI=.978, TLI=969, RMSEA=.069, SRMR=.095) and was further improved (CFI=.994, TLI=979, RMSEA=.057, SRMR=.037) by specifying that residual variance at adjacent visits was correlated. This specification of the residual structure for gait speed was used in subsequent models. Figure 44 depicts the empirical and model-estimated means for the latent basis model.

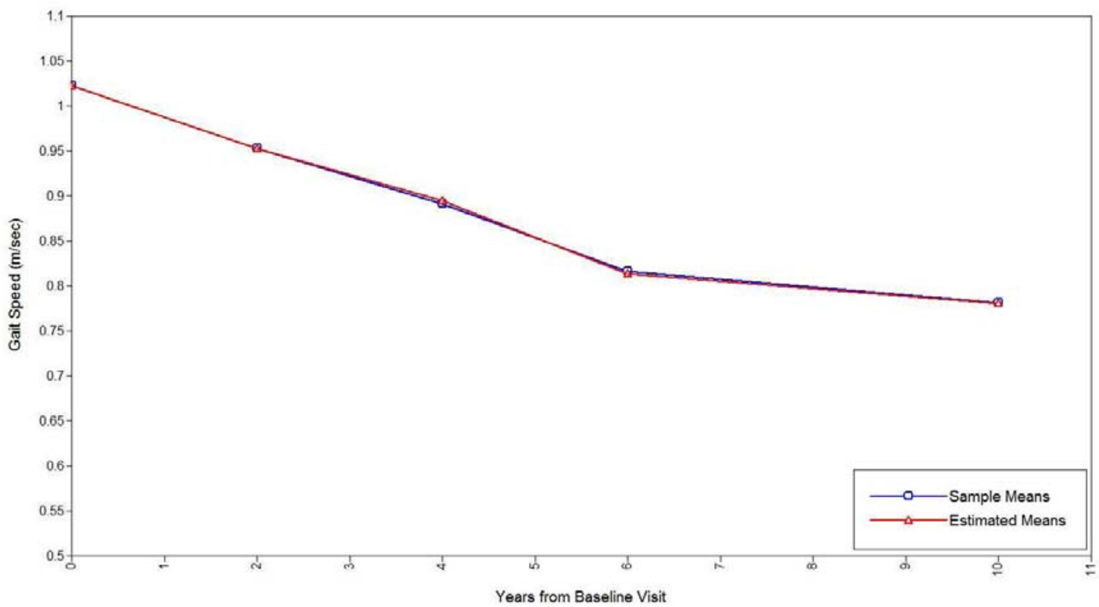


Figure 4.4. Empirical and model-estimated trajectories of mean gait speed: Latent basis model with correlated residuals.

The shape of the trajectory was somewhat puzzling, given that declines in function have previously been found to accelerate with advancing age (Beckett et al., 1996). However, fitting an unconditional pattern-mixture model to the data revealed differences in the trajectory of gait speed by time of attrition. Parameter estimates stratified by time of attrition are given in Table 4.10.

Table 4.10

Unadjusted, Latent-Basis, Pattern-Mixture Model of Gait Speed (m/sec) Stratified by Time of Attrition, SOF Neighborhood Study, 1986 -1998

		Intercept	Slope
Attrition point	N	b (SE)	b (SE)
Complete	589	1.084 (.009)**	-.248 (.009)**
Visit six	246	1.013 (.014)**	-.278 (.017)**
Visit four	164	.989 (.019)**	-.364 (.040)**
Visit three	105	.906 (.025)**	-.267 (.076)**
Visit two	152	.908 (.020)**	-.267 (.076)**
Cross-mixture average		1.021 (.007)**	-.273 (.018)**

Note: Model estimated with correlated residuals and neighboring case restriction.
*$p < .05$, **$p < .001$

Those participants who dropped out of the study had slower baseline gait speed and a steeper trajectory of decline compared with those who completed the study. This is graphically represented in Figure 4.5, which presents the model estimated trajectories for each dropout class using the neighboring case restriction

Examining the average parameter estimates across the attrition classes, we see that the slope estimate from the pattern-mixture model with neighboring case restriction indicated a steeper decline in gait speed over time, though the difference was rather small and over a ten-year period equated to roughly a .04 difference. The across-class slope estimate from the pattern-mixture model with a complete case identifying restriction (b=- .270) was essentially equal to that from the model with neighboring case restriction. Consequently, only estimates from the model with the neighboring case restriction are presented. A linear graph comparing the FIML estimated trajectory to the trajectory estimated from the pattern mixture models is presented in figure 4.6.

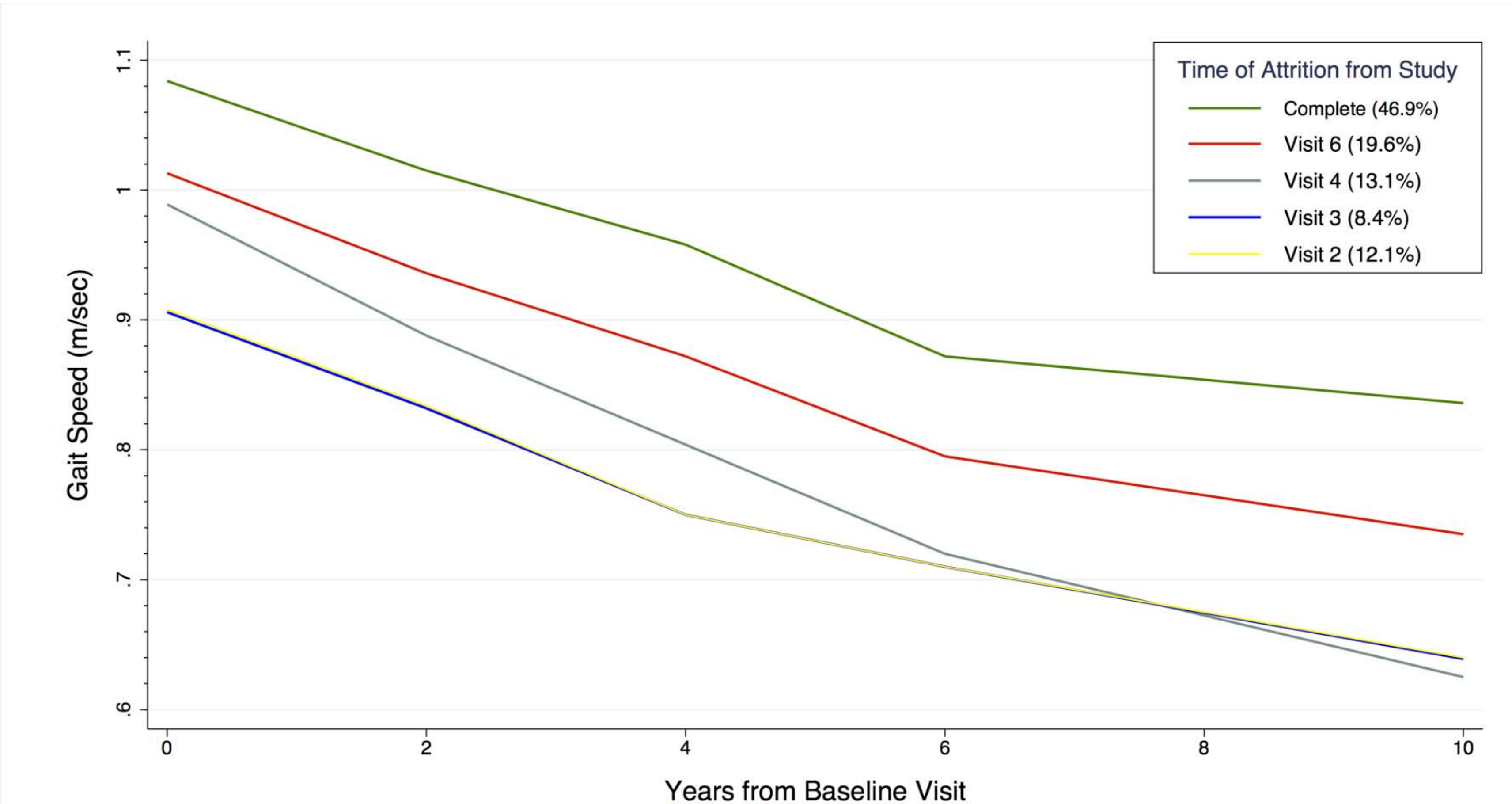


*Figure 4.5.*Model-estimated trajectory of average gait speed by time of attrition. Pattern-mixture model with neighboring case restriction

