Location or Design? Association between Neighborhood Location, Built Environment, Preference toward Neighborhood and Behaviors

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ABSTRACT

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(Under the direction of Daniel A. Rodríguez)

Understanding how the built environment on a neighborhood scale is associated with individuals' physical activity or walking has been a common research objective in urban planning and public health.

Although prior studies have shown evidence supporting the notion that specific attributes of a neighborhood are associated with individuals' walking or physical activity, very few studies have controlled for the impact of a neighborhood's regional location. Because regional location and neighborhood built environment attributes are likely to be correlated, previous associations are likely to be biased.

In contrast to existing literature, my thesis is based on the assumption that a neighborhood's location may be associated with walking or physical activity and that this association may be separately identifiable from the influence of the neighborhood built environment on behaviors.

The findings indicated that (1) the neighborhood built environment and neighborhood location had a strong association, even after controlling for potential confounding effects of socio-demographic factors; (2) a neighborhood's location was

associated with walking and transportation-purpose physical activity when the neighborhood built environment and individuals' socio-demographic factors were controlled; (3) walking for commuting purposes was more strongly associated with neighborhood location than the built environment, whereas walking for shopping-eating purposes had a stronger association with the neighborhood built environment, and finally, (4) the association between neighborhood location and walking became more manifest when residents' preference for neighborhood type accorded with their actual residential locations.

From a practical perspective, my thesis suggests that, without the provision of better public transportation service to suburban neighborhoods, walkable neighborhood development in suburbs may not be as successful as planners expect. A policy for relocating pro-urban residents in suburbs to the city needs to include sociologists and community-based participatory approaches along with interventions for the built environment.

From a research perspective, when one is examining the association between urban form and behaviors, the locational characteristics of a neighborhood need to be considered separately from the neighborhood built environment. In future studies, activity-based and purpose-specific research designs may be desirable.

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I. INTRODUCTION

Walking and outdoor activity have long been a subject of interest in the field of urban planning. Walking and outdoor movement are important, because these activities are the key elements linking urban space and society (Hillier & Netto, 2002). More walking implies a higher probability of social encounter. Intentional social interaction and spontaneously “bumping into” neighbors are believed to enhance a sense of trust and connection between people and the places where they live (Leyden, 2003). From a social perspective, places to shop, learn, and play are local spaces for socializing (Grant, 2006). Thus, outdoor pedestrian activity is considered to be an instrumental part of street life that enhances social interaction, perceptions of home territory, and comfort in people's daily lives (Appleyard, 1981; Sourthworth & Ben-Joseph, 1997; Bosselmann et al., 1999).

Attempts to link urban space and social interaction have proliferated because of the efforts of New Urbanists. New Urbanists believe that an attractive built environment can create conditions to enhance a sense of place and facilitate social interaction (Grant, 2006). Although they are commonly criticized for not considering social and political structures that may affect the characteristics of urban form, New Urbanists contribute to the normative theory of urban form and suggest practical strategies for achieving strong communities. The principles of good urban form include pedestrian-friendly street design; interconnected street grid networks; mixed-use zones within neighborhoods; mixed types of housing; more buildings; residences, shops, and services closer together for ease of walking; and human-scale architecture. For New Urbanists, walking and outdoor activities connect neighborhood design and social interaction.

In the field of public health, walking and physical activity can play a key role in the growing concerns over the high prevalence of inactivity, obesity, and associated chronic diseases. Walking and specific forms of physical activity are kinds of ‘‘bodily movement … produced by the contraction of skeletal muscle … that substantially increase energy expenditure” (Hoehner et al., 2003). An increasing body of research suggests that significant health benefits can be achieved through regular physical activity, such as walking (Frank and Engelke, 2001). Thus, the key question is how to encourage walking and physical activity. One approach is to modify the built environment to increase the population’s physical activity, thereby addressing one of the root causes of obesity (Handy et al., 2002). Walkable community design becomes the common goal of both urban planning and public health.

Indeed, public health researchers often understand the relationship between walking and social relationship differently from New Urbanists. While New Urbanists see walking as an important behavioral pattern for enhancing social cohesion and interaction, public health researchers believe that tight social relationships within the community are one of the main causes to increase walking by providing better access to resources, enforcing social norms for positive health behaviors, and providing tangible supports (McNeill et al., 2006). Notwithstanding some inconsistencies in understanding the causal relationship between social relationships and walking, the principles of healthy urban form are remarkably similar to those of New Urbanism. The principles of healthy urban form include walkable neighborhoods, variety within the neighborhood, sense of place, transit support, connectivity, safety, and conservation (Liptay, 2009), which are exactly the same virtues emphasized by New Urbanists.

The similarity with respect to the practical strategies to encourage walking and outdoor activity implies that proposed principles of healthy urban form may face challenges common to the New Urbanist approach. One of the major criticisms against New Urbanism is its scale of interest. At the scale of street design within neighborhoods, higher densities and mixed uses may offer many advantages to reduce automobile travels and encourage walking. However, the benefits of New Urbanist street patterns for the reduction of automobile commuting can be overwhelmed if the New Urbanist communities are just islands in a "sea of freeway-oriented suburbs" (Cervero & Gorham, 1995). Moreover, with 10% vacancy in commercial properties in the United States, adding retail supply to all new developments clearly exceeds demand (Bohl, 2002). Retail is concentrated in specific areas in the region and may replaces sales elsewhere (Grant, 2006). Once destinations (jobs and retail) are external to the community, transit services are needed to link New Urbanist communities with nearby areas so that inhabitants have an alternative to automobile travel. However, New Urbanist communities are hardly dense enough to justify frequent transit service (Gordon & Richardson, 1998). Thus, regional approaches to land-use and transportation planning will be required to fully reap the advantages of New Urbanist designs (Ellis, 2002).

In examining the association between an individual's behavior and urban form, I propose to distinguish the characteristics of the neighborhood environment from the location of the neighborhood in a region. Perhaps this approach assembles one of the most long-standing epistemological views in defining urban form as a combination of *property* and *position*.

> Place is a part of space which a body takes up and is, according to the space, either absolute or relative…Positions have no quantity; nor are they so much the places themselves as the properties of places…the place of the whole is the same as the sum of the places of the parts, and for that reason it is internal and in the whole body. (Newton, 1687)

These words, written by Isaac Newton more than three centuries ago, still provide insight into urban form. From this perspective on urban form, a *place* is a small-scale space, and the sum of places is a large-scale space—the whole city. A *property* of urban form is defined by attributes of physical elements of the city. A *position* indicates a relative location that a physical element occupies with respect to the whole city. A *position* is a zero-dimensional feature and does not have any attributes. The density of a development, the width of a street, or the land-use mixture of a neighborhood are the *properties* of the development, street, or neighborhood. Meanwhile street hierarchy or a suburban neighborhood is defined by relative locations of the development, street or neighborhood with respect to the whole body of the city or street network.

The relationship between *property* and *position* has been the principal subject of urban form theories. Bid-rent theory (Alonso, 1964) refers to how price and demand for urban lands change as distance from the Central Business District (CBD) decreases. The theory of the polycentric city (Griffith, 1981) explains that the traditional principles in the relation between density and distance from CBD change as the city transforms into a polycentric structure. Transect theory (Duany and Talen, 2002) emphasizes a proper combination of built environment characteristics and context.

Property and *position* usually refer to clearly distinguishable qualities of urban form. However, as they are strongly associated in urban space, we often define an urban phenomenon or a physical element of urban form in a manner that refers to both qualities simultaneously. One definition of *urban sprawl* is a low-density development spreading on the outskirts of a city (What is Sprawl? SprawlCity.org). 'Low-density' is a *property* of development, while 'outskirts of a city' is a *position* of the development. Similarly, the term *arterial road* refers to a multi-lane, high-capacity road that lacks direct residential entrances. 'Multi-lane' and 'high-capacity' are *properties* of a road, while limited access to and from residential areas is characterized by the configural connectivity and hierarchy of the road network, which relate to *position*.

As *property* and *position* frequently indicate a single phenomenon of urban form, many studies on the association between neighborhood environments and behaviors have considered only *properties* of urban form and neglected *positions*. Often, these studies have defined the spatial scope of a neighborhood in terms of walkable distances from a residence and have examined the association between walking or types of physical activity and built environment characteristics observable within neighborhood boundaries. Attempts to identify the relationship between neighborhood positions with respect to the whole body of a city are rare.

Perhaps one of the reasons for neglecting neighborhood positions is a belief that non-motorized activities are more heavily influenced by the characteristics of the neighborhood built environment, while motorized travel is more strongly associated with characteristics defined on a regional scale (Handy et al., 2002). Therefore, conducting research on a neighborhood scale has become the dominant approach in this area of study (Saelens and Handy, 2008).

Although neighborhood-scale studies have found meaningful relationships between behaviors and neighborhood *properties*, they have not accounted for a neighborhood environment's situation within a continuous and hierarchical urban structure, which may have an independent effect on behaviors. Space syntax theory (Hiller, 1984) defines an axial space, which is often interchangeably used with street space, and derives an integration measure for each axial space. In practical terms, integration of a street segment is determined by the number of turns to be made in traveling from the street segment to all other street segments in the network. The theory suggests that, even when one does not consider any *properties* of the street segment such as width or sidewalk condition, walking flows within the street network can be successfully predicted by analyzing spatial configurations—that is, the *positional* character of the street.

Given that myriad links have been hypothesized between environmental exposures and behaviors, it is worthwhile to clarify the scope of my study within a socio-ecological framework. Schulz and Northridge (2004) proposed linkages between macro, meso, and micro phenomena that affect individual and population health. Although the framework shown in Figure 1.1 has been developed in an effort to understand the implications of social inequalities and the interplay of social processes with features of the physical environment in terms of health outcomes, it is useful in elucidating multiple pathways through which the built environment may affect individual behavior and health. In the framework, political, economic, and legal processes and the unequal distribution of material resources are included as fundamental factors. These factors may influence both the built environment and the social context through the spatial concentration of poverty and wealth (Northridge et al., 2003). The built environment and social context are intermediate factors in pathways that eventually influence health and well-being. Proximate factors are observable behavioral characteristics at the personal level or social relationships at the interpersonal level.

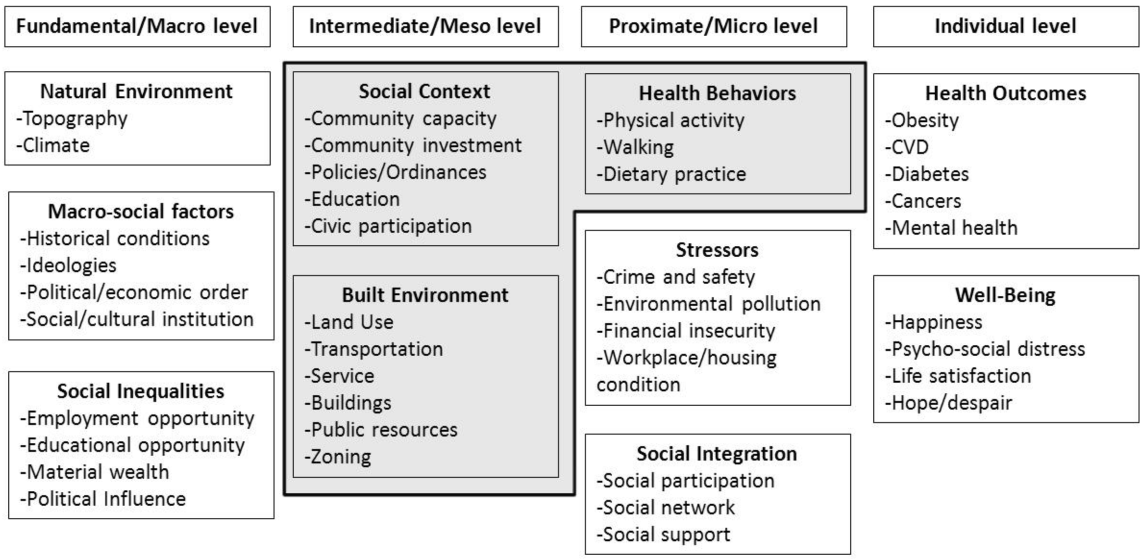


FIGURE 1.1 Socio-ecological frameworks for determinants of health and environmental health promotion, from Schulz and Northridge (2004)

The proposed ecological framework is too broad to be investigated adequately within the confines of a single thesis. Therefore, in this study, I focus on the relationship between intermediate and proximate factors (i.e., the shaded area in Figure 1.1), which concerns the linkage between the familiar territory of the urban planner and the familiar territory of the public health practitioner (Northridge et al., 2003). One of the innovative aspects of this study is its dichotomous approach to understanding urban form. The neighborhood built environment represents physical attributes of individuals' residential surroundings. Policy and planning for enhancing the walkability of streets and the connectivity of the street network, increasing the spatial mixture between residential and non-residential uses, and encouraging New Urbanist-type development may affect the characteristics of the built environment on a neighborhood scale. The relationship between each neighborhood (a partial space) and the metropolitan area to which it belongs (the whole space) can be identified in terms of the positional characteristics of the neighborhood in its region. Policy and planning to support development within and near existing communities, limit the expansion of the development footprint in the region, and provide better public transit service to suburbs may alter the positional characteristics of a neighborhood in a region and individuals' travel patterns. The importance of the positional characteristics of a neighborhood on a regional scale to behavioral patterns has been addressed in multiple contexts within urban planning and transportation studies (Handy, 1993; Handy et al., 2002; Northridge et al., 2003; Næss, 2005).

However, there have been few attempts to investigate empirically the influence of a neighborhood's relative location on individuals' behavior compared to the influence of the built environment. The framework I propose (Figure 1.2) emphasizes the interplay of a neighborhood's relative location with the neighborhood built environment. Hypothetically, the neighborhood built environment and neighborhood location are associated with each other. By considering both the location of the neighborhood and the built environment in explaining individuals' behavioral patterns, I intend to reveal the true associations among neighborhood location, neighborhood design, and behaviors. Accounting for the potential influence of self-selection, individuals' preferences for physical attributes of neighborhoods are considered at the same time.

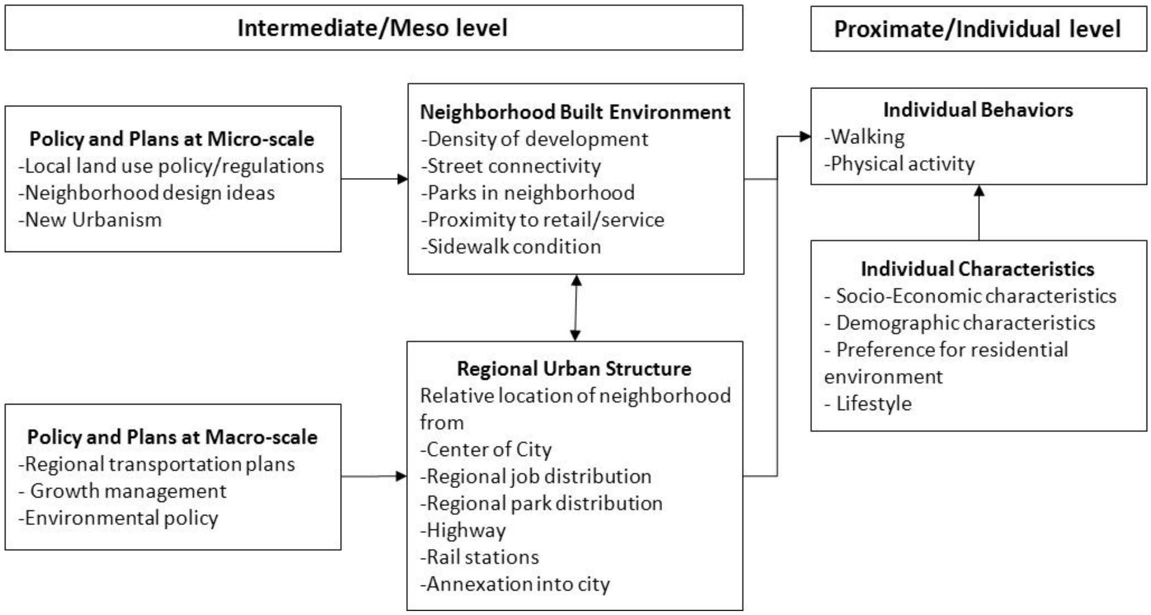


FIGURE 1.2 Hypothesized relationships among planning, urban form, and individual behaviors

The overarching purposes of my thesis are to (a) appropriately define neighborhood location in a region, (b) distinguish the influence of neighborhood location on individuals' behavior from the influence of the built environment, and (c) articulate practical implications for urban and regional planning efforts to encourage walking and physical activity. To pursue these purposes, this dissertation presents an introductory paper and three interrelated papers. The introductory paper (Chapter II) contains an ecological analysis of the relationship between neighborhood built environments and neighborhood locations, including their correlates among socio-economic factors. The first paper (Chapter III) examines how associations between built environments and behaviors change when neighborhood location is considered simultaneously. The second paper (Chapter IV) compares associations of neighborhood location and the built environment with the purpose of walking trips. The third paper (Chapter V) examines how preferred neighborhood environment and actual residential location are associated with residents’ behaviors.