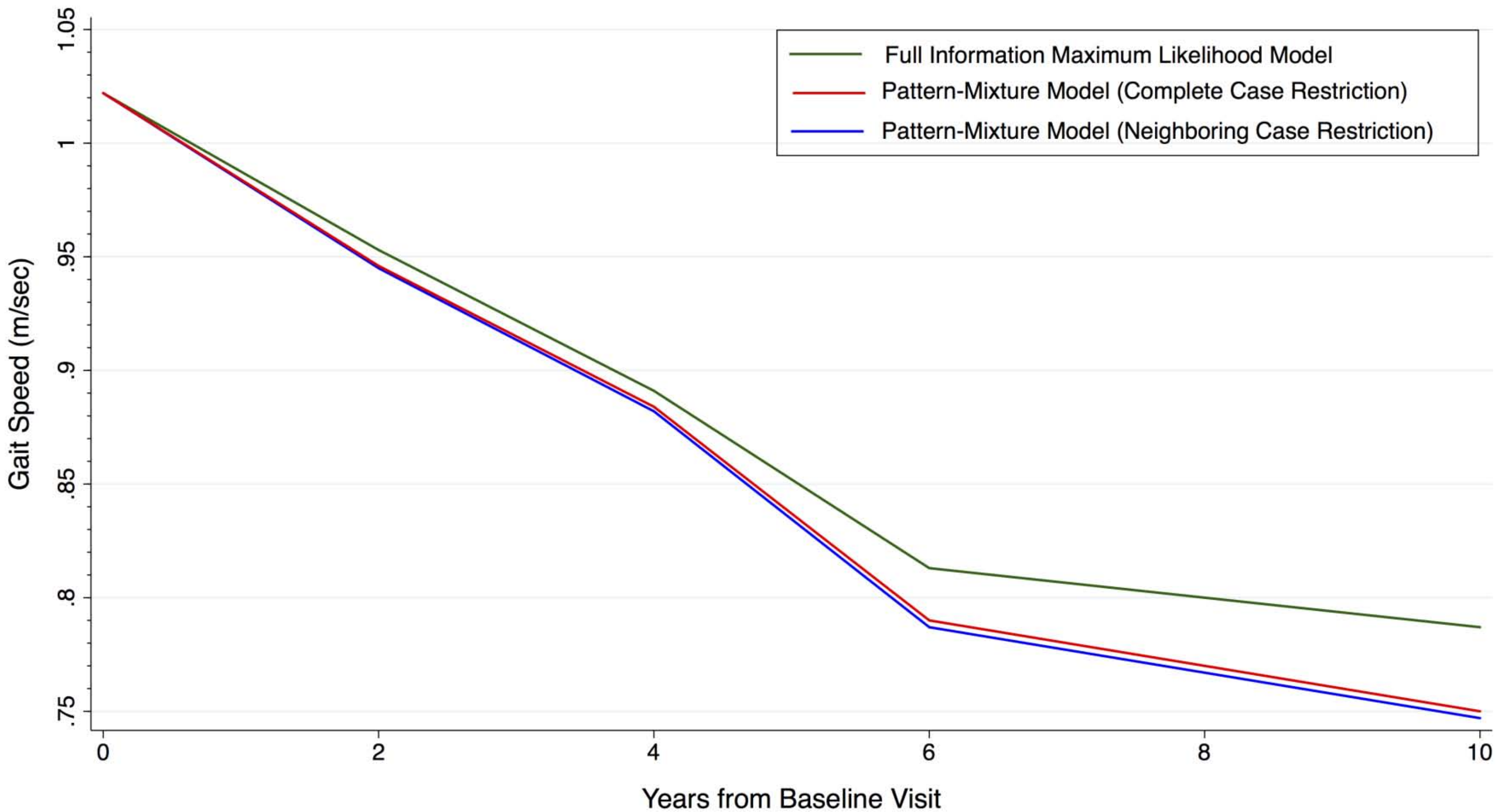


Figure 4.6. Comparison of model-based estimates of average decline in gait speed.

Neighborhood built environment. Figures 4.7 and 4.8 display the trajectories of walkability and distance to park/green space in the neighborhoods of 50 randomly sampled individuals. Figure 4.7 illustrates the substantial variability among participants in the walkability score of their neighborhood at baseline, though there was relatively little change in the slope of walkability over time. Figure 4.8 depicts the variability among participants in their distance to the nearest park or green space, as well as the significant change in that distance over time for a large number of participants. This indicates that there was substantial development of park/green space in the Portland Metro area during the study period.

The parameter estimates and fit statistics for walkability and distance to park/green space are presented in table 4.11. As with gait speed, a linear model was a poor fit to both of the variables. Because there were not enough time points to estimate a quadratic model, a latent basis model was fit to the data and the residual variance was constrained as equal across time points to reduce the number of estimated parameters in the model.

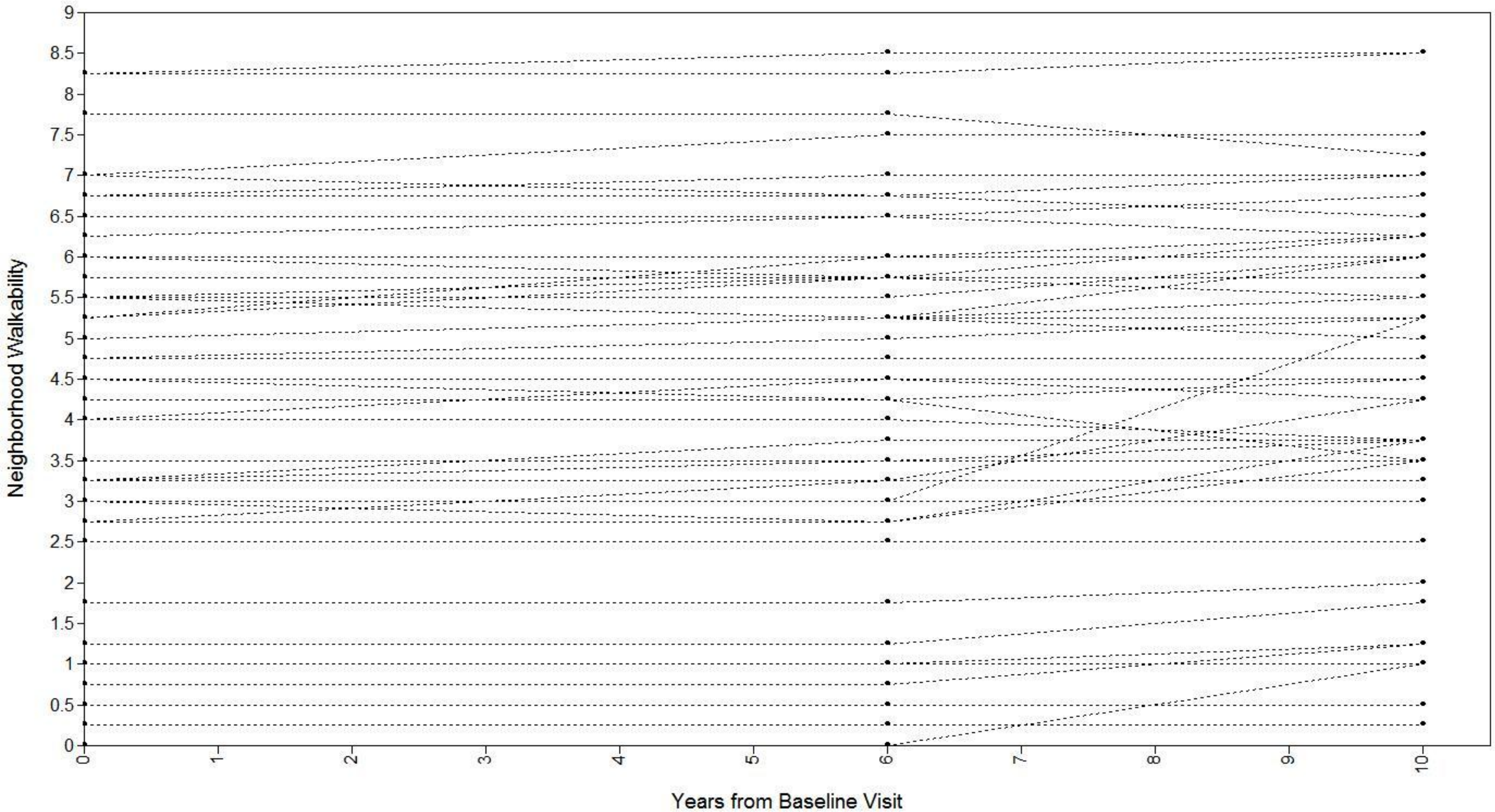


*Figure 4.7.*Change in walkability in the neighborhoods of 50 randomly selected participants