The principal geographic areas examined within this study are Montgomery County, Maryland, and the Twin Cities, Minnesota. Although I adopt a quantitative and analytical approach in investigating individual research questions, it is worthwhile to outline the general contexts and urgent planning issues of the two study sites in order to make the implications of my study for planning explicit.

In Montgomery County, Maryland, there has been rapid growth over the last several decades. Between 1960 and 2008, the population of the county increased from 340,928 to 946,100. Over the same period, the number of jobs increased from 73,870 to 503,822. Accordingly, new development has rapidly consumed developable lands in the county. Today, only 4 percent of the county’s land area (approximately 14,000 acres) remains vacant and developable. The population of Montgomery County is expected to grow steadily with an increase of 195,000 residents anticipated by 2030, for a growth rate of 21 percent. This amount of growth would be roughly the same as that which occurred over the previous 20 years. Given the constraint represented by developable land area, the current pattern of development cannot be sustained to accommodate the expected growth in population and jobs.

This situation in Montgomery County has introduced the need for a new planning strategy for future development. Intensifying the development capacity of underdeveloped areas is necessary. A practical question to be answered concerns where growth should be directed. Under current growth policy in Montgomery County, three types of lands are to be developed in the near future: 14,000 acres of vacant land, 8,000 acres of surface parking, and 10,500 acres of growth area (Figure 1.3). Among 30,500 acres of developable lands in Montgomery County, which should have priority?

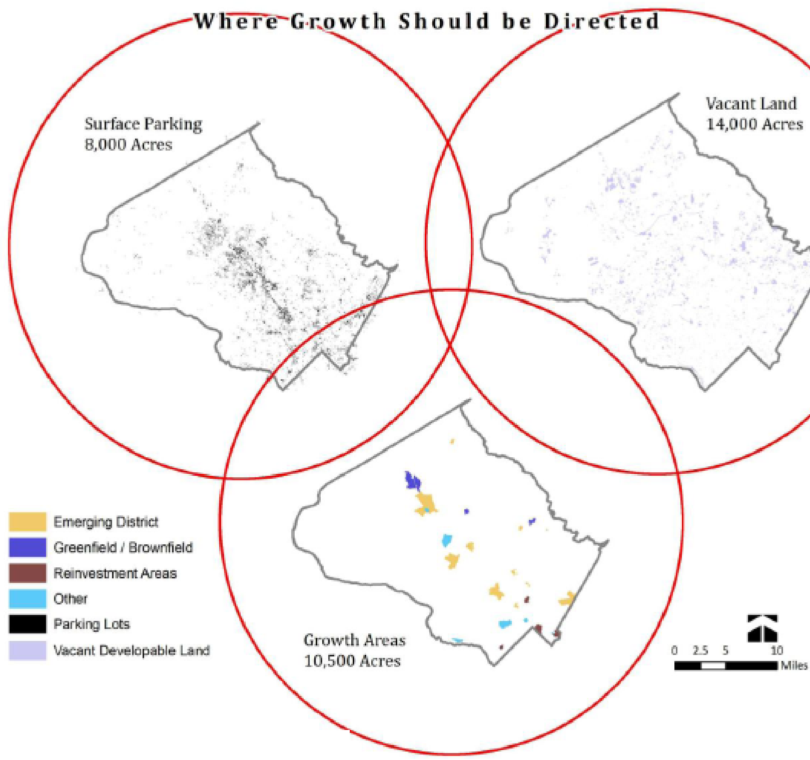


FIGURE 1.3 Developable lands in Montgomery County (from 2009-2011 Growth Policy, Montgomery County Planning Department)

Development priorities may be based on the effectiveness of the proposed development in achieving planning goals. In principle, planning goals to be attained as a result of new development are reducing vehicle miles of travel (VMT), increasing walk mode shares, encouraging the use of public transportation, balancing local jobs and housing, and reducing carbon emissions. The attainment of these planning goals may be affected by built environment characteristics on a neighborhood scale. Within the constraints of time and budgets, however, identifying smarter locations and prioritizing new development in the most suitable locations may be even more important planning issues in Montgomery County.

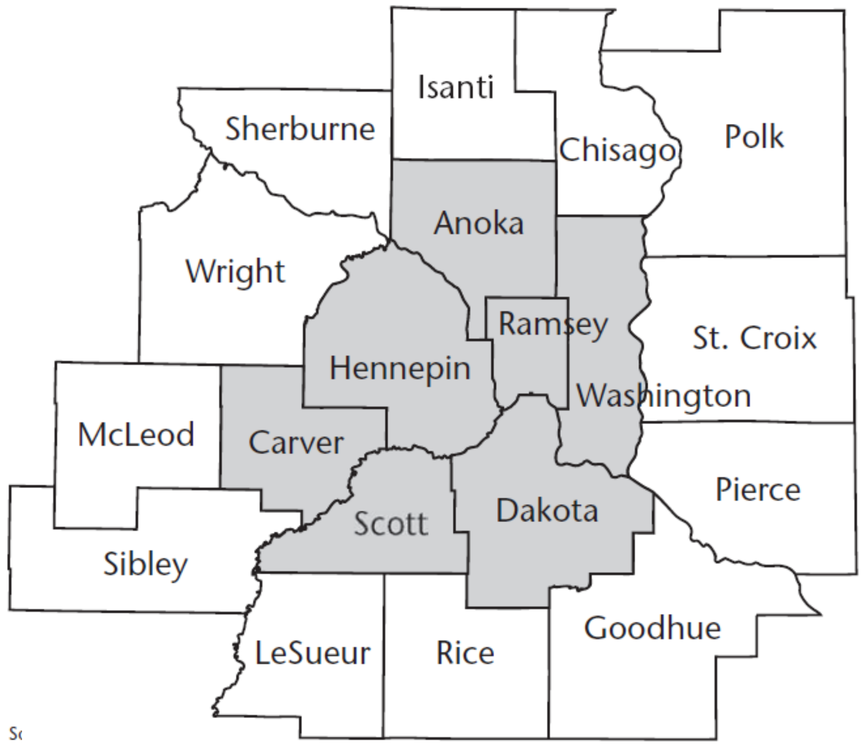


FIGURE 1.4 The seven-county Metropolitan Council jurisdictional area and contiguous counties (source: Twin Cities Metropolitan Council)

The Twin Cities region is among the metropolitan areas that have adopted urban service areas as a tool for growth management, along with Fayetteville in North Carolina; Orange, Sarasota, Citrus, and Seminole Counties in Florida; and Loudon County in Virginia (Woo, 2007), yet it has important, unique features in terms of governmental pluralism (Johnson, 1998). The jurisdiction of the Metropolitan Council covers a seven-county region, while the “real” metropolis includes twelve contiguous counties (Figure 1.4). The social and economic boundaries of the region are vague, and its topography permits suburban sprawl in all directions. Its two central cities (Minneapolis and St. Paul) have historically been rivals for dominance of the region. Since a Metropolitan government was initiated in 1967, every move of the government has generated political debate. Under a strong political tradition of governmental pluralism, planning for the larger metropolitan area has been on less firm ground (Johnson, 1998). The Urban Service Areas (MUSA) are not inherently against urban growth. Most of them have greater financial and political incentives to accommodate growth than to restrict it. Such flexibility in MUSA has been denounced as resulting in the insufficient control of sprawl, but Johnson (1998) points out that rigid policy could bring about political backlash that would doom the entire growth management program.

The Metropolitan Council has forecasted growth of 471,000 households and 966,000 people for the region by 2030, with growth of 563,000 jobs between 2000 and 2030 (Metropolitan Council, 2006). Although the Council may collaborate with local communities to accommodate the expected growth in the region, it is important that the Council hold limited powers to regulate local land-use characteristics. Increasing development density by accommodating attached houses, making viable commercial corridors in downtown, enhancing street connectivity, and providing better maintenance for sidewalks are posited as important planning strategies to encourage walking and reducing vehicle use, as well as reducing the footprint of new development. The fates of those planning interventions, however, depend on the somewhat whimsical policy frameworks of local authorities. At the Metropolitan level, controlling the locations of new development may be one of the few ways to attain coordinated planning goals by influencing the development patterns of localities. For instance, emphasizing reinvestment in developed lands throughout the region may intensify densities and encourage mixed land use of new developments in local areas in an indirect manner.

I have briefly described the context of growth management planning for the two study sites, but it is important to note that the experiences of these two sites are not unique among North American cities. Constraints on the capacity of developable lands to accommodate population and job growth in the near future and limited political powers and appropriate planning tools of the Metropolitan agency to affect physical characteristics of development are issues shared by numerous U.S. cities. Thus, such conditions underscore the role of locational characteristics of development in achieving intended planning goals. In the context of this thesis, the planning goal I am interested in is increasing walking and physical activity. Therefore, I will explore how the locational characteristics of a neighborhood affect the behavioral patterns of residents.

II. Associations between Neighborhood Location, Built Environment and Socio-Demographic Confounders

2.1. INTRODUCTION

Association between the built environment and individual behaviors has become a common research subject in urban planning, public health and transportation disciplines. The basic assumption of studies in this area is that the characteristics of the built environment within walkable distance of a residence affect individual behavior. Accordingly, many researchers have adopted neighborhood-scale approach in explaining travel behavior or physical activity in relation to the built environments (Saelens and Handy, 2008).

Studies examining urban form and its behavioral correlates have neglected the effects of the locational factors of the region or have not defined the neighborhood location in a region separately from a neighborhood's built environment. One of the reasons to disregard locational factors might be based on the belief that automobile trips are more heavily influenced by regional scale environment than the characteristics of the neighborhood, whereas travel behaviors are more heavily influenced by characteristics of the neighborhood than by regional scale environment (Handy et al., 2002).

From an analytical perspective, however, neglecting the neighborhood location becomes reasonable only when the neighborhood built environment has either perfect or no association with the neighborhood locations. If neighborhoods located close to downtown or job centers in the metropolitan areas always have the characteristics of dense, mixed land use and well-connected street networks, the built environment of a neighborhood fully explain the neighborhood location. But studies on urban form (Orfield, 2002; Duany and Talen, 2002; Næss, 2005) consistently addressed that the relationship between neighborhood location and built environment has been weakened by decentralizing activity and restructuring to polycentric urban form. Affluent job centers in suburbs have more than four times the office space per household of other suburbs, more even than central cities (Orfield, 2002). On the other hand, it is equally unrealistic to assume that the neighborhood built environment has no relationship with it's a neighborhood location in a region. The built environment is very likely to have a certain level of, but not perfect, association with location. Therefore, unless we consider the neighborhood location factor separately from a neighborhood's built environment, as well as other confounding factors, we may not come to appropriate conclusions regarding the relationship between urban form and behavior.

As an introductory analysis to this dissertation, this paper intends to emphasize the necessity of considering neighborhood locations in behavioral studies. In particular, two main questions guide the first analysis. First, how is the neighborhood location defined in a reliable way? Second, does a neighborhood's built environment relate to its location? The existence of potential confounding variables, such as income or marital status, makes it difficult to answer the latter question. By comparing the association between socio-demographic characteristics of neighborhoods and the built environment with the association between socio-demographic characteristics of neighborhoods and neighborhood location, this study examines how the relationship between the built environment and neighborhood location changes when potential confounders are considered simultaneously.

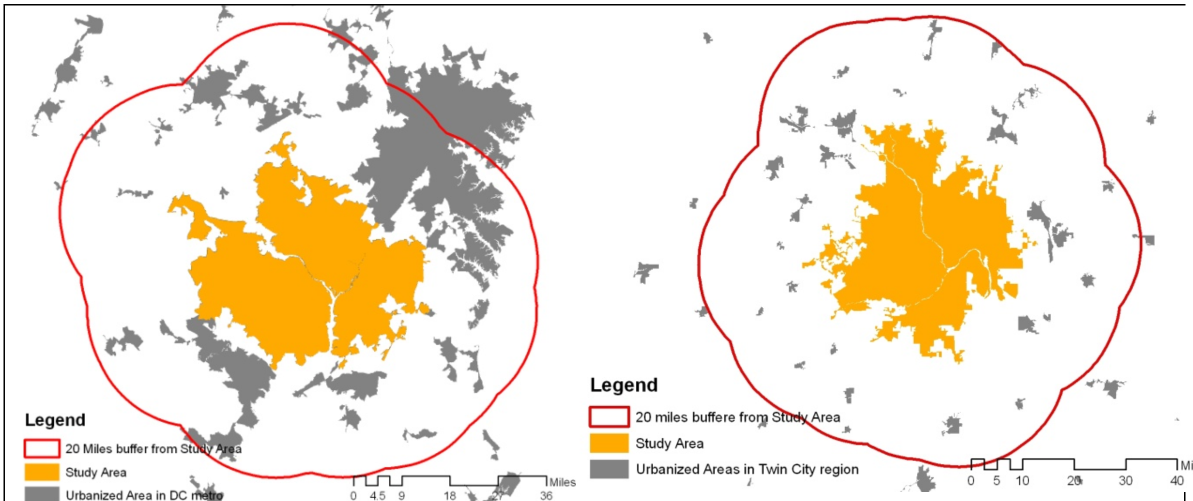
2.2. METHODS

a. Study Areas

This study involves two U.S. metropolitan areas: Washington, DC, and Minneapolis-St. Paul (Twin Cities), Minnesota. As prior research has suggested that policy and environmental characteristics are highly context-dependent, the combination of data from two sites would offer the ability to compare results between sites and enhance the external validity of the findings (Rodriguez et al., 2008). In 2009, the populations of the Washington DC, and Twin Cities regions were approximately 5.5 million and 3.2 million, respectively.

The focused study areas in two metropolitan areas are urbanized areas of DC and the Twin Cities (www.census.gov/geo/www/ua/ua_2k.html). The focused study area in DC region is situated in District of Columbia, two counties in Maryland and six counties in Virginia, while the focused study area in the Twin Cities is located in seven counties in Minnesota. In addition, data from 20 miles from the focused study areas were considered to reduce boundary effects (Figure 2.1).

As a unit of analysis, I used a census block group to represent a neighborhood. In microscopic studies, a block group representation has limitations in identifying continuous variations between administrative demarcations (Guo and Bhat, 2007). However, it seemed the most appropriate representation of a neighborhood in this study, as the spatial scope of the study was much larger than that of a neighborhood. Furthermore, the average sizes of census block groups in DC and the Twin Cities study region were 0.43 and 0.53 square miles, respectively, which corresponded well with the concept of a walkable radius of a quarter- to a half-mile.



(a) Washington, DC | (b) Twin Cities, MN

FIGURE 2.1 Study Areas in Washington and Twin City Metropolitan Areas

Accordingly, 2202 and 1802 census block groups were selected from the focused study areas of DC region and the Twin Cities, respectively. After deleting blocks having zero population, data from 2193 and 1798 census block groups in DC and Twin Cities region were used in the analyses.

b. Variables

Neighborhood Built Environment

I defined the neighborhood built environment as four sub-dimensions (Table 2.1): density, land use mix, street characteristics, and proximity to parks. Two variables, population density and housing unit density, were selected to represent density. Figures on population and number of housing units at the census block group level were derived from the Census 2000 database.

The second sub-dimension, land use mix, is composed of employment density and retail/service job density. Because land use data at the parcel level were not available, I used employment density and retail or service job density as proxy measures of land use mix. These measures imply the relative proximity of residences to retail facilities or services (Cervero and Duncan, 2006). The source of employment data was the Census Transportation Planning Package 2000 (CTPP), Part II. As the geographical unit of the CTPP is the Census-defined Traffic Analysis Zone (TAZ), the boundaries of TAZs and census block groups are not identical. To estimate the number of jobs in each census block group, the area proportions of TAZs situated in each census block group were calculated by intersecting the TAZs with census block groups using ArcGIS 9.2. The apportioned numbers of employees were summed by each census block group.

TABLE 2.1 Neighborhood Built Environment and Neighborhood Location

Dimensions	Variables	Source
Neighborhood Built Environment		
Density	Population density	Census 2000
	Housing unit density	Census 2000
Land Use	Employment density	CTPP 2000/ Census 2000
	Retail/service job density	CTPP 2000/ Census 2000
Street	Road density	Census 2000/TIGER 2009
	Ratio of 3- or 4-way intersections	Census 2000/TIGER 2009
Park	Park density	Tele Atlas North America 2008
Neighborhood Location		
Regional job center	Regional job accessibility	CTPP 2000/Census 2000
	Network distance from downtown	TIGER 2009
Regional transport system	Network distance from rail stations (DC metro only)	Census 2000/TIGER 2009
	Network distance from highway	Census 2000/TIGER 2009
Regional park system	Regional park accessibility	Tele Atlas North America 2008

The third sub-dimension, street, is composed of road density and the ratio of 3- or 4-way nodes to segments; the 2009 Topologically Integrated Geographic Encoding and Referencing (TIGER)/Line shapefiles were used for identifying street patterns. The fourth sub-dimension is the ratio of 3- or 4-way intersections to all intersections, thought to be indicative of more connected street patterns than is a higher ratio of cul-de-sacs.

Finally, park area within each census block group was calculated. The source of park data was the 2008 Tele Atlas North America. Based on Tele Atlas Feature Class Codes (FCC), parklands were identified as national park or forest (D83), state park or forest (D85), or local park or recreation area (D89).

Neighborhood Location

Five measures were used to identify neighborhood location (Table 2.1). First is the distance from main core area of each metropolitan area, which is expected to be associated with the density of the neighborhood and the intensity of development. The main core area in DC Metropolitan area was defined as Dupont Circle metro-station. In Twin Cities, two main core areas were defined; Minneapolis Convention Center in Minneapolis and State Capitol in St. Paul. A shorter network distance to the core area was used. Network analysis in ArcGIS 9.2 was used to calculate network distances from the selected core area to the center of each neighborhood.

The second measure to characterize neighborhood locations is regional job accessibility. The scope of the region for working was defined based on commuting distances. Since more than 80 percent of commuting distances are less than 20 miles (Transportation Statistics Annual Report, 2008) in the United States, all census-defined Traffic Analysis Zones (TAZ) within 20 miles from the focused study areas were used for calculating regional accessibility measures.

Among the various approaches used to measure accessibility, the gravity approach has been widely adopted because it provides the great advantages of being easily understandable, less demanding on data, and able to show spatial variations (Baradaran and Ramjerdi, 2001). However, the gravity approach also has limitations. First, the estimation of accessibility using the gravity approach is largely dependent on the value of the distance decay parameter, but the parameter cannot be determined with empirical data. Second, gravity measures quickly increase to infinity when the distances approach zero because the functional form relies on a negative exponential function.

As an alternative, a Gaussian function, which is widely used in statistics describing normal distributions, was used for calculating regional job accessibility. I used Gaussian distribution as a distance-weight function. The graph of a Gaussian function is a symmetrical bell curve, and the basic functional form of Gaussian distribution is

$$f(x_{ij}) = ae^{-\frac{(x_{ij}-b)^2}{2c^2}}$$

e: Euler's number
a: the height of the curving function
b: the position of the center of the peak
c: the width of the bell
X_{ij}: the distance between census block *i* and *j*

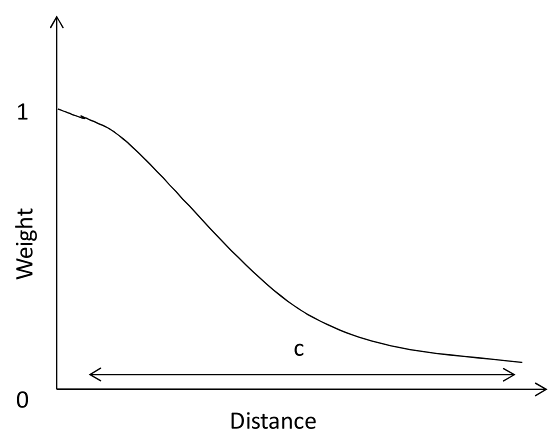


FIGURE 2.2 Gaussian Distribution as a Distance-Weight Function

In calculating job accessibility, the values of *a* and *b* are set to 1 and 0, respectively, and the value of *c* is determined by the standard deviation of distances between census block groups and jobs. Regional job accessibility of census block *i* is the sum of distance-weighted number of jobs within a region. Higher accessibility value indicates better access to jobs in a region. The primary data source that this study used to identify job locations was the Census Transportation Planning Package (CTPP) 2000, Part II, at the TAZ level.

The third and fourth measures are the shortest network distance to a rail station and to a highway ramp. Accessibility of the neighborhood in a region depends largely on the regional transportation infrastructure, because proximity to the regional transportation infrastructure makes it easier to reach various destinations within a short amount of time. A relative location from rail and highway networks is important regional transportation infrastructure to represent the geographic locations of neighborhoods. However, as a commuter rail system has not been operated in the Twin Cities until June 2004, I did not consider the shortest distance to a rail station in the analysis of the Twin Cities. Using network analysis in ArcGIS 9.2, the network distances from the center of each neighborhood to the closest rail station and highway ramp were calculated.

The fifth measure was regional park accessibility. Park and recreational services are essential infrastructure elements in planning (Mertes and Hall, 1995). Our calculation of this measure was based on methods proposed by Mertes and Hall (1995). First, each park was classified as one of four classes based on size: neighborhood park (<20 acres), community park (<50 acres), large urban park (<200 acres), and regional park (>200 acres). The service areas for these classes were ½ mile, 3 miles, 5 miles, and 10 miles, respectively. The LOS of each park was defined as the size of the park divided by the population located within the service area of the park. The regional park accessibility of a neighborhood was defined as the sum of LOS of each park classification.

Regional park accessibility = LOS of neighborhood parks within ½ mile + LOS of community parks within 3 miles + LOS of large urban parks within 5 miles + LOS of regional parks within 10 miles

Socio-economic* and D*emographic variables

The source of dataset was 2005-2009 American Community Survey (ACS) at a census block group, which provided the most recent socio-economic characteristics in the study regions. Among various inter-related socio-economic or demographic variables, I attempted to select variables to enhance the parsimony of data while increasing the variation to be explained. For instance, the level of education was not selected, because, in an exploratory analysis, I found that it was highly associated with household income (γ=0.69). Consequently, I selected five individual confounders: gender, age, marital status, work, and household income. Given the unit of analysis was an aggregated unit as a neighborhood, the variables used in the analytical models were the percentage female, mean age, percentage married, percentage having a job, and mean household income in each census block group.

c. Analytical Methods

Principal Component Analysis (PCA)

To represent the degree of urban location and urban built environment, I conducted principal component analysis (PCA). PCA was used to reduce strongly associated variables into a single factor. Typically, a scale is considered reliable if its Cronbach's alpha is 0.70 or higher, although Nunnally and Bernstein (1994) claimed that values greater than 0.80 are highly desirable.

As I used data from multiple sites and the variables representing neighborhood characteristics were mostly secondary measures, I sought to examine whether the variables at the two sites had a consistent data structure. If they were not consistent, the extracted components in the DC and the Twin Cities study regions might convey substantially different meanings. As I did not consider proximity to a rail station in the Twin Cities, the configural invariance test, which examines whether the same factor structure holds across groups, was not appropriate. Thus, I conducted a separate analysis for each site and then compared the component loadings of the two study sites. Ideally the component loadings should be equal across sites ($\lambda_{D11} = \lambda_{M11}$, $\lambda_{D21} = \lambda_{M21}$, $\lambda_{D41} = \lambda_{M41}$, $\lambda_{D51} = \lambda_{M51}$) (Figure 2.3). Using the estimated component loading on each manifest variable, the component scores of the 4004 census block group were calculated.

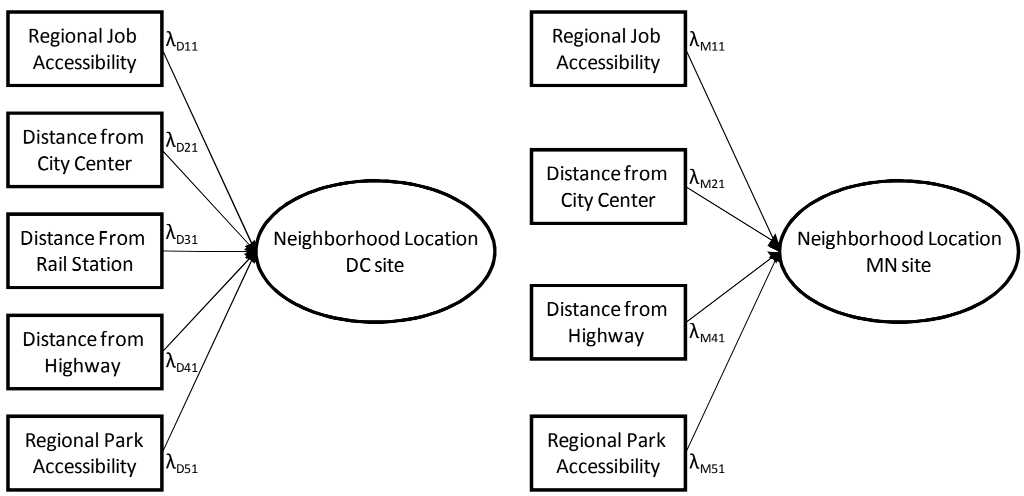


FIGURE 2.3 Principal Component Analysis with Two Groups

Ordinary Least Squares (OLS) Regression

Potential confounding effects of socio-economic or demographic factors make it difficult to understand true intensity of associations between the built environment and neighborhood location. For instance, if household income is positively associated with both the built environment and neighborhood location, associations between the built environment and neighborhood location tend to increase by the mediation effect of household income.

There are no formal statistical methods that one can use to test for confounding effects in a comprehensive manner (Pearl, 1998). Despite this limitation, I used multivariate OLS analyses to control socio-economic or demographic factors by including potential confounders in the models. First, I examined associations between neighborhood location and the built environment. Second, I examined how the association between neighborhood location and the built environment changed when potential confounders were considered in the models. Third, I sought to determine whether the compositional characteristics of highly urbanized built environments were similar to those of highly urbanized neighborhood locations. In other words, I was interested in whether the same group or class of residents was likely to live in both highly urbanized built environments and highly urbanized locations.

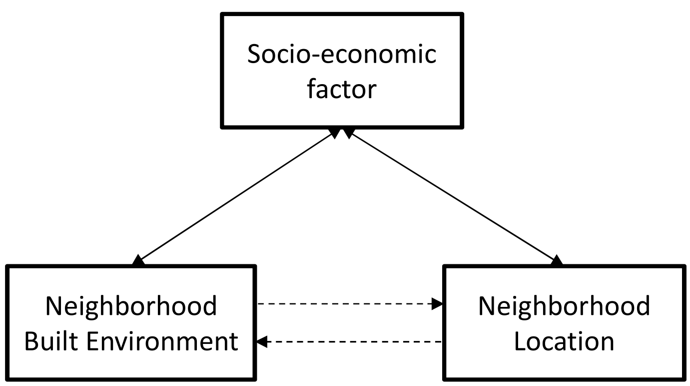


FIGURE 2.4 Potential Confounders in Association between Built Environment and Location

Using the Bayesian information criterion (BIC) and R-squared value, I compared the fits of multiple models. The BIC is a criterion for model selection with different numbers of parameters. By introducing a penalty term for the number of parameters in the model, the BIC solves overfitting problem caused by adding excessive number of parameters. Altogether, I conducted six regression models. The analysis was conducted using STATA 9.2.

2.3. RESULTS

a. Descriptive Statistics

Table 2.2 shows descriptive statistics for socio-demographic characteristics and urban form characteristics of the population in neighborhoods by site. As the two sites were situated in completely different regional contexts, the urban forms at the two sites had slightly different characteristics. On average, neighborhoods in the DC region had higher job accessibility than neighborhoods in the Twin Cities region. This was due to the higher number of total jobs in the DC region, although the DC region was physically larger than the Twin Cities region. With respect to the neighborhood built environment, the neighborhoods in the DC region were relatively dense and mixed in land use. Mean densities of population, household, employment, and retail/service jobs in the DC region were a little higher than in the Twin Cities, whereas streets in the Twin Cities were well-connected compared to the DC region. The socio-economic characteristics of the two sites were very similar, with the exception of mean household income. On average, households in the DC region earned more than households in the Twin Cities region.

TABLE 2.2 Descriptive Statistics for Neighborhoods Location, Built Environment and Socio-Economic Characteristics

		Washington, DC (n=2193)				Twin Cities, MN (n=1798)			
Variable	**Unit**	**Mean**	**S.D.**	**Min**	**Max**	**Mean**	**S.D.**	**Min**	**Max**
Neighborhood Location									
Regional job accessibility	Relative scale	43.2	25.3	2.4	90.9	29.1	15	1.3	52.9
Distance from the main core	miles	11.1	6.4	0.6	34.8	8.7	5.6	0.1	27.4
Distance from rail stations	miles	3.5	3.5	0	26.4	-	-	-	-
Distance from highway	miles	2.6	2.6	0	21.5	1.8	1.9	0	16.2
Regional park accessibility	Relative scale	23.9	15.7	8.2	111.7	28.3	11.7	8.1	93.4
Neighborhood Built Environment									
Population density	Person/acre	13.1	13.6	0.3	120	8.3	6.8	0	58.2
Household density	Unit/acre	5.9	7.3	0	67	3.5	3.4	0	31.8
Employment density	Job/acre	6.6	25.1	0	394.6	4.1	21.3	0	793.3
Retail/service job density	Job/acre	3.8	13.5	0	237.9	2.4	12	0	444.7
Road density	feet/acre	180.2	78.2	21.8	478	177.6	70.8	21	493.4
Ratio of 3/4 way- intersections	%	81.5	13.1	50.7	100	88.1	10.6	50	100
Park Area	Acre	2.2	6.7	0	152.7	2.2	6.9	0	154.4
Socio-Economic Characteristics									
Percentage female	%	51.5	6.8	0.0	86.1	50.8	6.4	8.6	78.3
Mean age	year	38.0	7.6	16.1	84.4	37.0	8.2	11.5	83.6
Percentage married	%	49.1	17.3	0.0	90.0	49.6	16.0	0.0	88.3
Percentage working	%	83.5	9.0	30.1	100.0	85.3	8.8	34.7	100.0
Mean household income	1000 dollars	95.2	47.3	5.9	250.0	65.5	29.4	6.9	246.3

b. Principal Component Analysis

Table 2.3 shows the results of PCA. The first and second columns are component loadings derived from PCA.