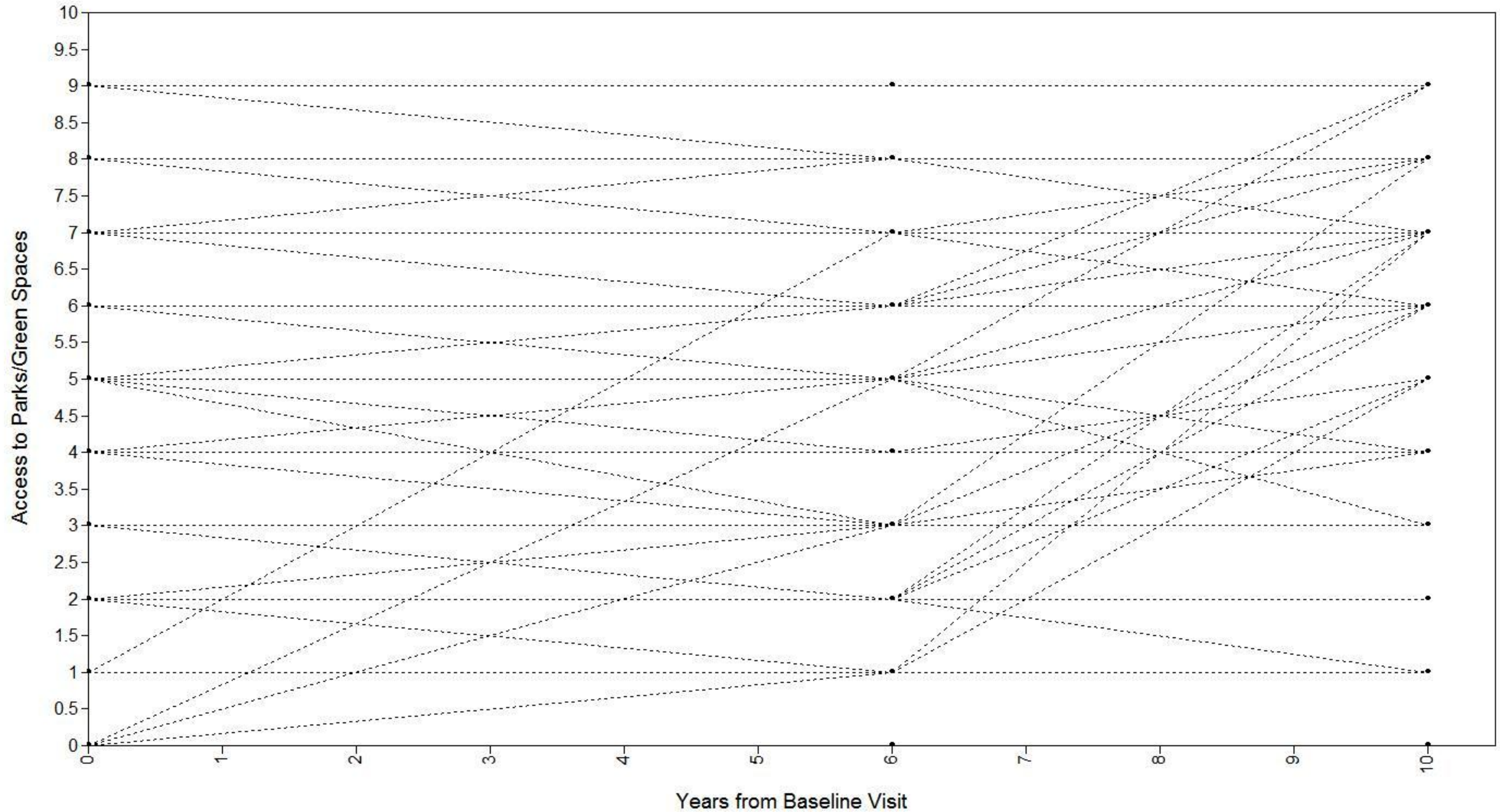


Figure 4.8. Change in distance to park/green space in the neighborhoods of 50 randomly selected participants

In the unconditional latent basis model of neighborhood walkability, the parameter estimates indicate that the walkability score was 4.44 at baseline and increased an average of .23 over the study period. There was a statistically significant negative correlation between the intercept and slope, as we would expect from looking at the comparison of change in low, medium and high walkability neighborhoods that was presented in table 4.7 and the individual trajectories in figure 4.7. Both the intercept and slope variance were significant. The fit statistics were mixed (CFI=.994, TLI=992, RMSEA=.145, SRMR=.012), partially because of the imposed equality constraint, though taken as a whole they suggested adequate model fit. A graph of the empirical and model-estimated means of neighborhood walkability is presented in figure 4.9

In the unconditional latent basis model of distance to park/ green space, the parameter estimates indicate that the walkability score was 4.65 at baseline and increased an average of 1.00 over the study period. As with neighborhood walkability, there was a statistically significant negative correlation between the intercept and slope, indicating that those neighborhoods with the lower access at baseline had greater increases over time. Both the intercept and slope variance were significant. Model fit was excellent (CFI=.999, TLI=.998, RMSEA=.034, SRMR=.009). A graph of the empirical and model-estimated means of neighborhood walkability is presented in Figure 4.10.

Table 4.11

Unconditional Models of Neighborhood Walkability and Distance to Park/Green Space, SOF Neighborhood Study, 1986 -1998

		Walkability		Distance to park/green space	
Model Parameters		Linear	Latent basis	Linear	Latent basis
η_{0y}	Intercept (SE)	4.426 (.062)**	4.444 (.062)**	4.573 (.085)**	4.648 (.082)*
η_{1y}	Slope (SE)	.225 (.015)**	.229 (.016)**	.937 (.061)**	1.000 (.061)*
ψ_{01}	Slope with intercept (SE)	-.155 (.034)**	-.189 (.035)**	-2.397 (.216)	-2.524 (.207)*
ψ_{00}	Intercept variance (SE)	4.804 (.193)**	4.820 (.193)**	7.980 (.364)**	7.763 (.339)*
ψ_{11}	Slope variance (SE)	.216 (.012)**	.267 (.013)**	2.229 (.207)**	2.907 (.204)*
Fit Statistics					
Chi-square		554.490(3)*	54.826(2)**	226.641(3)**	4.975(2)**
CFI		.942	.994	.922	.999
TLI		.942	.992	.922	.998
RMSEA		.383	.145	.244	.034
SRMR		.020	.012	.073	.009