The standardized Cronbach's alphas of the location component were 0.880 and 0.870 for the DC and Twin Cities areas, respectively. Those of the built environment component were 0.795 and 0.793 for the DC and Twin Cities areas, respectively—lower than for the neighborhood location component. A higher location component implies higher regional job accessibility, lower regional park accessibility and proximity to the main core area, rail stations, and highway ramps, whereas a higher built environment component implies a more compact and mixed-use environment and a well-connected street pattern in the neighborhood but lower accessibility to local parks. Based on our definition of regional park accessibility, neighborhoods close to the main core are tend to have lower level of service for park, because population density of the neighborhoods are higher and large-scale parks are more concentrated at the edges of cities.

If we consider that the locational contexts of the two study sites were very different, the estimated component loadings in the two sites had remarkably consistent values. In the next step, the built environment and neighborhood location scores were estimated using the results of PCA. These scores conveyed relatively consistent meanings across two study sites.

TABLE 2.3 Results of Principal Component Analysis

		DC n=2193	Twin Cities n=1798
Neighborhood Location	Regional job accessibility	0.485	0.528
	Distance from the main core area	-0.521	-0.565
	Distance from rail stations	-0.481	-
	Distance from highway	-0.375	-0.446
	Regional park accessibility	-0.347	-0.450
	Alpha	0.880	0.870
Neighborhood Built Environment	Population density	0.459	0.477
	Household density	0.461	0.461
	Employment density	0.278	0.268
	Retail/service job density	0.283	0.286
	Road density	0.456	0.463
	Ratio of 3/4 way- intersections	0.403	0.388
	Park Area	-0.220	-0.205
	Alpha	0.795	0.793

c. Relationship between Neighborhood Built Environment and Location

Estimated neighborhood location and built environment scores were mapped in Figure 2.5. Overall, the spatial patterns of location scores had concentric forms; thus, neighborhoods located closer to the main core are of the region were more likely to have higher scores. However, as the scores account for job and park locations and the regional transportation system, the patterns were different from the pattern of distance from downtown. The estimated scores were standardized values adjusting the mean to zero. Positive location scores (yellow, orange, and red) indicate that a neighborhood is in an highly urban location, and negative scores (light green, green, and dark green) represent a less urban location or suburban location.

Likewise, the neighborhood built environment scores were likely to have higher values as they approach the main core area of a region. However, some neighborhoods located in suburban locations had positive built environment scores, and some located in highly urban locations had negative built environment scores. Again, I defined neighborhoods that have positive built environment scores as being highly urban built environments and those having negative built environment scores as suburban built environments.

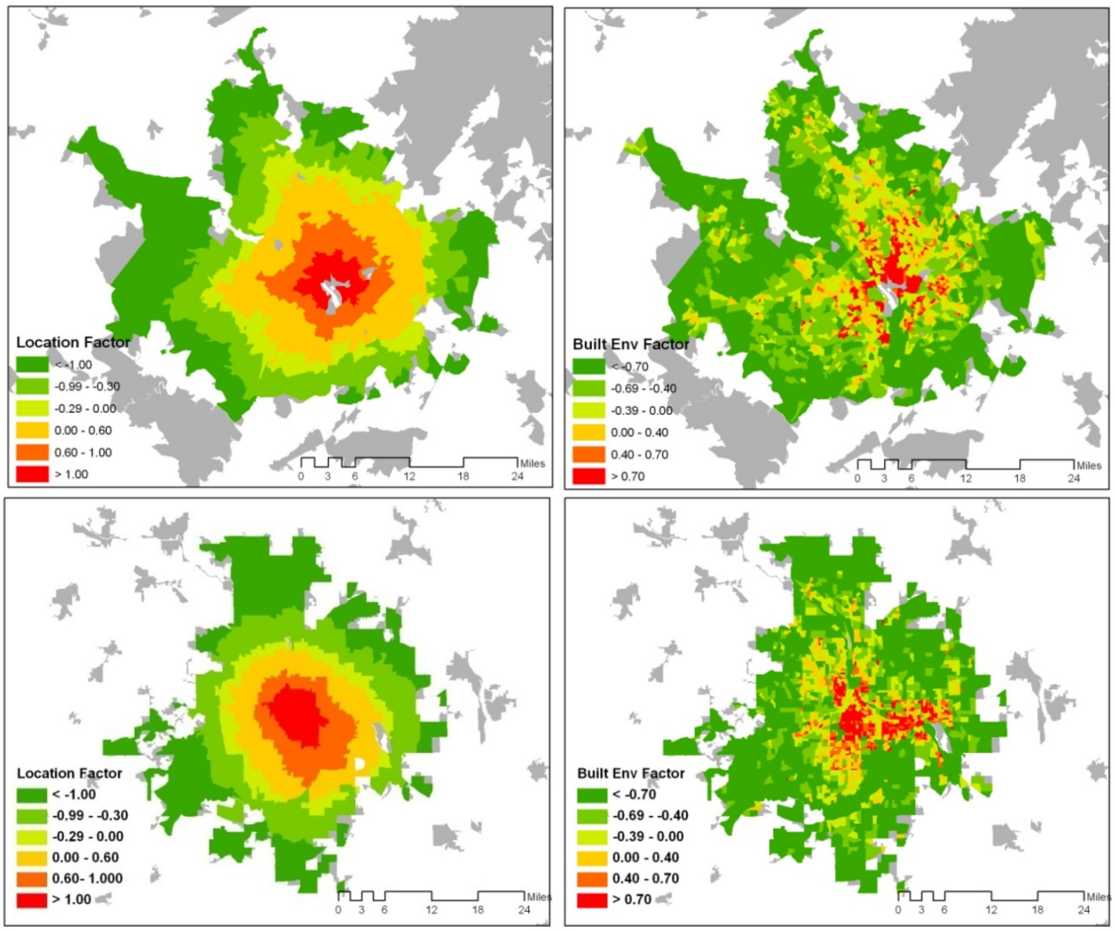


FIGURE 2.5. Neighborhood Location Scores in DC (upper left) and the Twin Cities (lower left) and Built Environment Scores in DC (upper right) and the Twin Cities (lower right)

The estimated neighborhood location and built environment scores were scattered in Figure 2.6, representing built environment scores on the x-axis and location scores on the y-axis. Not surprisingly, these scores were highly correlated, but the relationships were not strictly linear. The location scores sharply decreased as built environment scores decreased. This implies that the scores may have a non-linear relationship. The functional forms of simple linear and exponential regressions are shown below. Table 2.4 shows the results of linear and exponential regressions.

$$\text{Linear regression: } y = b_0 + b_1 \cdot X$$

$$\text{Exponential regression: } y = b_0 + b_1 \cdot {b_2}^X$$

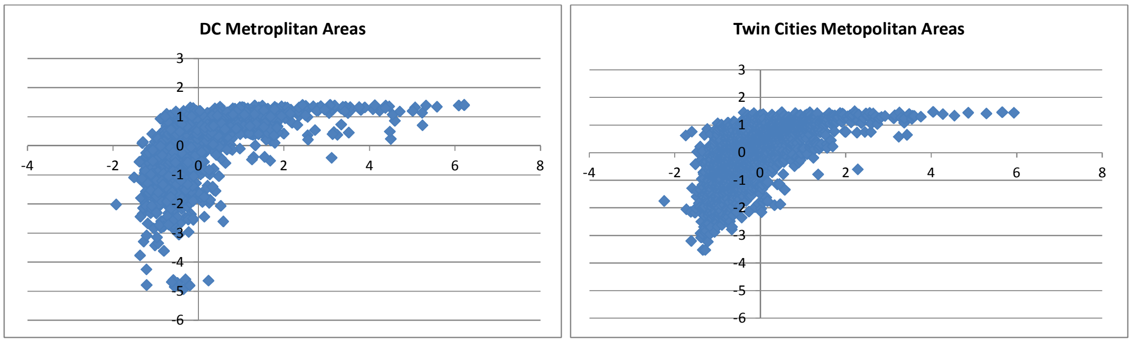


FIGURE 2.6 Scatter plots of neighborhood location scores (y axis) and built environment scores (x axis)

TABLE 2.4 Linear and Exponential Associations between Built Environment and Location Scores

Dep. Variable Location Score		Washington, DC			Twin Cities, MN		
		Coeff.	t value	95% of CI	Coeff.	t value	95% of CI
Linear Regression	b1	0.56	30.8	[0.53, 0.60]	0.68	35.6	[0.64,0.72]
	b0	0	-0.1	[-0.04,0.03]	0	0.20	[-0.03,0.04]
	R-squared	0.30			0.41		
Exponential regression	b1	-1.1	-11.7	[-1.29,-0.92]	-1.55	-9.90	[-1.86,-1.25]
	b2	0.48	18.1	[0.43,0.53]	0.6	21.1	[0.54,0.65]
	b0	1.31	15.1	[1.14,1.18]	1.71	11.7	[1.43,2.00]
	R-squared	0.35			0.48		

In the DC region, the r-squared value in linear and exponential regression was 0.302 and 0.349, respectively. This implies that an exponential regression explained a little more variations in built environment scores than a linear regression did. In the Twin Cities region, the difference of r-squared values between the two models (0.414 and 0.475) was 6%. When the neighborhoods in both sites were included in one model, a linear and an exponential regression explained 35% and 43% of variations in location scores, respectively.

d. Relationship with Socio-Economic Characteristics

Table 2.5 shows the associations between socio-economic factors and neighborhood location score, and between socio-economic factors and built-environment score. The coefficients of the models indicated an increase in neighborhood location and built-environment score was associated with a 1-point increase in percentage female population, percentage married, percentage employed, a 10-year increase in mean age, and a $1,000 increase in mean household income of a neighborhood.

The results indicated that mean age and mean household income in DC were positively associated with neighborhood location score, whereas percentage married and percentage employed were negatively associated with the same score. In the Twin Cities, percentage married was negatively associated with location score, and mean age was positively associated with the same score when built-environment score was controlled. A 1-point increase in percentage married was associated with decreases of 3.4% and 2.7% in neighborhood location scores in the DC and the Twin Cities regions, respectively. Similarly, a $1,000 increase in mean household income of a neighborhood was associated with increases of 0.65% in neighborhood location scores in DC.

TABLE 2.5 Associations between Location, Built Environment and Socio-Demographic factors in Washington, DC (n=2193) and the Twin Cities (n=1798)

Dep. Variable	**Location Score**				**Built Environment Score**			
	Washington, DC		Twin Cities, MN		Washington, DC		Twin Cities, MN	
	Coeff.	t value	Coeff.	t value	Coeff.	t value	Coeff.	t value
Female	0.66	1.40	1.06	1.97 *	-1.84	-4.36 **	-1.94	-3.97 **
Age	0.28	6.20 **	0.11	2.57 **	-0.06	-1.50	-0.18	-4.53 **
Married	-3.36	-12.17 **	-2.62	-8.26 **	-3.36	-12.26 **	-1.83	-6.30 **
Work	-1.84	-5.26 **	-0.43	-1.08	1.96	6.25 **	0.00	-0.01
Income	0.65	7.21 **	0.18	1.09	-0.33	-4.02 **	-0.75	-4.97 **
Built Environment	0.55	26.32 **	0.60	27.33 **				
Location					0.44	26.32 **	0.49	27.33 **
BIC	7774		6375		7298		6033	
R squared	0.429		0.461		0.484		0.505	

* p<0.05; ** p<0.01

This study found that the associations between socio-economic factors and built-environment score were not consistent with the associations between socio-economic factors and neighborhood location score. Percentage female population was negatively associated with built-environment score, whereas no association or weak positive association was found between the percentage female population and location score. In DC, percentage employed was positively associated with built-environment score whereas it was negatively associated with location score. In the Twin Cities, mean age was negatively associated with built-environment score but positively associated with location. The only demographic factor to have consistent association with built-environment and neighborhood location scores was percentage married. It is not surprising that married couples are more likely to select a residence in a neighborhood with suburban built-environment characteristics in a suburban location.

2.4. DISCUSSION

The non-linear aspect of the relationship between neighborhood location and the built environment was mainly attributable to the neighborhoods having suburban built environment characteristics but being located in highly urban locations. Among the 2193 neighborhoods in DC and 1798 neighborhoods in the Twin Cities regions, 828 (38%) and 672 (37%) neighborhoods had positive scores for both built environment and location. They were located in highly urban locations and had highly urbanized built environments. 812 neighborhoods in DC (37%) and 684 neighborhoods in the Twin Cities (38%) were located in suburban locations and had suburban built environment characteristics. However, both sites had unbalanced proportions of highly urbanized location but suburban built environment cases to suburban location but highly urbanized built environment cases; 466 in DC (21%) and 342 in the Twin Cities (19%) were located in highly urbanized areas and had suburban built environment characteristics, whereas only 87 in DC (4.0%) and 106 in the Twin Cities (5.5%) were located in suburban areas and had highly urbanized built environment characteristics. Borrowing Duany and Talen's expression (2002), the 'suburbanizing of the urban neighborhoods' is much commonly found than the urbanizing of the suburban neighborhood.

The concentric patterns of location scores (Figure 2.5) was not a surprising result, although it somewhat differed from our expectations. Distance from the main core area was only one of the variables comprising neighborhood location score. Assuming polycentric development patterns of midsize metropolitan areas in the United States (Orfield, 2002), I expected the patterns of location scores to have multi-centered patterns. The two study regions showed highly concentric patterns with respect to number of jobs. I examined the percentage of jobs located in the downtown area. The findings indicated that 28.8% and 30.4% of jobs of the focused study area in DC and the Twin Cities, respectively, were located within 3 miles of the main core areas (Dupont Circle in DC and two downtown points in the Twin Cities), and 35.6% and 45.4% of jobs were located within 5 miles. Meanwhile, 9.6% and 21.1% of population of the focused study area in DC and the Twin Cities, respectively, were located within 3 miles of downtown, and 18.7% and 35.2% of population were located within 5 miles.

From an analytical perspective, the concentric patterns of location scores are believed to be largely influenced by a smoothing effect in defining the spatial scope of analysis. In this study, the job accessibility of a neighborhood was defined as the weighted sum of jobs located within 20 miles from the neighborhood. Because a 20 mile-radius covers a lot of ground within a single metropolitan area, a single dominant job center in a downtown area tends to dwarf the effect of minor centers located further from downtown. For instance, Cervero and Duncan (2006) used the number of jobs within 4-mile radii of their residential locations to indicate job accessibility. Reducing buffered distance from residence is one method of showing polycentric characteristics of the regions.

More conventional approaches in identifying subcenters depend on spatial trends in employment density (Redfearn, 2007). Giuliano and Small's study (1991) identified subcenters based on a predefined cut-off point for employment density and on total employment thresholds. McMillen (2001) proposed a more sophisticated model for identifying subcenters by using statistically significant local increases in employment density. Adopting these methods may make spatial boundary and size of subcenters manifest; however, the appropriateness of measuring accessibility to the identified subcenters still relies on the context of the study (Cervero and Duncan, 2006). In the context of my study, regional job accessibility was meant to imply opportunity to access various destinations within distance constraints, rather than proximity to the specific subcenters or workplace. I expect that proximity to subcenters may be partially explained by employment density within a half-mile from residence, one of the measurements of the neighborhood built environment.