Note: parameter estimates are unstandardized

*$p < .05$, **$p < .001$

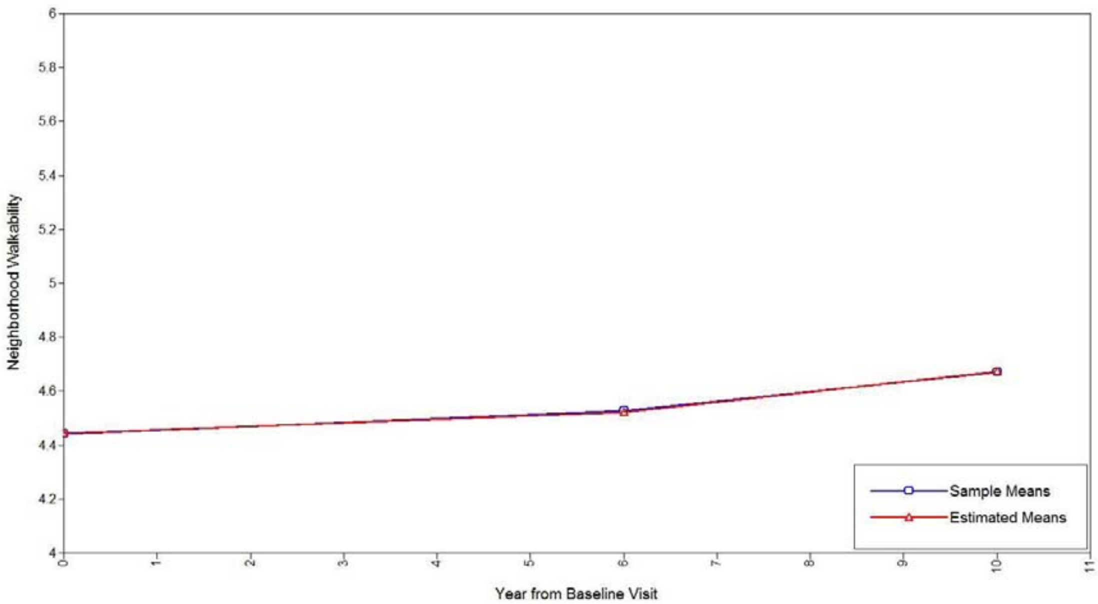


Figure 4.9. Empirical and model-estimated trajectories of average neighborhood walkability score: Latent basis model.

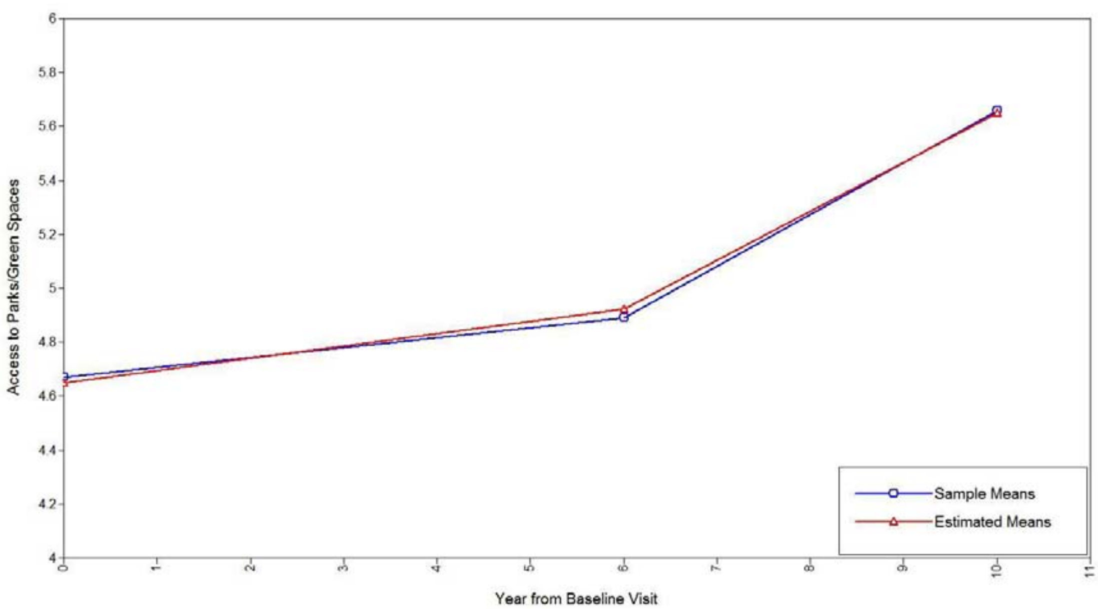


Figure 4.10. Empirical and model-estimated trajectories of average neighborhood distance to park/green space: Latent basis model.

Parallel-Process Latent Growth Curve Models of Gait Speed and Neighborhood Walkability

The results from the unadjusted parallel-process latent growth curve model of the relationship between gait speed and neighborhood walkability is presented in Table 4.12 and the results from the covariate-adjusted model are presented in Table 4.13. A sensitivity analysis was performed by comparing the parameter estimates and associated standard errors from the covariate-adjusted model with FIML estimation, covariate-adjusted pattern-mixture model with neighboring case restriction, and covariate-adjusted pattern-mixture model with complete case restriction. This comparison revealed little difference in the results, indicating that the included covariates contributed sufficient information on the mechanism of attrition to satisfy the MAR assumption. Nevertheless, because the results from the unconditional model of gait speed indicated that the neighboring case restriction was best reflective of the true influence of attrition, the parameter estimates from the pattern-mixture model with neighboring case restriction are displayed in the path diagram and presented in the text as the final results. The path diagram of the covariate adjusted model is displayed in Figure 4.11. Statistically significant regression paths are bolded.

The fit of the covariate-adjusted model was excellent (CFI=.994, TLI=.990, RMSEA=.037, SRMR=.033). Age, educational attainment, and complex comorbidity were all significantly associated with the baseline gait speed value. These associations were in the expected direction. Increased age was significantly associated with slower baseline gait speed ($b=-.009$, $p<.001$). After controlling for the other variables in the model, women with two or more comorbid conditions had a baseline reduction in gait speed of .055 m/sec ($p<.001$) compared to women with less than two comorbid conditions. Conversely, higher educational attainment was associated with faster gait speed at baseline ($b=.035$, $p<.001$). Of the individual-level covariates included in the model, only age was significantly associated with the magnitude of decline over time ($b=-.003$, $p=.029$) Neighborhood SES was not significantly associated with the baseline gait speed value but was negatively associated with the degree of change in gait speed over time ($b=.003$, $p=.046$). The results of the regressions of the gait speed growth factors on the neighborhood walkability factors are presented below in the context of the study aims.

Specific aim 1: Describe the relationship between baseline neighborhood walkability and baseline lower-extremity function among older women. There was no association between the intercept of gait speed and the intercept of neighborhood walkability in either the unadjusted or covariate-adjusted models. Neighborhood walkability was not associated with baseline gait speed after controlling for age, education, complex comorbidity, incident fractures, and neighborhood socioeconomic status.

Specific aim 2: Describe the relationship between baseline neighborhood walkability and change in lower-extremity function among older women.

In the unadjusted model, there was a significant negative association between the intercept of neighborhood walkability and the slope of gait speed ($b=-.007$, $p=.003$), indicating that living in a more walkable neighborhood at baseline was associated with a steeper rate of decline in gait speed over time. This association was in the opposite direction from that hypothesized. However, this association was not significant in the covariate-adjusted model. Therefore, after controlling for age, education, complex comorbidity, incident fractures, and neighborhood socioeconomic status, baseline neighborhood walkability was not associated with the rate of decline in gait speed among study participants.

Specific aim 3: Describe the relationship between change in neighborhood walkability and change in lower-extremity function among older women.

In the unadjusted model, the slope of neighborhood walkability was positively associated with the slope of gait speed (b=.018, p=.024). This association remained significant in the covariate-adjusted model (b=.024, p=.020). Therefore, after controlling for age, education, complex comorbidity, incident fractures, and neighborhood socioeconomic status, participants residing in a neighborhood that became more walkable over time had a reduced rate of decline in gait speed. A one decile increase in walkability over the study period was associated with a .024 m/sec reduction in the overall rate of decline over the study period.