The positive association between household income and location scores in DC contradicted the well-known suburbanization process by which middle- and upper-income classes move to the edges of cities. Recent studies examining the associations between socio-demographic factors and residential location have explained that this relationship is becoming more complex (Schwanen and Mokhtarian, 2007). Information and communications technologies can make the residential location process flexible by altering patterns of travel to the workplace (Shen, 2000). Because of the inability to provide suitable public facilities and services at prices affordable to residents, higher income families whose members hold professional jobs are more likely to reside in suburban areas than in exurban areas (Nelson and Sanchez, 1997). Perhaps, a more conventional and plausible reason for living close to downtown is workplace accessibility (Alonso, 1964). Although complicated and dynamic transitions in urban structure have occurred in U.S. cities, geographical proximity to the workplace may remain a key element encouraging workers to live close to the job center.

The association between the built environment score and socio-demographic variables exhibited patterns distinguishable from those for the association between neighborhood location score and socio-demographic variables. I speculated that the motivation to live close to downtown is different from the motivation to live in dense, diverse, and well-connected neighborhoods. The main advantage of living close to downtown is proximity to work (Næss, 2005; Karsten, 2007), whereas living in dense and well-connected neighborhoods may be largely influenced by positive attitudes regarding a diverse social environment, as physical proximity to neighbors encouraged residents to build a wide and locally rooted social network (Karsten, 2007). Thus, living close to downtown may carry a different implication from living in neighborhoods with dense populations and well-connected streets. This may be another reason why neighborhood location needs to be considered in examining the association between the built environment and behaviors.

With respect to interpret the results of analyses, there are several limitations in the study. This study found that marital status was strongly associated with both neighborhood location and built-environment scores, and this relationship may strengthen the association between these scores. However, this finding may oversimplify the neighborhood selection process. Married families tend to have more family members and need living spaces that are more spacious; therefore, they select less populated and privacy-protected neighborhoods (Schwanen and Moktarian, 2007).

Meanwhile, the relationship between marital status and neighborhood location is unclear unless we do not account for the quality of the school system and racial segregation. Fennelly and Orfield (2008) examined the relationship between demographic characteristics and school segregation in the Twin Cities. Their paper showed that suburban residents were more likely to agree with the statement that immigrants were hurting the quality of public schools and draining resources from the whole community than urban residents were. Therefore, when the numbers of minority residents reaches a 'tipping point', middle-class families seek to move farther out of urban areas, purportedly in search of 'better schools' elsewhere (Fennelly and Orfield, 2008). It is possible that married families select suburban neighborhoods not because they prefer living further from job centers, but because they desire living close to better school districts and farther from less prosperous urban districts. Married households may trade greater accessibility of employment for better quality of public schools.

Interpretation of the results based on aggregate values of census block groups risks committing an ecological fallacy. For instance, I interpreted that the negative association between married status and neighborhood location implied that married families were more likely to live in suburbs. A more appropriate interpretation, however, is that any given family from the married family group had a higher probability of living in the suburbs than the general population.

Finally, I did not use updated population and employment data. Population and employment data were derived from 2000 sources, while physical elements of neighborhoods, parks, and streets were determined from either 2008 or 2009 data. I used a recent version of physical attribute data because TIGER/Line 2000 did not provide accurate spatial information (Frizzelle et al., 2009). Given that change of the built environment and urban structure within 10 years is relatively slow, eight to nine years of time gap may not produce large bias in understanding associations between compositional characteristics and the physical attributes of urban form.

Although I used aggregated data at neighborhood scale, this study may provide some implications for a policy. The demand to live in neighborhoods close to job centers and demand to live in neighborhoods with urban built-environment characteristics should be understood separately. For instance, if the average married family selects a less populated built environment in the suburbs and the average non-married household selects a dense neighborhood in a highly urban location, the development of a new urbanist type of neighborhood in a suburban location may not be appropriate for both non-married and married families.

2.5. CONCLUSION

The main findings of this study are two-fold. First, higher-than-moderate levels of association exist between built-environment and neighborhood location scores. Second, and more importantly, the association cannot be explained by confounding effect or neighborhood selection. The findings of the study imply that, in examining association between environment and behaviors, the neighborhood location characteristics must be considered separately from neighborhood built-environment score even when the main interest lies in modifiable characteristics of the microscopic area. Otherwise, the results may be biased so that the influence of neighborhood built-environment score on behaviors is overestimated.

III. A Tale of Two Metros: Neighborhood Location, Design and Walking

3.1. INTRODUCTION

Over the last thirty years, the obesity rate for the U.S. population has risen from 15 to 30 percent while physical activity has declined (Flegal et al., 2002). Accordingly, social losses in the form of medical costs have increased dramatically (Finkelstein et al., 2005). In order to confront this serious and widespread social problem, scholars and professionals in many disciplines have suggested modifying the built environment to increase the population's physical activity and thereby address one of the root causes of obesity (Handy et al., 2002). Thus, understanding how the built environment can be a barrier or support to individual's physical activity or walking has become a common research topic.

Although researchers have investigated the association between the built environment and physical activity with regard to various subjects and using various methodologies, one of the common characteristics in much of this research is the manner in which the spatial scope of the built environment is defined. Typically, the built environment considered in these studies consists of the area within 10 to 20 minutes by foot of a person's residence. Using this framework, researchers have examined walking behavior or physical activity in relation to neighborhood built environments (Saelens and Handy, 2008). Examining this research problem on a neighborhood scale offers various advantages in terms of analyzing the observable relationship between the neighborhood environment and activity and developing practicable planning strategies for modifying the built environment.

These studies have shown some empirical evidence supporting the notion that specific physical attributes of a neighborhood are associated with individuals' walking or physical activity. However, as long as the built environment at the neighborhood scale is highly related to its relative location defined at the regional scale, it is not clear whether the associations between the built environment and behaviors are solely attributable to a direct relationship between the two, even with a well-conceived research design.

In contrast to the common approach of defining urban form on a neighborhood scale, this study attempts to understand the physical attributes of urban form on both neighborhood and regional scales. In particular, I defined the relative location of a neighborhood in a region as a key attribute of a neighborhood identifiable at the regional scale. Assuming that the density and land-use mix of neighborhoods may be associated with physical activity or walking, this study examines whether the association is altered significantly when the location of the neighborhood is accounted for, and it seeks to determine how much variation in behavioral outcomes can be explained by reference to built environment characteristics and neighborhood location

3.2. BACKGROUND

Neighborhood-based studies disaggregate the physical attributes of the neighborhood environment into a number of measurable components, such as street connectivity, population density, and land use mixture, before examining the association between each component and walking. Many researchers have adopted this approach in explaining walking behavior in relation to built environments. Saelens and Handy (2008) reviewed 30 papers that examined the associations between walking and the built environment published during 2005 and 2006. Only three among the 30 reviewed papers defined environments in terms of larger-scale units such as city, county, or metropolitan area.

Neighborhood-scale studies have found meaningful associations for transport-related walking and density, (Lee et al., 2006; Rodriguez et al., 2006; Coogan et al., 2007; Forsyth et al., 2007; Oakes et al., 2007; Lee, 2007; Rodriguez et al., 2009), mixed land use (Giles-Corti et al., 2002; Suminski et al., 2005; Rodriguez et al. 2006; Aytur et al, 2007; Brown and Werner, 2007; Coogan et al., 2007; McCormack et al., 2008), and well-connected street patterns (Giles-Corti et al., 2002; Troped et al., 2003; Owen et al., 2004; Badland et al., 2005; Guo et al., 2008). It is encouraging that the modifiable built environment characteristics may increase walking because community-level interventions are more readily applicable (Rodriguez et al., 2008) in micro-scale environments.

However, the challenge may be much more complex than what is observable at the neighborhood scale. If we expand the spatial scope to that of the region, the number of retail facilities or jobs in a region is an externally determined factor rather than a factor that is affected by the neighborhood built environment. Moreover, the spatial distribution of the population in a region is closely related to the locations of jobs (Small and Song, 1994; Cho et al., 2008). Therefore, an increase in population density or land use mix in a specific neighborhood may yield a decrease in these measures in other neighborhoods in the same region. A design-oriented policy for the neighborhood environment may simply deter the appearance of a problem or change the locations of a problem while the main cause of the problem remains unsolved (Banerjee and Baer, 1984).

In contrast to the neighborhood-scale approach, a handful of studies examining travel patterns have developed a concept defining the relationship between a neighborhood and a region. I understand the concept as relevant to the relative location of neighborhoods from specific facilities in a region. In her earlier work, Handy (1993) developed two concepts of accessibility and pointed out that these two concepts are closely related but convey qualitatively different dimensions. In her definition, *regional accessibility* can be measured with respect to regional retail centers such as suburban shopping malls or downtown commercial areas. This is a way of describing the spatial structure of a metropolitan region. Meanwhile, *local accessibility* is defined with respect to convenient establishments such as supermarkets, drugstores, or dry cleaners. These establishments are found in stand-alone neighborhoods. Thus, the concept *of local accessibility* is a way of differentiating between specific neighborhoods within a region.

On a practical level, *regional accessibility* and *local accessibility* indicate relative residential locations to job distribution in a region and the land-use mixture of the neighborhood, respectively. In her study (Handy, 1993), the two concepts of accessibility were correlated, but they had distinct effects on travel patterns. The study demonstrated that the effect of each type of accessibility was most significant in those neighborhoods in which the other type of accessibility was low. Handy's theoretical study (2002) distinguished five dimensions of neighborhood characteristics and a *regional structure* to characterize neighborhoods. The *regional structure* dimension depends on the distribution of facilities across the region and a decline in density with distance from downtown. Meanwhile, the other five dimensions address the characteristics of the built environment within a neighborhood's boundaries, such as density, land use mix, and street connectivity.

Næss (2005) distinguished *urban structural factor* and *a detailed-urban from factor*. He identified that the spatial distribution of facilities within a region or the location of a residence relative to the facilities may influence travel patterns, and this effect can be separable from the influence of the built environment within a specific neighborhood. Other studies in transportation and regional science have used distance to rail stations (van Wee et al., 2002; Kitamura et al., 1997), distance to jobs (Cervero and Duncan, 2006), distance to parks (Kitamura et al., 1997), and distance to public transport (van Acker et al., 2007) to characterize the relative location of neighborhoods from facilities in a region. Those studies, however, did not distinguish the concepts of neighborhood locations and the neighborhood built environment in their empirical models.

A related area of research that examined the impact of urban form on land values (Rodriguez and Targa, 2004; Rodriguez and Mojica, 2009) also shared the two distinctly identifiable dimensions of urban form. In those studies, *neighborhood attributes* referred physical attributes of the neighborhoods observable within the neighborhood boundary, for instance, population density or proportion of neighborhood area in industrial uses. The other dimension of urban form was *regional accessibility* to downtown and employment centers. In contrast to *neighborhood attributes*, *t*he *regional accessibilit*y was determined by the spatial relationship with other urban facilities.

From a planning policy perspective, it seems apparent that the relative location of a neighborhood in the urban spatial structure conveys a different substantial meaning from the characteristics of the neighborhood built environment. Handy (2002) proposed a set of land use strategies to reduce automobile dependence and to improve the accessibility of desired facilities. These strategies include New Urbanist design, transit-oriented development, infill development, and improved street connectivity. Although these land use strategies have common characteristics in specific principles, it is evident that New Urbanist design addresses a different dimension of urban form from that of infill development. New Urbanists have emphasized specific design characteristics including interconnected street networks, narrow streets with sidewalks, mixes of housing types, front porches, and other traditional design features (Duany and Plater-Zyberk 1991), with the intention of putting the activities of daily living within walking distance from residences (Handy, 2002). As explained, walking distance from the residence is the key concept in defining a neighborhood. Meanwhile, a defining feature of infill development is the location of development within the existing limits of an already urbanized area to slow the expansion of the urbanized area. Thus, an infill development strategy is focused on the location of a neighborhood in a region.

Leadership in Environmental and Energy Design (LEED) for Neighborhood Development (LEED, 2009) proposed a rating system that indicates whether a development's location and design meet accepted levels of sustainable development. The rating system is largely composed of three elements: Smart Location and Linkage (SLL), Neighborhood Pattern and Design (NPD), and Green Infrastructure and Building (GIB). The key principles of NPD, which shape the characteristics of the neighborhood built environment, include compact development, a mixed-use neighborhood center, a well-connected street network, good street conditions, and accessible transit facilities. Meanwhile, the principles of SLL are, as described in the LEED report, mainly intended to encourage development within and near existing communities and public transit infrastructure and encourage the redevelopment of existing cities while limiting the expansion of the development footprint in the region.

Inconsistency in terminology and concepts notwithstanding, the notions of regional accessibility (Handy, 1993), regional structure (Handy et al., 2002), urban structural factor (Næss, 2005), accessibility (Rodriguez and Targa, 2004; Rodriguez and Mojica, 2009), infill development, and smart location (LEED, 2009) are commonly invoked in explaining the relative location of a neighborhood in a region. Neighborhood locations involve a different dimension for understanding urban development from the built environment of a neighborhood, which is defined by the observable physical attributes of a stand-alone neighborhood.

To my knowledge, no study has systematically examined the interactions between the neighborhood built environment and neighborhood location. The focus of this study is the association between walking or physical activity and neighborhood built environment when socio-economic characteristics are controlled for, and how those associations change when the relationship between neighborhood built environment and neighborhood locations are considered.

3.3. METHODS

a. Study Areas and Study Participants

Data was collected from two related projects assessing the relationship between residential environments and behaviors in two U.S. areas: the northern sector of Minneapolis–St Paul metropolitan area and Montgomery County, Maryland in theWashington DC metropolitan area. Although the two projects were conducted independently, they followed a similar research design and shared common exposure and outcome measures. The combination of data from two sites would offer the ability to compare results between sites and enhance the external validity of the findings (Rodriguez et al., 2008).

For the Twin Cities, a stratified cluster design was used. One hundred thirty neighborhood areas, each 805*805 meters, were identified and stratified into high, medium or low categories across the dimensions of gross population density and street connectivity. To maximize variability, the study randomly selected 36 areas that ranked high or low on each of the two dimensions. In the second stage, approximately 20 residents were randomly sampled from each area for an original sample size of 716 persons in total. Inclusion criteria included aged 25 year or older, primary residence in one of the 36 neighborhoods, not out of town during week of data collection, and self-reported ability to walk unaided for 20 minutes (Oakes et al., 2007; Forsyth et al., 2007).

Montgomery County, Maryland contains 318 CAZs (Community Analysis Zone). Each of the CAZs was characterized according to their development characteristics (density of population, employment, open space and housing), motorized activity (proximity to bus and rail, population percentage taking transit commuting to work in 2000, and roadway and bus route density), and pedestrian infrastructure (sidewalk connectivity, sidewalk coverage and population percentage walking or cycling to work in 2000). A built environment score was then used as a basis to classify zones into one of three types of built environments using factor and cluster analysis: high (30 zones), middle (135 zones) and low (153 zones) supportive of walking. Two zones were then selected at random from the high group, two from the middle group and one from the low group. 293 participants in Montgomery County enrolled in the studies between January

2005 and September 2006.

Among a total of 1008 individuals (715 is the Twin Cities and 293 in Montgomery County), 612 in the Twin Cities and 255 in Montgomery County completed a questionnaire about socio-demographic characteristics and physical activity patterns, and filled out travel diaries during study period.

b. Variables

Neighborhood Built Environment

In this study, a neighborhood was defined as the area that could be reached by foot within 10 minutes of a participant's home, which translates to a quarter-mile (400m) radius of the participant's home, assuming that an average walking speed is less than 2 mph. Two of the built environment characteristics most commonly associated with physical activity or walking outcomes are the density and land-use mix of a neighborhood. Those who live in dense and diverse neighborhood environments may be more likely to be active than those who live in suburban neighborhoods. The rationale for the hypothesized association between the land-use mix of a residential neighborhood and individual physical activity or walking is that those who live in neighborhoods where retail shops, workplaces, and certain other types of destinations are located may be more likely to travel to these destinations on foot. The association between the density of an individual's neighborhood and his or her travel behaviors is based on a similar logic. The density of a neighborhood enhances individuals' proximity to destinations within the neighborhood. Thus, density may result in the substitution of walking trips for out-of-neighborhood vehicular trips (Cervero and Kockelman, 1997).

To represent the density of a neighborhood, the study used net population density. In areas with many lakes such as the Twin Cities, water presents a physical barrier to walking; therefore, it was determined that land area should exclude water. I used the Herfindahl-Hirschman Index (HHI) to represent land-use mix. The HHI is the sum of squares of the percentages of each type of land use in user-defined neighborhoods. The seven major types of land use considered in this study were residential, commercial, office, industrial, institutional, park and recreation, and vacant use. If there is only one type of land use, HHI indicates the maximum value, 10000. The GIS protocol for the Twin Cities study (Forsyth, A., Environment and Physical Activity: GIS Protocols Version 4.1, 2007) elaborated on the detailed methods calculating net population density and HHI for neighborhoods.

Using their median values for density and HHI, all neighborhoods were classified among four strata: high-density, high land-use mix (HDHM); high-density, low land-use mix (HDLM); low-density, high land-use mix (LDHM); and low-density, low land-use mix (LDLM). The numbers of neighborhoods in these strata were 52, 75, 76, and 52 in Montgomery County and 130, 185, 179, and 118 in the Twin Cities.

Neighborhood Location

Five measures were used to identify neighborhood location (Table 3.1). First is the distance from main core area of each metropolitan area, which is expected to be associated with the density of the neighborhood and the intensity of development. The main core area in DC Metropolitan area was defined as Dupont Circle metro-station. In Twin Cities, two main core areas were defined; Minneapolis Convention Center in Minneapolis and State Capitol in St. Paul. A shorter network distance to the core area was used. Network analysis in ArcGIS 9.2 was used to calculate network distances from the selected core area to the center of each neighborhood.

TABLE 3.1 Neighborhood Location Variables and Dimensions

Dimensions	**Variables**	**Source**
Regional job center	Distance from the main core area	TIGER 2009
	Regional job accessibility	CTPP 2000/Census 2000
Regional transportation system	Distance from rail stations (Montgomery County only)	Census 2000/TIGER 2009
	Distance from highway	Census 2000/TIGER 2009
Regional park system	Regional park accessibility	Tele Atlas North America 2008

The second measure to characterize neighborhood locations is regional job accessibility. The scope of the region for working was defined based on commuting distances. Since more than 80 percent of commuting distances are less than 20 miles (Transportation Statistics Annual Report, 2008) in the United States, all census-defined Traffic Analysis Zones (TAZ) within 20 miles from the focused study areas were used for calculating regional accessibility measures.

Among the various approaches used to measure accessibility, the gravity approach has been widely adopted because it provides the great advantages of being easily understandable, less demanding on data, and able to show spatial variations (Baradaran and Ramjerdi, 2001). However, the gravity approach also has limitations. First, the estimation of accessibility using the gravity approach is largely dependent on the value of the distance decay parameter, but the parameter cannot be determined with empirical data. Second, gravity measures quickly increase to infinity when the distances approach zero because the functional form relies on a negative exponential function.

As an alternative, a Gaussian function, which is widely used in statistics describing normal distributions, was used for calculating regional job accessibility. I used Gaussian distribution as a distance-weight function. The graph of a Gaussian function is a symmetrical bell curve, and the basic functional form of Gaussian distribution is

$$f(x_{ij}) = ae^{-\frac{(x_{ij}-b)^2}{2c^2}}$$

e: Euler's number
a: the height of the curving function
b: the position of the center of the peak
c: the width of the bell
X_{ij}: the distance between census block *i* and *j*

In calculating job accessibility, the values of *a* and *b* are set to 1 and 0, respectively, and the value of *c* is determined by the standard deviation of distances between census block groups and jobs. Regional job accessibility of census block *i* is the sum of distance-weighted number of jobs within a region. Higher accessibility value indicates better access to jobs in a region. The primary data source that this study used to identify job locations was the Census Transportation Planning Package (CTPP) 2000, Part II, at the TAZ level.

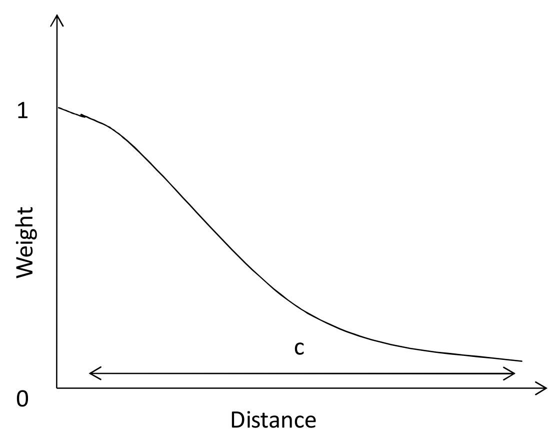


FIGURE 3.1 Gaussian Distribution as a Distance-Weight Function

The third and fourth measures are the shortest network distance to a rail station and to a highway ramp. Accessibility of the neighborhood in a region depends largely on the regional transportation infrastructure, because proximity to the regional transportation infrastructure makes it easier to reach various destinations within a short amount of time.

A relative location from rail and highway networks is important regional transportation infrastructure to represent the geographic locations of neighborhoods. However, as a commuter rail system has not been operated in the Twin Cities until June 2004, I did not consider the shortest distance to a rail station in the analysis of the Twin Cities. Using network analysis in ArcGIS 9.2, the network distances from the center of each neighborhood to the closest rail station and highway ramp were calculated.

The fifth measure was regional park accessibility. Park and recreational services are essential infrastructure elements in planning (Mertes and Hall, 1995). Our calculation of this measure was based on methods proposed by Mertes and Hall (1995). First, each park was classified as one of four classes based on size: neighborhood park (<20 acres), community park (<50 acres), large urban park (<200 acres), and regional park (>200 acres). The service areas for these classes were ½ mile, 3 miles, 5 miles, and 10 miles, respectively. The LOS of each park was defined as the size of the park divided by the population located within the service area of the park. The regional park accessibility of a neighborhood was defined as the sum of LOS of each park classification.

Regional park accessibility = LOS of neighborhood parks within ½ mile + LOS of community parks within 3 miles + LOS of large urban parks within 5 miles + LOS of regional parks within 10 miles

Outcomes

I used five outcome measures from two data sources. First, data on physical activity outcomes were drawn from the International Physical Activity Questionnaires (IPAQ), which assessed the frequency and duration of activity over the preceding seven days. The reported transportation-related or recreation-related physical activity and walking were transformed into Metabolic Equivalent (MET) minutes to facilitate the measurement of the energy cost of walking behaviors. The value of 1 MET represents the typical energy cost at rest of an average individual, and MET minutes are a measure of intensity by duration (Ainsworth, 2000). The variables used from IPAQ were (1) transportation-related walking MET minutes/week, (2) leisure-related walking MET minutes per week, and (3) leisure-related physical activity MET minutes per week. I did not use transportation-related physical activity because it was not greatly different from the transportation-related walking MET minutes/week.

The second data source was a travel diary. In both study sites, participants used slightly different travel diaries. Participants in the Montgomery County site used a location diary (Cho et al., 2011). This diary required participants to fill in trip start and arrival times, mode of travel, and location of activity in a closed-ended format. The participants in the Twin Cities site used a modified form of the National Household Transport Survey (NHTS) (Forsyth et al., 2007). Perhaps the main difference between the two types of diary is the protocol for filling in a chain of subsequent travel events. The NHTS diary was designed to enable the recording of a multi-mode travel event in a single row, such as walk-car or bus-walk, whereas the location diary was designed to fill out each trip separately by mode of travel. The variables derived from the travel diary were (1) mean number of walking trips per day, and (2) the proportion of walk/jogging as a mode of travel.

Socio-Economic Characteristics

I used five socio-economic variables: gender, age, marital status, employment, and household income. Gender (female: 1), marital status (married: 1), and employment (employed: 1) were binary variables. Household income was converted into four categorical values: less than $30k, $30k-$60k, $60k-$100k, and more than $100k. Assuming that those younger than age 60 were not likely to have mobility problems caused by aging, I converted the age variable to a binary value: older than 60 years or less than 60 years of age.

c. Analytical Methods

Principal Component Analysis (PCA)

The five variables representing neighborhood location (Table 3.1) are likely to be highly spatially correlated. Given the limited number of participants in the study, it is useful to condense these variables into a smaller set of variables that eliminate redundancy and correlation in the data (Song and Knaap, 2007). PCA was used to reduce strongly associated variables into a single factor. Typically, a scale is considered reliable if its Cronbach's alpha is 0.70 or higher, although Nunnally and Bernstein (1994) claimed that values greater than 0.80 are highly desirable. I used STATA SE 9.2 to extract a factor representing the location of a neighborhood. Estimated location scores were converted to ordinal variables for the next step of the analysis.

Ordinal Logistic Regression

Ordinal logistic regression models by site were used minimize the impact of measurement error, as the measurement of behavioral patterns was not thought to be sufficiently precise (Oakes et al., 2007). Outcome measures were classified in terms of five ordered categories based on percentiles. I conducted a Brant test for each model in order to test the proportional odds assumption. Because participants at the two study sites were spatially clustered, all models used robust standard errors (Oakes et al., 2007). I compared models with and without the neighborhood location variable for each site. Thus, I employed four models for each outcome variable. The analysis was conducted using STATA 9.2.

3.4. RESULTS

a. Descriptive Statistics

Table 3.2 shows descriptive statistics for the two study sites. Socio-economic characteristics of the two study sites were similar in general. The proportions of female, employed, and married participants were consistent across the study sites. The mean age of participants in Montgomery County was slightly higher than the mean age of participants in the Twin Cities. On average, participants in Montgomery County earned more than participants in the Twin Cities. Given that mean household income was higher in the DC metropolitan area ($72k) than in the Twin Cities metropolitan area ($56k), the higher household income of the Montgomery County participants might not have resulted from sampling bias.

In regard to built environment measures, the degree of land-use mix indicated by HHI showed that the neighborhoods at both sites had a similar mixture level. On average, neighborhoods in Montgomery County were denser than neighborhoods in the Twin Cities in terms of net population density. Again, this difference mainly resulted from the regional context. An introductory paper (Chapter II) showed that the mean population density of 2193 census block groups in the DC metropolitan area was 13.1 person/acre, whereas that of 1798 census block groups in the Twin Cities metropolitan area was 8.3 person/acre. For the same reason, neighborhoods in Montgomery County had higher job accessibility than neighborhoods in the Twin Cities region. Meanwhile, neighborhoods in the Twin Cities were closer to inter-regional highway ramps and downtown relative to neighborhoods in Montgomery County. The LOS of park area of the neighborhoods at the two sites was very similar.

With respect to physical activity outcomes, participants at the two study sites expended a similar level of energy for transportation and recreational-purpose walking. The variables derived from travel diaries indicated that residents of Montgomery County walked slightly more than residents of the Twin Cities. It is not clear why the walking-related outcomes derived from travel diaries in Montgomery County were higher than those in the Twin Cities while the outcomes related to walking at the two sites derived from IPAQ were similar. Perhaps differences in the type of travel diaries maintained at the study sites resulted in a systematic bias. Or the participants in the Twin Cities might have less number of walking trips per day while longer duration of the trips in average.

TABLE 3.2 Descriptive Statistics for Neighborhood Location, Neighborhood Built Environment, Socio-Economic Characteristics and Behavioral Outcomes (Montgomery County, MD: n=255; The Twin Cities, MN: n=612)

		Montgomery Co.				**Twin Cities**			
Variable	**Unit**	**Mean**	**S.D.**	**Min**	**Max**	**Mean**	**S.D.**	**Min**	**Max**
Neighborhood Location									
Regional job accessibility	Relative scale	35.1	18.1	9.5	60.8	29.5	9.6	11.4	48.3
Distance from the main core	miles	12.4	4.7	7.2	20.5	5.5	3.1	0.6	12.5
Distance from rail stations	miles	2.8	3.0	0.3	8.9	-	-	-	-
Distance from highway	miles	3.8	3.2	0.2	10.2	1.2	0.9	0.1	3.6
Regional park accessibility	Acres/1000 people	23.0	5.1	15.9	30.7	23.3	3.5	17.7	32.6
Neighborhood Built Environment									
Net Population density	Person/acre	13.1	6.2	0.6	24.1	9.2	4.9	0.8	22.7
Herfindahl-Herschmann Index	Relative scale	5808	2242	2227	9994	5871	1866	1872	10000
Socio-Economic Characteristics									
Proportion of female	%	65.9				65.0			
Mean age	year	50.7	14.4	19.0	90.0	46.3	13.3	24.0	86.0
Employed	%	68.2				71.9			
Proportion of the married	%	56.5				58.2			
Household income	Relative scale	3.2	0.9	1.0	4.0	2.3	1.0	1.0	4.0
Outcome									
Transport walking	MET min/week	242.5	356.8	0.0	2376.0	257.3	566.3	0.0	4158.0
Recreational physical activity	MET min/week	1313.7	1249.4	0.0	8670.0	855.4	1123.5	0.0	7920.0
Recreational walking	MET min/week	320.3	432.7	0.0	2079.0	321.9	497.6	0.0	4158.0
Number of walk trips per day	#/day	1.2	1.3	0.0	6.0	0.9	1.0	0.0	7.3
Proportion of by walking	%	22.5	20.4	0.0	100.0	15.6	16.7	0.0	86.8

b. Principal Component Analysis

Table 3.3 shows that the sign of component loading on each manifest variable was consistent for the two study sites. Higher location scores indicated higher regional job accessibility, proximity to downtown, rail/metro stations and highways, and lower regional park accessibility. The sizes of component loadings were not identical across groups, but all had loadings higher than 0.4. Thus, location scores derived from PCA would have a moderate level of reliability. The Cronbach's alphas of the five variables in Montgomery County and the Twin Cities were 0.96 and 0.87, respectively.

TABLE 3.3 EFA for Five Neighborhood Location Variables

	Montgomery Co.	Twin Cities
Regional job accessibility	0.467	0.558
Network distance to the main core	-0.479	-0.545
Network distance to rail/metro stations	-0.437	-
Network distance to highway ramps	-0.451	-0.403
Regional park accessibility	-0.401	-0.479
Cronbach's Alphas	0.956	0.867

c. Associations between Location, Built Environment, and PA Outcomes

Among the twelve models, two models relevant to energy expenditure (EE) for transportation walking in the Twin Cities did not meet the proportional odds assumption. A generalized logit model (GLM) can relieve the statistical assumption, but I did not include the results of GLM in this paper for enhancing parsimony.