Table 4.12

Unadjusted, Parallel-Process Model of Gait Speed and Neighborhood Walkability, SOF Neighborhood Study, 1986 -1998

	Maximum likelihood model		Pattern-mixture model (Neighboring case restriction)	
Regression parameters	Gait speed intercept b (SE)	Gait speed slope b (SE)	Gait speed intercept b (SE)	Gait speed slope b (SE)
Walkability intercept	-.005 (.003)	-.006 (.003)*	-.003 (.003)	-.007 (.003)*
Walkability slope	NA	.018 (.011)*	NA	.018 (.010)*
Model Fit: CFI=.995, TLI=.992, RMSEA=.053, SRMR=.026				

Note: parameter estimates are unstandardized

*$p < .05$, **$p < .001$

Table 4.13
Covariate Adjusted, Parallel-Process Model of Gait Speed and Neighborhood Walkability, SOF Neighborhood Study, 1986 -1998

	Maximum likelihood model		Pattern-mixture model (Neighboring case restriction)	
Gait speed parameters				
η_{0y}	1.022		1.021	
η_{1y}	-.246		-.275	
ψ_{01}	-.016		-.013	
Regression parameters	Gait speed intercept b (SE)	Gait speed slope b (SE)	Gait speed intercept b (SE)	Gait speed slope b (SE)
Walkability intercept	-.001 (.003)	-.004 (.003)	-.001 (.002)	-.004 (.003)
Walkability slope	NA	.023 (.010)*	NA	.023 (.010)*
Age	-.012 (.001)**	-.003 (.001)*	-.009 (.001)**	-.003 (.002)*
Education	.039 (.008)**	-.004 (.009)	.035 (.008)**	-.003 (.009)
Comorbidity	-.052 (.014)**	-.016 (.015)	-.055 (.014)**	-.012 (.015)
Incident fracture	NA	-.005 (.012)	NA	-.004 (.012)
Neighborhood SES	0.00 (.001)	.003 (.001)*	0.00 (.001)	.003 (.001)*
Model Fit: CFI=.994, TLI=.990, RMSEA=.037, SRMR=.033				

Note: parameter estimates are unstandardized
**p* < .05, ***p* < .001

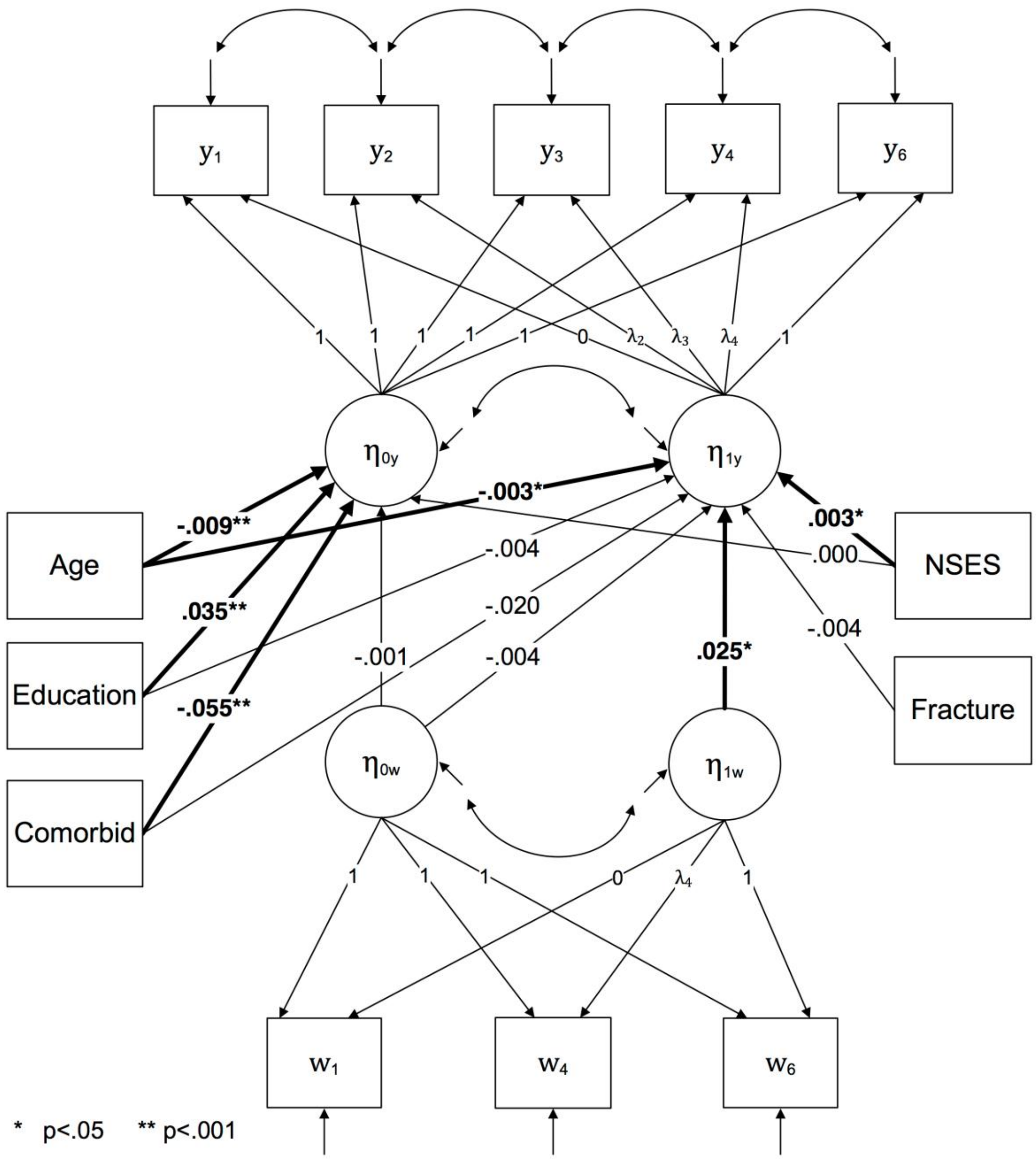


Figure 4.11. Path diagram of covariate adjusted, parallel-process model of gait speed and neighborhood walkability.

Parallel-Process Latent Growth Curve Models of Gait Speed and Distance to Park/Green Space

The results from the unadjusted parallel-process latent growth curve model of the relationship between gait speed and distance to park/green space is presented in Table 4.14 and the results from the covariate-adjusted model are presented in Table 4.15. Model fit was excellent (CFI=.996, TLI=.993, RMSEA=.021, SRMR=.034).Similar to the model of gait speed and neighborhood walkability, there was little difference in the parameter estimates and standard errors between the FIML and pattern-mixture models with neighboring case and complete case identifying restrictions. As above, the results of the pattern-mixture model with a neighboring case restriction are reported in Table 4.14 and displayed in the path diagram in Figure 4.12. Statistically significant regression paths are bolded. The results of these models are presented below in the context of the study aims.

The patterns of association observed between the covariates and the growth factors for gait speed in this model are virtually identical to those from the model of gait speed and neighborhood walkability. Age, educational attainment, and comorbidity were all significantly associated with the baseline gait speed value. Of those, only age was associated with the magnitude of decline over time. Neighborhood SES was not associated with the baseline gait speed value but was negatively associated with the degree of change in gait speed over time.

Specific aim 4: Describe the relationship between baseline distance to neighborhood parks/green spaces and baseline lower-extremity function among older women. There was no association between the intercept of gait speed and the intercept of distance to park/green space in either the unadjusted or covariate-adjusted models. After controlling for age, education, complex comorbidity, incident fractures, and neighborhood socioeconomic status, distance to park/green space was not associated with differences in baseline gait speed among the study participants.

Specific aim 5: Describe the relationship between baseline distance to neighborhood parks/green spaces and change in lower-extremity function among older women. There was no association between the intercept of gait speed and the slope of distance to park/green space in either the unadjusted or covariate-adjusted models. After controlling for age, education, complex comorbidity, incident fractures, and neighborhood socioeconomic status, distance to park/green space was not associated with the rate of gait speed decline during the study period.

Specific aim 6: Describe the relationship between change in the distance to neighborhood parks/green spaces and change in lower-extremity function among older women. There was no association between the slope of gait speed and the slope of distance to park/green space in either the unadjusted or covariate-adjusted models. After controlling for age, education, complex comorbidity, incident fractures, and neighborhood socioeconomic status, change in the distance the park/green space was not associated with the rate of gait speed decline during the study period.

Table 4.14

Unadjusted, Parallel-Process Model of Gait Speed and Distance to Park/Green Space, SOF Neighborhood Study, 1986 -1998

	Maximum likelihood model		Pattern-mixture model (Neighboring case restriction)	
Regression parameters	Gait speed intercept b (SE)	Gait speed slope b (SE)	Gait speed intercept b (SE)	Gait speed slope b (SE)
Park/Green space intercept	.003 (.002)	-.001 (.003)	.002 (.002)	.000 (.003)
Park/Green space slope	NA	.004 (.005)	NA	.004 (.005)
Model Fit: CFI=.996, TLI=.993, RMSEA=.031, SRMR=.027				

Note: parameter estimates are unstandardized

*p < .05, **p < .001

Table 4.15

Covariate Adjusted, Parallel-Process Model of Gait Speed and Distance to Park/Green Space, SOF Neighborhood Study, 1986 -1998

	Maximum likelihood model		Pattern-mixture model	
Gait Speed Parameters				
η_{0y}	1.022		1.021	
η_{1y}	-.245		-.277	
ψ_{01}	-.015		-.013	
Regression Parameters	intercept, b (SE)	slope, b (SE)	intercept, b (SE)	slope, b (SE)
Park/Green space intercept	.003 (.002)	-.003 (.003)	.002 (.002)	-.002 (.002)
Park/Green space slope	NA	.000 (.005)	NA	.000 (.004)
Age	-.012 (.001)**	-.003 (.001)*	-.010 (.001)**	-.003 (.002)*
Education	.039 (.008)**	-.004 (.009)	.035 (.008)**	-.003 (.009)
Complex comorbidity	-.051 (.014)**	-.019 (.016)	-.054 (.014)**	-.015 (.015)
Incident fracture	NA	-.005 (.012)	NA	-.005 (.012)
Neighborhood SES	.000 (.001)	.003 (.001)*	.000 (.001)	.004 (.001)*
Model Fit: CFI=.996, TLI=.993, RMSEA=.021, SRMR=.034				

Note: parameter estimates are unstandardized.

*$p < .05$, **$p < .001$

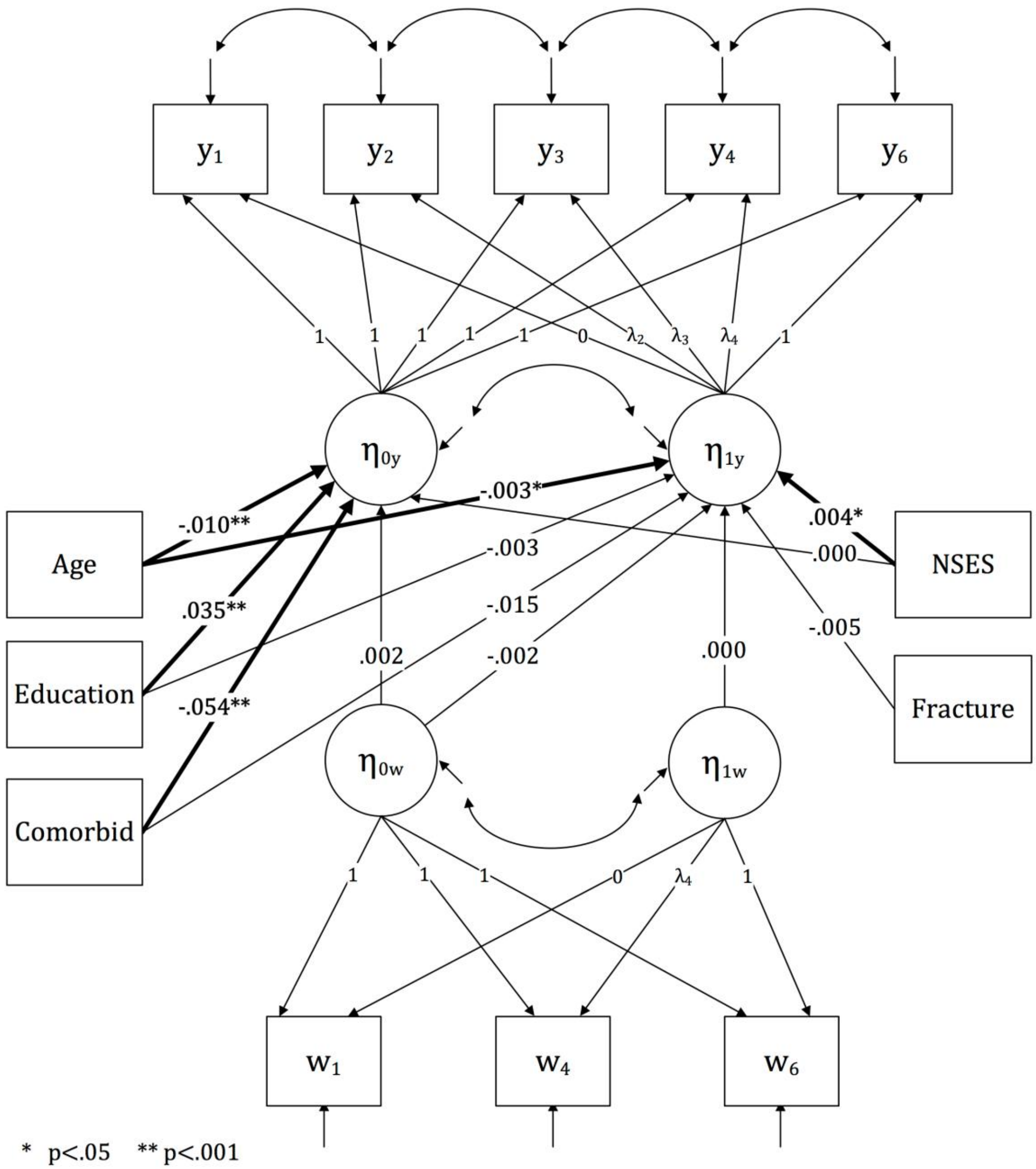


Figure 4.12. Path diagram of covariate adjusted, parallel-process model of gait speed and distance to park/green space.

Chapter 5—Discussion

This study examined the association of neighborhood built environment lower-extremity function among older women in Portland, Oregon over a 12-year period. A parallel-process modeling approach was employed to describe the relationships between the trajectory of neighborhood walkability and the trajectory of gait speed, and the trajectory of neighborhood distance to parks or green spaces and the trajectory of gait speed. The hypothesis underlying the study was that characteristics of the neighborhood built environment demonstrated in previous studies to be associated with physical activity among older adults would have a measurable effect on lower-extremity function, given the well-established relationship between engagement in physical activity and risk of lower-extremity functional decline.

Trajectory of Gait Speed

Few studies have examined long-term trajectories of gait speed decline among older adults. In the Cardiovascular Health Study All Stars Study, gait speed decreased between 0.2 and 0.3 m/sec over a 13 year period (Newman et al., 2009). A similar rate of gait speed decline ($b=-234$, $p<.001$) was observed in this study. In this study, older women had both slower gait speeds at baseline ($b=-.009$, $p<.001$) and an accelerated rate of decline ($p=-.003$, $p<.001$). Educational attainment was found to be predictive of baseline gait speed ($b=.035$, $p<.001$). Women with higher levels of educational attainment had a faster gait speed at baseline after adjustment for age, comorbidity, and neighborhood built environment. However, educational attainment was not associated with the trajectory of gait speed decline over time. The presence of two or more comorbid conditions was associated with a slower gait speed at baseline ($b=-.055$, $p<.001$), but not with the rate of gait speed decline over time. These findings are congruent with previous studies which have examined the individual-level determinants of functional decline (Chaudhry et al., 2010; Inzitari et al., 2006; Murray et al., 2011; Nusselder et al., 2005).

This study was the first to employ a pattern-mixture modeling approach to stratify gait speed trajectory by time of attrition. This approach revealed that participants who dropped out of the study had lower baseline gait speed and steeper trajectories of decline than those participants who completed the study. This observation is best explained by the established association between gait speed and future morbidity and mortality, particularly in light of the high proportion of mortality related attrition from the study. Although the covariate-adjusted models with FIML estimation do appear to have been robust to the attrition related missingess in this study, the observation of attrition-related differences in gait speed serves as a cautionary example of the need to closely examine missing data mechanisms in longitudinal studies.

Change in Neighborhood Built Environment

The univariate, latent growth model of neighborhood walkability revealed that, although there was a statistically significant increase in walkability over time, the magnitude of that change was empirically fairly small. Over a 10-year period, the average increase in walkability score was .229 ($p<.001$). This indicates that most participants were in the same decile of walkability at the end of the study that they were in at baseline. Given the emphasis in Portland on pedestrian-friendly urban planning during this time period, this was a somewhat surprising finding, although the observation that the greatest change occurred in areas with low walkability suggests that urban planning efforts to improve walkability targeted less walkable neighborhoods. Nevertheless, there was only a modest level of improvement in the lowest quartile of neighborhood walkability (mean=3.2, SD=.070). One possible explanation is that the neighborhood measures available for this study did not adequately capture the pedestrian-friendly improvements in the built environment that were made during the study period. In contrast to the modest degree of change observed in neighborhood walkability, there was both substantial overall change and between-neighborhood variability in the measure of distance to park/green space. The degree to which this reflected true change in the distribution of parks and green spaces in the Portland area during the study period, or whether it was related to measurement error is unclear, though as previously mentioned the data were checked for accuracy by the analysts in the mapping department at Metro.