When the location of a neighborhood was not included in the model, the combination of land-use mix and density (HDHM) was positively associated with EE for transportation-purpose walking (Table 3.4). If the neighborhood had only one of those built environment characteristics (HDLM or LDHM), the residents of the neighborhood had marginally higher odds to engaging transportation walking than those who lived in LDLM neighborhoods. In contrast to our expectations, I found notable inconsistency in the results for the two study sites. In the Twin Cities, density and land-use mix were negatively associated with EE for recreation-related walking and EE for recreation-related physical activity, whereas in Montgomery County, density and land-use mix had insignificant associations with recreation-related outcomes.

The inclusion of the neighborhood location variable did not result in significant changes to the models. The neighborhood location had a significant association with EE for transportation-purpose walking in the Montgomery County. But other models did not show that the neighborhood location was associated with physical activity outcomes.

In regard to socio-economic variables, household income was positively associated with recreation-related outcomes. Often individuals were less likely to walk for transportation, and, in the Montgomery County, unemployed tended to walk more for recreational purposes. Although this finding was not statistically significant in Montgomery County, males had higher odds of walking for transportation purposes relative to the odds of females.

TABLE 3.4 Ordered Logistic Regressions for Physical Activity Outcomes

	Montgomery Co.						Twin Cities					
	Partial			Full			Partial			Full		
	OR	Z		OR	Z		OR	Z		OR	Z	
EE for Transport walking												
HDHM	4.36	3.92	**	2.64	2.22	*	3.02	4.24	**	3.01	3.96	**
HDLM	1.64	1.72		1.10	0.29		1.56	1.86		1.56	1.75	
LDHM	1.35	0.93		1.67	1.59		1.61	2.07	*	1.60	1.94	
LDLM (reference)												
Location				1.61	2.86	**				1.00	0.06	
Female	0.69	-1.51		0.72	-1.33		0.60	-3.10	**	1.67	3.09	**
Employ	0.69	-1.28		0.74	-1.01		0.71	-1.84		0.70	-1.84	
Age	0.46	-2.21	*	0.40	-2.51	**	0.77	-1.02		0.77	-1.02	
Married	1.01	0.05		1.14	0.47		0.78	-1.36		0.78	-1.35	
Income	0.95	-0.33		0.93	-0.43		0.84	-1.66		0.84	-1.66	
LL	-358			-349			-730			-730		
BIC	782			770			1530			1537		
Brant	0.19			0.88			0.00			0.00		
EE for Recreational walking												
HDHM	1.24	0.60		1.22	0.49		0.42	-3.52	**	0.36	-3.83	**
HDLM	1.22	0.61		1.20	0.51		0.50	-3.15	**	0.44	-3.51	**
LDHM	1.58	1.47		1.60	1.48		0.58	-2.63	**	0.51	-2.96	**
LDLM (reference)												
Location				1.02	0.13					1.13	1.72	
Female	1.39	1.33		1.39	1.34		0.98	-0.10		1.01	0.08	
Employ	0.42	-2.96	**	0.42	-2.91	**	0.62	-2.64	**	0.60	-2.76	**
Age	0.79	-0.70		0.78	-0.70		1.25	1.04		1.22	0.93	
Married	1.35	1.06		1.35	1.08		0.89	-0.69		0.90	-0.63	
Income	1.16	1.00		1.15	0.97		1.36	3.17	**	1.36	3.21	**
LL	-379			-379			-876			-873		
BIC	825			830			1830			1829		
Brant	0.34			0.14			0.51			0.55		
EE for Recreational activity												
HDHM	2.20	1.87		2.32	1.88		0.51	-2.62	**	0.51	-2.45	**
HDLM	1.32	0.78		1.39	0.84		0.63	-2.18	*	0.63	-2.08	*
LDHM	1.79	1.54		1.76	1.49		0.76	-1.33		0.76	-1.23	
LDLM (reference)												
Location				0.95	-0.34					1.00	0.03	
Female	1.15	0.56		1.15	0.55		0.67	-2.46	*	1.49	2.46	*
Employ	0.53	-2.42	*	0.53	-2.44	*	0.75	-1.68		0.75	-1.66	
Age	0.94	-0.24		0.95	-0.18		1.17	0.76		1.17	0.76	
Married	0.76	-0.97		0.75	-1.01		0.64	-2.46	*	0.64	-2.46	*
Income	1.68	3.54	**	1.68	3.54	**	1.78	5.83	**	1.78	5.83	**
LL	-399			-398			-950			-950		
BIC	864			869			1977			1983		
Brant	0.14			0.09			0.30			0.15		

* p<0.05; ** p<0.01

d. Associations between Location, Built Environment, and Walking Trips

Number of walking trips and proportion of walking trips were derived from travel diaries. Among the eight models, two models in Montgomery County with respect to the number of walking trips did not meet the proportional odds assumption. For the same reason, I did not include the results of GLM in this paper.

TABLE 3.5 Ordered Logistic Regressions for Walking

	Montgomery Co.						Twin Cities					
	Partial			Full			Partial			Full		
	OR	**Z**		**OR**	**Z**		**OR**	**Z**		**OR**	**Z**	
# of walk trips												
HDHM	4.41	3.57	**	2.25	1.86		1.17	0.66		0.97	-0.14	
HDLM	2.08	2.17	*	1.19	0.47		1.05	0.23		0.91	-0.44	
LDHM	1.66	1.53		2.14	2.23	*	1.03	0.15		0.91	-0.47	
LDLM (reference)												
Location				1.87	3.76	**				1.25	3.34	**
Female	0.49	-2.68	**	0.52	-2.47	*	0.98	-0.10		1.01	0.05	
Employ	0.91	-0.33		1.00	0.00		0.83	-1.11		0.80	-1.26	
Age	0.37	-2.88	**	0.29	-3.50	**	0.90	-0.56		0.88	-0.69	
Married	0.65	-1.52		0.78	-0.86		0.85	-0.97		0.87	-0.88	
Income	0.90	-0.62		0.85	-1.00		0.97	-0.30		0.97	-0.30	
LL	-389			-386			-981			-976		
BIC	845			844			2039			2035		
Brant	0.02			0.04			0.93			0.93		
Proportion of by walking												
HDHM	5.29	3.95	**	2.63	2.22	*	1.32	1.23		1.10	0.40	
HDLM	2.04	2.23	*	1.07	0.19		1.24	1.07		1.08	0.36	
LDHM	1.88	1.92		1.86	1.90		1.14	0.68		1.00	0.02	
LDLM (reference)												
Location				2.04	4.21	**				1.24	3.30	**
Female	0.36	-3.57	**	0.38	-3.37	**	0.97	-0.22		1.03	0.19	
Employ	0.81	-0.79		0.90	-0.42		0.64	-2.51	*	0.62	-2.60	**
Age	0.54	-1.74		0.41	-2.49	*	0.91	-0.48		0.89	-0.60	
Married	0.51	-2.26	*	0.61	-1.60		0.85	-0.97		0.86	-0.91	
Income	1.01	0.08		0.97	-0.17		0.87	-1.40		0.87	-1.42	
LL	-389			-384			-974			-969		
BIC	844			839			2024			2021		
Brant	0.14			0.10			0.53			0.50		

* $p<0.05$; ** $p<0.01$

Similar to the results shown in Table 3.4, I found some inconsistent results regarding walking-trip outcomes by study site (Table 3.5). When neighborhood location was not included in the model, the land-use mix and density of neighborhoods in Montgomery

County were positively associated with the number of walking trips or the proportion of walking as a travel mode. Those who lived in HDLM neighborhoods were more likely to walk than were residents of LDLM neighborhoods. LDHM neighborhoods showed marginally positive associations. The combination of high density and high land-use mix in neighborhoods (HDHM) was associated with even higher odds of walking trips in Montgomery County. I could not find these associations in the samples of the Twin Cities.

When neighborhood location was included in the models, associations between the built environment and outcomes were greatly reduced in Montgomery County. In particular, the association between the density of a neighborhood and outcomes was greatly weakened, whereas the association between land-use mix and outcomes remained unchanged. This implies that the density of neighborhoods may work as an approximate indicator of neighborhood location. Consistently, the location of a neighborhood had a positive association with the number of walking trips and the proportion of walking as a travel mode. The positive associations between neighborhood location and total walk trips were found in both sites.

Male, young, unmarried, and unemployed individuals walked more. On average, these relationships were more evident in Montgomery County.

3.5. DISCUSSION

This study found that the neighborhood location had a significant association with EE for transportation-purpose or walking in the Montgomery County. But other models did not show that the neighborhood location was associated with physical activity outcomes.

In the Twin Cities, density and land-use mix of neighborhoods were negatively associated with EE for recreation-related walking. Using the same dataset, Forsyth et al. (2007) suggested that higher density might promote walking for transportation purposes and that lower density might promote walking for recreation purposes. This study added that land-use mix of a neighborhood was also negatively associated with recreation-purpose walking in the Twin Cities. With our analytical framework, the causal relationship between the neighborhood built environment and recreation-purpose activity is not clear. More green areas in low density neighborhoods may encourage walking for recreation-purpose. I also speculate that household income may play an important role as a confounder. This study found that household income had a strong positive association with recreation-purpose outcomes whereas the income was negatively associated with density and land use mix of a neighborhood. Furthermore, for explaining recreation-purpose outcomes, the physical attributes of an individual's immediate surroundings may not be as important as we assumed them to be. The distance decay parameters for usage of recreational areas are relatively small (Giles-Corti and Donovan, 2002) because people may be more willing to travel greater distances to use certain types of recreational facilities (Rutt and Coleman, 2005).

In regard to number of total walking trips and proportion of walking trip, this study found that associations between the density of neighborhoods and outcomes were greatly reduced when the location of the neighborhood was included in the model in Montgomery County. This result is mainly attributable to the high correlation between neighborhood density and location. Furthermore, it implies that the density of a neighborhood may be an intermediate variable of other urban form elements, such as neighborhood location (Ewing and Cervero, 2010). In other words, dense environments are more likely to be located close to downtown areas, and those who live in the locations are more likely to be actively involved in walking activity.

Table 3.6 shows the cumulative proportion of neighborhoods in each classification by quartiles of location scores. For instance, second quartiles (median value) of location scores in Montgomery County correspond to 83.6% of low-density neighborhoods and 45.7% of high-density neighborhoods, respectively. In the Twin Cities, the median value for location score corresponds to 61.1% of low-density neighborhoods and 39.5% of high-density neighborhoods. The covariance between local land-use mix and location score was relatively small. In general, neighborhoods in Montgomery County showed higher covariance between density and location score than did neighborhoods in the Twin Cities.

The sampling methods may explain in these findings. In particular, the neighborhoods in the Twin Cities were selected using stratified sampling, thus approximately a half of the dense neighborhoods were purposefully selected in low street connectivity areas. Given that poorly connected street patterns are more likely to be found in suburban location than in urban location, a considerable number of neighborhoods having dense and low connectivity characteristics should be selected from suburban locations.

TABLE 3.6 Cumulative proportions by quartiles of location scores

	Montgomery Count, MD				Twin Cities, MN			
	Low-density	High-density	Low-mixed use	High-mixed use	Low-density	High-density	Low-mixed use	High-mixed use
1	21.9	14.2	17.2	4.7	37.9	15.0	25.5	27.5
2	83.6	45.7	58.6	39.4	61.1	39.5	38.9	61.8
3	93.0	97.5	67.2	71.7	77.1	74.8	66.3	85.6
4	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0

In Table 3.5, the results showed that the density and land-use mix of neighborhoods were moderately associated with the number of walking trips and the proportion of walking trips in Montgomery County. However, these associations were not found in the Twin Cities. This may be explained by the findings of Table 3.4. As shown in Table 3.4, for residents of the Twin Cities, density and land-use mix were positively associated with transportation-related walking but were negatively associated with recreation-related walking. Thus the total number of walking trips derived from travel diaries might neutralize the variations of outcomes to be explained by built environment characteristics.

Notwithstanding the inconsistent results across the two study sites, one point is worth emphasizing: total walking trips were positively associated with the location of neighborhoods, while the location of neighborhoods might not be an important factor explaining physical activity outcomes. Often, the location of a neighborhood, defined at the regional level, has been neglected in studies examining associations between urban form and behaviors. This study found that location was significantly associated with total walking trips and that, more importantly, this association was distinguishable from the association between the built environment and behaviors. As shown in the Twin Cities, neighborhood location could be positively associated with total walking trips, even when recreation-related walking were negatively associated with built environment characteristics.

Still the causal relationship between neighborhood location and walking is not as clear as the relationship between immediate surroundings and walking. I speculate that living close to downtown areas may increase the opportunity to walk out of the neighborhood boundary as well as within their residential neighborhoods. For instance, living close to metro station may encourage walking from home to the station and, at the same time, increase walking from station to workplace located out of their residential neighborhoods. Knowing the specific origins and destinations of individuals' walking trips enhances understanding of the true relationship. Future research may use GPS technology for identifying the accurate location and duration of walking trips (Cho et al, 2011). Inconsistencies between the results for the two study sites imply that further research needs be conducted in other regional contexts to derive more generalizable findings in regard to the association between urban form and behaviors.

From a policy perspective, although interventions related to new development in suburban areas might be more feasible than re-development in urban locations, New Urbanist-style neighborhoods in suburban locations might not be as successful for promoting walking trip as planners anticipate. It is important to acknowledge that neighborhood location, as I defined it, is not an unchangeable attribute akin to geographic coordinates, as it indicates the location of a neighborhood relative to an entire urban structure. Like the characteristics of the built environment, the characteristics of locations are modifiable through appropriate planning interventions. Enhancing job-housing balance, promoting proximity between transportation infrastructure and new development, and encouraging infill development have been more heavily emphasized in the realm of 'smart growth' than has the development of walkable environments on a neighborhood scale. The findings of this study suggest that interventions for smart growth might be more useful for promoting individuals' physical activity or walking than what they has been assumed.

In both study regions, it is important to re-invest in underused land to accommodate growth on a smaller urban footprint for the purpose of reducing traffic congestion, supporting walking, conserving rural land, and saving construction and maintenance costs for infrastructure. The Twin Cities Metropolitan Council recommended that at least 29% of growth in housing units be accommodated in developed lands (Metropolitan Council, 2006). However, current growth management policy embracing large flexibility with respect to the Metropolitan Urban Service Area (MUSA) has not provided planners with effective tools to control the location of development. More importantly, although MUSA in the Twin Cities region covers vast amounts of land (670,000 acres in the approved 2020 MUSA) in a seven-county region, the policy framework of the Council tends to treat the lands indiscriminately with respect to development strategies. The only meaningful geographic planning division reflecting varied community needs within MUSA is the division into two areas: the Developing Communities and the Developed Communities. This paper has shown that individual's walking may be moderately influenced by locational characteristics of neighborhoods. It underscores the importance of a policy framework that locates new developments in appropriate places in the region for enhancing the policy effect of walkable communities.

Montgomery County has a plan to accommodate further growth into three types of lands: vacant lands, underdeveloped parking lots, or smart-growth locations near transit or in existing strip malls. In my study, the locations near transit stations or existing job centers imply more "urban" locations in the region. Thus, the study findings suggest that, for encouraging walking or transportation-purpose walking, prioritizing development of smart-growth locations may be desirable. In contrast, vacant lands, which are more likely to be located further from transit or job centers, may have relatively limited influence on individual's walking regardless of the density of the developments.

3.6. CONCLUSIONS

The findings of this study suggest that neighborhood location, which was identified from the distance from downtown, regional job accessibility, accessibility to regional transportation network and level of service of parks in the region, may play a role in explaining walking trips. It is noteworthy that residing in a highly urban location had a consistently positive association with total walking. However, the inclusion of the neighborhood location variable did not result in significant changes to the models for recreation-purpose activity. Other models did not show that the neighborhood location was associated with physical activity outcomes.