Baseline Neighborhood Walkability and Trajectory of Gait Speed

This study did not find a significant association between baseline neighborhood walkability and baseline gait speed. There was a significant association between baseline neighborhood walkability and change in gait speed over time, though this association was in the opposite direction from that hypothesized. However, this association was not significant in the model adjusted for age, educational attainment, complex comorbidity, incident fracture, and neighborhood SES. These findings differ somewhat from those of previous studies which reported select neighborhood characteristics to be significantly associated with functional limitation and disability risk among older adults, although there are also notable similarities with previous studies as well. For example, Beard et al. (2009) reported that a census-tract measure of “street characteristics”, consisting of intersection density, density of street trees, and bus stop distance, was associated with disability prevalence, although a composite measure of land-use mix was not. In findings similar to this study, Freedman et al. (2008) found that a census-tract level measure of street connectivity was not associated with risk of functional limitation among women aged 55 years and older. Previous studies also found no association between functional decline and self-reported access to public transport (Balfour et al., 2002), or between ADL disability and nearness of likely walking destinations (Bowling et al., 2007). As noted in Chapter Two, differences in study design and the measurement of neighborhood characteristics and outcome measures limits the degree to which the findings of this study can be compared to results from previous studies, particularly those which examined micro-scale design features such as sidewalk condition or variables such as adequate street lighting, perceived crime, and noise. Given the substantial differences in measurement of neighborhood characteristics between previous studies and this one, the findings of this study may be attributable to its relatively narrow focus on objectively measured neighborhood built environment or to differences in the scale of the measures employed in this study relative to previous studies. Of the prior studies examining the relationship between neighborhood built environment and functional decline, the most similar in design and measurement to this study was that of Michael et al. (2011). Notably, that study also found no association between baseline gait speed or change in gait speed and baseline measures of street connectivity. They did find that lower connectivity was associated with steeper decline lower extremity function as measured by chair stand time, though connectivity was not associated with baseline differences in lower-extremity function.

The lack of a significant relationship between baseline neighborhood environment and the trajectory of gait speed observed in this study should first be examined in the context of the inconsistent findings regarding the association of the built environment to physical activity. The potential association between neighborhood built environment and lower-extremity function tested in this study was hypothesized to be mediated by physical activity. However, while the general consensus is that the built environment is related to physical activity, there is no clear consensus on precisely which characteristics of the built environment are most influential for older adults (Rosso et al., 2011; Van Cauwenberg et al., 2011; Wendel-Vos, Droomers, Kremers, Brug, & van Lenthe, 2007). Furthermore, evidence from a number of studies suggests that there are significant gender, race, and socioeconomic differences in the influence of specific neighborhood characteristics on physical activity (Casagrande, Whitt-Glover, Lancaster, Odoms-Young, & Gary, 2009; Hooker, Wilson, Griffin, & Ainsworth, 2005; Michael et al., 2010; Zenk et al., 2009). Thus, given the relative homogeneity of the sample in this study, it is possible that there was a mismatch between the neighborhood characteristics which influence physical activity among this population and those that were measured in the study

Another possibility is that the underlying hypothesized mechanism was present, but the effect of the built environment on physical activity was not sufficient to result in downstream functional benefit. Recently, a similar pattern of findings has been emerging in regards to the association of the built environment to body mass index, where a growing number of studies have failed to find consistent significant associations between the walkability of the built environment and body mass index (BMI). A recent systematic review of the literature by Feng, Glass, Curriero, Stewart, and Schwartz (2010) found that over half of the studies examining the relationship between GIS measures of the built environment and BMI reported a non-significant association. Interestingly, some studies that have simultaneously examined levels of physical activity and BMI have reported that characteristics of the built environment were significantly associated with walking but not associated with BMI. For example, Berke et al. (2007) in a cross-sectional study of 986 older adults, found that a GIS-based composite walkability measure was significantly associated with more blocks walked for exercise, but that it was not associated with participant’s BMI.

This lack of consistent findings regarding the effects of the built environment on physical activity related health and functional outcomes may result from the small effect sizes generally observed in the studies of neighborhood influences on physical activity. This raises an important question, one that is directly relevant to this study of neighborhood built environment and function. If neighborhood built environment is a determinant of physical activity, is the effect large enough to produce measurable and, more importantly, clinically meaningful changes in health and function? In regards to lower-extremity function, this study suggests that it is not, particularly given that there was no observed effect of baseline neighborhood environment on change in gait speed over time. The effect of baseline neighborhood walkability on baseline gait speed is analogous to a cross-sectional analysis, and small differences in function may not be apparent at a single point in time. However, the cumulative impact of even small effects should be more apparent in a longitudinal analysis, so the absence of an observable effect on the trajectory of functional decline over a ten-year period is compelling.

In regards to neighborhood SES, this study did not find baseline neighborhood SES to be significantly associated with baseline gait speed. There was, however, a significant relationship between baseline neighborhood SES and the trajectory of gait speed decline. Women who lived in a neighborhood with higher baseline SES had a reduced rate of decline in gait speed over time, after controlling for age, educational attainment, comorbidity, and neighborhood walkability. While the parameter estimate of this change was fairly small (B=.003), the estimated difference between women living in the top and bottom deciles of neighborhood SES is .09, which is a clinically meaningful difference (Kwon et al., 2009). The pattern of association observed between neighborhood SES and gait speed observed in this study may be an example of a small effect not appearing significant on cross-sectional analysis but having a significant effect over time.

Trajectory of Gait Speed and Change in Neighborhood Walkability

In contrast to the null findings for the relationship between baseline neighborhood walkability and the trajectory of gait speed, this study did find a significant relationship between the slope of neighborhood walkability and the slope of gait speed (B=.024, p= .025). The parameter estimate indicates that women who lived in a neighborhood where walkability improved over time had a reduced rate of gait speed decline. After adjusting for age, educational attainment, comorbidity, neighborhood SES, and incident fracture, a one decile increase in neighborhood walkability during the study period was associated with a .024 reduction in the decline of gait speed over 12-years. A .05 m/sec change in gait speed is regarded as clinically meaningful (Perera et al., 2006), indicating that a two decile increase in neighborhood walkability over the study period was associated with a clinically meaningful reduction in the magnitude of decline by year 10.

That change in gait speed over time was associated with change in neighborhood walkability over time but not with baseline level of walkability is puzzling, though it is a finding that can be understood in the context of the theory of environmental press. As discussed in Chapter 2, the relationship between personal competence and environmental press is generally held in equilibrium. In other words, individuals achieve a level of adaptation to their environment. With advancing age and reduced personal competence, this equilibrium grows increasingly unstable, resulting in impaired function if environmental pressures remain constant (Lawton, 1985). However, the presence of environmental buoys can, in Glass's addition to Lawton's theory, buffer the effects of declining competence and reduce the sequelae of functional impairment (Glass & Balfour, 2003). From this perspective, the value of neighborhood walkability was not in its theoretical influence on activity behavior but as a measure of the general accessibility of neighborhood resources. With declining competence and the resulting restriction in life-space, those women whose environments provided greater access to local resources may have been able to maintain a higher level of function, as reflected in a slower decline in gait speed (Xue, Fried, Glass, Laffan, & Chaves, 2008). Simply put, some women lived in neighborhoods that grew more accessible as they grew less competent; their neighborhoods changed to meet them at their level of competence. Because of this buffering effect, these women experienced a slower rate of functional decline. This potential effect could be distinct from the hypothesized effect of physical activity mediating the relationship between neighborhood walkability and trajectory of gait speed, which would explain the observed pattern of associations. Several recent cohort studies, for example, have found that gait speed and life-space diameter are significantly correlated among older adults, and that life-space constriction is associated with increased risk of cognitive impairment (Crowe et al., 2008; James, Boyle, Buchman, Barnes, and Bennett, 2011) and mortality (Boyle, Buchman, Barnes, James, & Bennett, 2010) after controlling for physical activity level. The findings of this study are also congruent with those of Clarke and George (2005), who reported that built environment was not associated with the risk of disability among older adults without functional limitation, but did serve to moderate, or buffer, the relationship between lower-extremity functional decline and disability among older adults with existing functional impairment.

Trajectory of Gait Speed and Distance to Park/Green Space

No previous study has examined the relationship of distance to parks/green spaces and trajectory of lower-extremity function. This study found no significant associations between neighborhood distance to parks/green space and trajectory of gait speed. Neither the degree of distance to park/green space at baseline or change in access over time was related to gait speed in models adjusted for age, educational attainment, comorbidity, incident fracture, and neighborhood SES. In light of the pattern of associations observed between neighborhood walkability and gait speed, this is not surprising. These findings indicate that either there was no relationship between neighborhood distance to park/green space and physical activity, or that this effect was so small that it did not have measurable downstream effects on functional ability. In regards to the significant association observed between change in neighborhood walkability and change in gait speed over time, it is likely that increasing distance to park/green space would not serve to mitigate the effects of declining competence in the same fashion.

Limitations

There were several limitations of this study that warrant discussion. In regards to the neighborhood-level data, differences in the data sources used to construct the historical neighborhood measures at each time point introduced a potential source of measurement error. Of particular concern was the variability observed in the measure of distance to the nearest park or green space, if it resulted from changes in the manner in which park/green space were defined in the RLIS at each time point rather than actual change in neighborhood distance to park/green space. However, because the definition of park/green space at any given time point would have been the same across the study area, any potential misclassification would likely have been non-differential and not resulted in bias. Further, the data were subject to a quality control procedure at Portland METRO to ensure that any error was detected and erroneous measurements corrected. The measurement of the distance-based built environment variables was conducted by calculating the Euclidian distance, which has been shown to underestimate the actual distance traveled across the street network (Oliver et al., 2007). A preferable approach is to calculate the network distance, as discussed in Chapter 3. However, this is a labor-intensive, computationally demanding procedure and was not feasible for this study given the large sample size and measurements at multiple time points. Another important limitation is that the built environment variables employed in the current study were fairly macro-level urban design characteristics. Previous studies have found that characteristics such as perceived safety, sidewalk condition, and the presence of adequate street lighting are associated with increased risk of functional impairment (Balfour et al., 2002; Clark et al, 2009; Clarke & George, 2005; Schootman et al., 2006) and it is plausible that these features of the neighborhood built environment are more important determinants of lower-extremity function than those measured in this study. Lastly, Portland has a long history of progressive urban planning, which resulted in less variation in many of the measures than one would expect to see in other urban areas. As a result, this study was unable to describe the changes in gait speed that may occur across a wider range of neighborhood exposures, and this may help explain the lack of association between baseline neighborhood characteristics and trajectory of gait speed.

There were several limitations related to participant data as well. The most significant limitation was the exclusion of women who moved during the study period, a decision which was made to address both theoretical and methodological concerns with retaining them in the sample. Theoretically, the decision to exclude them was in order to have a neighborhood exposure measure that reflected the changes that were naturally occurring in participants' neighborhoods during this period of pedestrian-friendly development in Portland. Excluding those women who moved resulted in trajectories of neighborhood change that were, excluding potential measurement error, accurate representations of the changes in neighborhood walkability and distance to park/green space that occurred in participants neighborhoods. Methodologically, the trajectories of neighborhood change for participants who moved would potentially exhibit a degree of non-linearity that would make the parallel-process models inestimable. However, the exclusion of women who moved introduced the possibility of selection bias, which was assessed for by comparing the gait speed, neighborhood built environment, health and demographic characteristics of non-movers and movers. As noted in Chapter Four, women who moved were in significantly poorer heath and had slower baseline gait speed than women who did not move, although empirically these differences were small. However, there was no significant difference in either neighborhood walkability or distance to parks/green spaces between movers and non-movers, indicating that the exclusion of women who moved did not result in differential bias (Szklo & Nieto, 2007). Another limitation was that the sample was racially and ethnically homogenous, limiting the degree to which these findings can be generalized to more diverse populations. Similarly, given that Freedman et al. (2008) observed the effects of neighborhood built environment to differ among older men and older women, the findings from this study should not be generalized to older men. The lack of control for the length of time the participants lived in their residents prior to the study period was a limitation because the duration of their exposure to the neighborhood characteristics measured during the study is unclear. This would have the greatest impact on the measurement of the relationship between baseline neighborhood characteristics and baseline gait speed, though the potential direction or magnitude of any potential bias resulting from prior unmeasured neighborhood exposure is difficult to ascertain. Lastly, there were no data available on participants' income, which, as previously noted, is an important determinant of functional decline among older adults. Findings from previous studies suggest that low income is positively correlated with measures of neighborhood walkability. Given the hypothesized inverse relationship between neighborhood walkability and functional decline, a direct association of low income with both living in a more walkable neighborhood and greater functional decline among participants would result in negative confounding, leading to an underestimation of the true strength of the effect of built environment on gait speed (Szklo & Nieto). However, the statistical models were adjusted for educational attainment and neighborhood socioeconomic status, which likely reduced the degree of residual confounding related to differences in individual income. Overall, while substantial efforts were taken to minimize potential bias and ensure validity, the results of this study should nevertheless be interpreted cautiously in light of the methodological limitations discussed above.

Strengths

This study had several notable strengths. First, it is the first study to examine concurrent change in the neighborhood built environment and change in function among older adults. It utilized a novel approach to modeling the relationships between these two processes by merging historical neighborhood data with individual-level data from a large cohort study. It employed GIS-based, objective measures of the built environment centered on each participant's residence, rather than aggregate census-level data or other proxy measures of the built environment. Further, it employed a reliable, performance-based measure of lower-extremity function. The twelve-year study period was of a sufficient duration to measure the proposed relationships, and the sample size was adequate for the analysis. Lastly, the use of a parallel-process growth curve modeling approach was appropriate for the aims of the study and the adjustment for MNAR attrition adjusted for a potential source of significant bias.

Summary and Implications

This study examined the relationship between characteristics of the neighborhood built environment and the trajectory of lower-extremity function among older women in Portland, Oregon. It was notable in being the first study to describe the relationship between change in neighborhood built environment and change in lower-extremity function, and thus took a step toward addressing the question of whether community efforts to promote pedestrian-friendly environments for older adults will result in downstream health benefit. This study found that neither baseline gait speed nor change in gait speed over time were associated with baseline neighborhood built environment. However, this study did find that change in neighborhood walkability over time was associated with the degree of change in gait speed over time. Women who lived in neighborhoods that became more walkable over the 12 year study period (i.e. increased access to public transit, more diverse land-use mix, and greater street connectivity) had a reduced rate of gait speed decline. This is an intriguing finding, for it suggests that these improvements in neighborhood design may have buffered the effects of declining competence, facilitating continued engagement in usual activities and, as a result, slowing the progression of functional decline. However, these findings must be regarded cautiously, given both the methodological limitations discussed above and the dearth of previous research in this area. Future research must address several key areas raised by this study. First, no study has examined whether change in neighborhood built environment results in increased physical activity among older adults. Answering this question is an important step in understanding the relationship of neighborhood built environment to health and functional outcomes. Second, it is unclear whether the relationship between neighborhood built environment and physical activity, observed in previous cross-sectional studies, is of sufficient magnitude to result in significant effects on health. The relationship between neighborhood built environment, physical activity, and downstream health effects among older adults should be addressed by future longitudinal studies, which must examine this question among diverse populations while adjusting for confounders identified in previous studies. Third, there is a strong theoretical basis for hypothesizing a relationship between micro-scale features of the neighborhood built environment and functional health among older adults. A promising approach for future studies would be to design natural experiments in order to observe the health and functional benefit resulting from improvement of neighborhood micro-scale built environment features. Lastly, future studies should explore the relationship of neighborhood built environment to life-space constriction among older adults, and how this may impact the development of disability independent of previously hypothesized mechanisms related to physical activity promotion.

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