IV. How Neighborhood Design and Location Affect Three Types of Walking: Results from the DC area

4.1. INTRODUCTION

Modifying the neighborhood built environment is recognized as a means of facilitating walking in addition to creating a positive social environment (Handy et al., 2002). Previous studies have provided ample empirical evidence that the neighborhood built environment plays a role in increasing walking (Frank and Engelke, 2001; Lee and Moudon, 2004; Saelens and Handy, 2008). Walking for transportation is associated with living in neighborhoods that offer convenient access to destinations, connected street networks, and higher residential densities, whereas neighborhood aesthetics, access to parks and beaches, and quality of the pedestrian infrastructure tend to be associated with increased walking for recreation purposes (Saelens and Handy, 2008).

In contrast to the neighborhood-scale or micro-scale environment, the regional-scale or macro-level environment comprises to the distribution of activities and transportation facilities across the region (Handy et al., 2002). Understanding the regional-scale environment and its association with the neighborhood-scale environment is important, as the regional-scale environment is likely to influence the neighborhood-level characteristics of the built environment, including residential density, land-use mix, and street connectivity (Næss, 2005).

Næss (2005) explicitly explained a relationship among regional-scale environments, neighborhood-scale environments, and travel behaviors. The location of an individual's residence close to the center of a region increases the likelihood of that individual being surrounded by a high-density and mixed-land-use neighborhood. Proximity to a high-density and mixed-land-use neighborhood indicates shorter distance to job opportunities as well as local services. Shorter distances to destinations also imply that inner-city residents may choose to walk or bike instead of using motorized transportation. Admittedly, these causal inferences overly simplify the relationships between the regional and neighborhood-scale environments, while the historical urban core has lost its dominant position (Hansen, 2003). However, the location of a residence close to the center of a region still provides enormous advantages for expanding selectable destinations within time and budget constraints (Næss, 2005). In analytical terms, the weighted sum of distance to destinations tends to decrease as a residence approaches the center, even in a highly poly-centric urban structure.

Although existing studies have examined the association between neighborhood-scale environmental features and walking (Saelens and Handy, 2008), the association of the regional-scale environment with behaviors has rarely been explored. A handful of studies have examined the association between the regional-scale environment and travel mode, with a focus on motorized trips. The researchers in this area have used distance to rail network (van Wee et al., 2002) or proximity to jobs (Cervero and Duncan, 2006) or distance to downtown (Næss, 2005). To our knowledge, no study has systematically compared the influences of the regional and neighborhood-scale environments on walking. In particular, walking behaviors are commonly believed to be influenced by the neighborhood-scale environment rather than the regional-scale environment (Handy et al., 2002). This belief is based on the assumption that the influence of the neighborhood-scale environment on walking is consistent, whether the neighborhood is located in the downtown area or in the suburbs. I assert that this assumption is a subject of empirical inquiry.

This study defined the physical characteristics of the regional-scale environment as the locations of neighborhoods relative to urban facilities in a region. The aim is to compare the influence of a neighborhood's location defined at the regional scale and built environment characteristics defined at the neighborhood scale on the specific purpose of walking trips. This study is designed to address the following questions:

- Is the location of a neighborhood in a region associated with walking? If so, is the association between the neighborhood's location and walking greater than the association between built environment characteristics and walking?
- Do the relationships between walking, built environment characteristics, and neighborhood location change as the purpose of walking is considered?

4.2. METHODS

a. Study Context

The focused study area is situated in the Washington, DC Metropolitan area. In 2009, the population of the DC Metropolitan area was approximately 5.5 million. The focused study area, urbanized area in the DC region, involves District of Columbia, two counties in Maryland and six counties in Virginia (Figure 4.1). In addition, data from the area within a 20-mile radius of the selected study areas was considered as adjusting the boundary effect in estimating regional-dimension variables.

I used the 2009 National Household Travel Survey (NHTS version 2.0) to identify individuals' travel pattern and residential locations. The residential locations of study participants were identifiable at a census block-group level, which is considered a neighborhood in this study. In microscopic studies, a block group representation has limitations in identifying continuous variations between administrative demarcations (Guo and Bhat, 2007). However, it seemed the most appropriate representation of a neighborhood in this study, as the spatial scope of the study was much larger than that of a neighborhood. Furthermore, the average sizes of census block groups in the Washington, DC and Twin Cities regions were approximately 0.50 square miles, which corresponded well with the concept of a walkable radius of a quarter- to a half-mile.

I selected participants older than 15 years of age who lived within the focused study area. In total, 1183 participants in 698 households were selected from 516 census block groups.

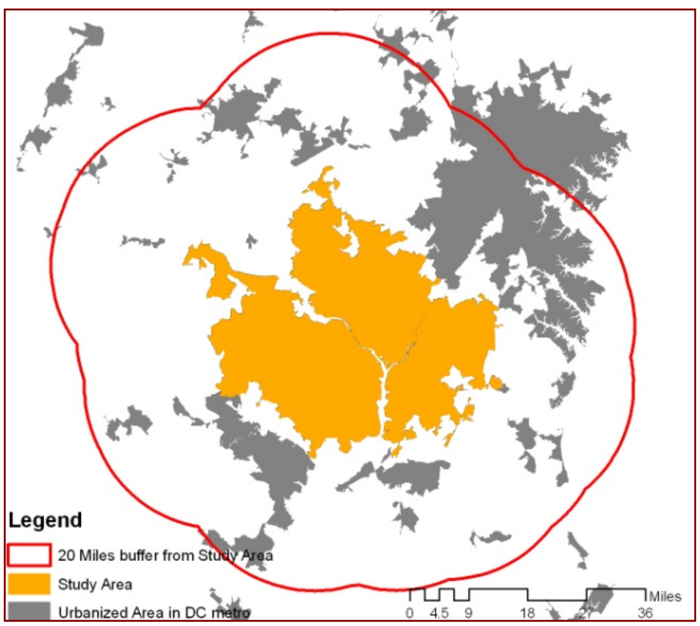


FIGURE 4.1 Focused Study Area in Washington, DC Metropolitan Area

b. Variables

Neighborhood Built Environment

I defined the neighborhood built environment as four sub-dimensions (Table 4.1):

density, land use mix, street characteristics, and proximity to parks. Two variables, population density and housing unit density, were selected to represent density. Figures on population and number of housing units at the census block group level were derived from the Census 2000 database.

TABLE 4.1 Neighborhood Built Environment and Neighborhood Location

Dimensions	Variables	Source
Neighborhood Built Environment		
Density	Population density	Census 2000
	Housing unit density	Census 2000
Land Use	Employment density	CTPP 2000/ Census 2000
	Retail/service job density	CTPP 2000/ Census 2000
Street	Road density	Census 2000/TIGER 2009
	Ratio of 3- or 4-way intersections	Census 2000/TIGER 2009
Park	Park density	Tele Atlas North America 2008
Neighborhood Location		
Regional job center	Regional job accessibility	CTPP 2000/Census 2000
	Network distance from downtown	TIGER 2009
Regional transport system	Network distance from rail stations (DC metro only)	Census 2000/TIGER 2009
	Network distance from highway	Census 2000/TIGER 2009
Regional park system	Regional park accessibility	Tele Atlas North America 2008

The second sub-dimension, land use mix, is composed of employment density and retail/service job density. Because land use data at the parcel level were not available, I used employment density and retail or service job density as proxy measures of land use mix. These measures imply the relative proximity of residences to retail facilities or services (Cervero and Duncan, 2006). The source of employment data was the Census Transportation Planning Package 2000 (CTPP), Part II. As the geographical unit of the CTPP is the Census-defined Traffic Analysis Zone (TAZ), the boundaries of TAZs and census block groups are not identical. To estimate the number of jobs in each census block group, the area proportions of TAZs situated in each census block group were calculated by intersecting the TAZs with census block groups using ArcGIS 9.2. The apportioned numbers of employees were summed by each census block group.

The third sub-dimension, street, is composed of road density and the ratio of 3- or 4-way nodes to segments; the 2009 Topologically Integrated Geographic Encoding and Referencing (TIGER)/Line shapefiles were used for identifying street patterns. The fourth sub-dimension is the ratio of 3- or 4-way intersections to all intersections, thought to be indicative of more connected street patterns than is a higher ratio of cul-de-sacs.

Finally, park area within each census block group was calculated. The source of park data was the 2008 Tele Atlas North America. Based on Tele Atlas Feature Class Codes (FCC), parklands were identified as national park or forest (D83), state park or forest (D85), or local park or recreation area (D89). There was a time gap in the sources of data.

Neighborhood Location

Five measures were used to identify neighborhood location (Table 4.1). First is the distance from main core area of each metropolitan area, which is expected to be associated with the density of the neighborhood and the intensity of development. The main core area in DC Metropolitan area was defined as Dupont Circle metro-station. Network analysis in ArcGIS 9.2 was used to calculate network distances from the selected core area to the center of each neighborhood.

The second measure to characterize neighborhood locations is regional job accessibility. The scope of the region for working was defined based on commuting distances. Since more than 80 percent of commuting distances are less than 20 miles (Transportation Statistics Annual Report, 2008) in the United States, all census-defined Traffic Analysis Zones (TAZ) within 20 miles from the focused study areas were used for calculating regional accessibility measures.

Among the various approaches used to measure accessibility, the gravity approach has been widely adopted because it provides the great advantages of being easily understandable, less demanding on data, and able to show spatial variations (Baradaran and Ramjerdi, 2001). However, the gravity approach also has limitations. First, the estimation of accessibility using the gravity approach is largely dependent on the value of the distance decay parameter, but the parameter cannot be determined with empirical data. Second, gravity measures quickly increase to infinity when the distances approach zero because the functional form relies on a negative exponential function.

As an alternative, a Gaussian function, which is widely used in statistics describing normal distributions, was used for calculating regional job accessibility. I used Gaussian distribution as a distance-weight function. The graph of a Gaussian function is a symmetrical bell curve, and the basic functional form of Gaussian distribution is

$$f(x_{ij}) = ae^{-\frac{(x_{ij}-b)^2}{2c^2}}$$

e: Euler's number
a: the height of the curving function
b: the position of the center of the peak
c: the width of the bell
X_{ij}: the distance between census block *i* and *j*

In calculating job accessibility, the values of *a* and *b* are set to 1 and 0, respectively, and the value of *c* is determined by the standard deviation of distances between census block groups and jobs. Regional job accessibility of census block *i* is the sum of distance-weighted number of jobs within a region. Higher accessibility value indicates better access to jobs in a region. The primary data source that this study used to identify job locations was the Census Transportation Planning Package (CTPP) 2000, Part II, at the TAZ level.

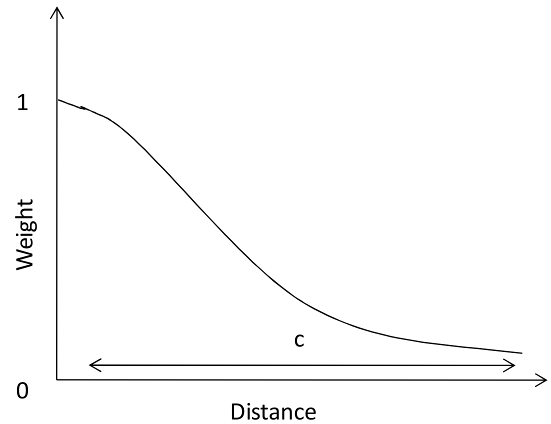


FIGURE 4.2 Gaussian Distribution as a Distance-Weight Function

The third and fourth measures are the shortest network distance to a rail station and to a highway ramp. Accessibility of the neighborhood in a region depends largely on the regional transportation infrastructure, because proximity to the regional transportation infrastructure makes it easier to reach various destinations within a short amount of time. A relative location from rail and highway networks is important regional transportation infrastructure to represent the geographic locations of neighborhoods. However, as a commuter rail system has not been operated in the Twin Cities until June 2004, I did not consider the shortest distance to a rail station in the analysis of the Twin Cities. Using network analysis in ArcGIS 9.2, the network distances from the center of each neighborhood to the closest rail station and highway ramp were calculated.

The fifth measure was regional park accessibility. Park and recreational services are essential infrastructure elements in planning (Mertes and Hall, 1995). Our calculation of this measure was based on methods proposed by Mertes and Hall (1995). First, each park was classified as one of four classes based on size: neighborhood park (<20 acres), community park (<50 acres), large urban park (<200 acres), and regional park (>200 acres). The service areas for these classes were ½ mile, 3 miles, 5 miles, and 10 miles, respectively. The LOS of each park was defined as the size of the park divided by the population located within the service area of the park. The regional park accessibility of a neighborhood was defined as the sum of LOS of each park classification.

Regional park accessibility = LOS of neighborhood parks within ½ mile + LOS of community parks within 3 miles + LOS of large urban parks within 5 miles + LOS of regional parks within 10 miles

Outcomes

Outcomes were binary: taking a walking trip (1) or taking no walking trip (0) on a designated 24-hour travel day. Based on the trip purposes defined in the 2009 NHTS codebook, the purpose of each walking trip was classified to one of four categories: to/from work, shopping-eating, social/entertainment, and other. The social-entertainment walking includes the trips going to gym/exercise, going to theater/sports event, visiting parks/library and visiting friends.

Socio-Demographic Characteristics

I used five socio-economic variables: gender, age, household size, employment, and household income. Gender (female: 1), and employment (employed: 1) were binary variables. Assuming that those younger than age 60 were not likely to have mobility problems caused by aging, I converted the age variable to a binary value: older than 60 years or less than 60 years of age. Household income was converted into four categorical values: less than $30k, $30k-$60k, $60k-$100k, and more than $100k. Household size was converted into five categorical values: one, two, three, four, and five or more.

c. Analytical Methods

Principal Component Analysis (PCA)

The variables representing neighborhood location and the built environment are likely to be highly spatially correlated. Given the limited number of participants in the study, it is useful to condense these variables into a smaller set in order to eliminate redundancy and correlation in the data (Song and Knaap, 2007). PCA was used to reduce strongly associated variables into a single factor. Typically, a scale is considered reliable if its Cronbach's alpha is 0.70 or higher, although Nunnally and Bernstein (1994) claimed that values greater than 0.80 are highly desirable.

Component scores for the built environment and neighborhood location were estimated using the component loadings. As the estimated component scores were standardized values with the mean centered on zero, I defined neighborhoods in highly urban locations (HU) as those having positive neighborhood location component scores, and neighborhoods in less urban locations relative to those having negative neighborhood location scores (LU). Using the same methods, I defined highly walkable neighborhoods (HW) as those having positive built environment scores, and I defined less walkable neighborhoods as those having negative built environment scores (LW). I then classified each neighborhood into one of four categories: highly urban-highly walkable (HUHW), highly urban-less walkable (HULW), less urban-highly walkable (LUHW), and less urban-less walkable (LULW) (Table 4.2).

TABLE 4.2 Classifications of Neighborhoods by Location and Walkability

<table>
<tr><th colspan="2" rowspan="2"></th><th colspan="2">Neighborhood Location Score</th></tr>
<tr><th>Positive</th><th>Negative</th></tr>
<tr><td rowspan="2">Built Environment Score</td><td>Positive</td><td>Highly Urban-Highly Wakable (HUHW)</td><td>Less Urban-Highly Wakable (LUHW)</td></tr>
<tr><td>Negative</td><td>Highly Urban-Less Wakable (HULW)</td><td>Less Urban-Less Wakable (LULW)</td></tr>
</table>

Binary Logistic Regression

As the outcomes were binary—walked or did not walk—a binary logistic regression was the primary statistical model utilized. Based on the assumption that those who live in LULW neighborhoods might be the least active group, the LULW group was designated as the reference group for each model. Using an odds ratio, I examined whether those who lived in neighborhood groups were more likely to walk for a specific purpose than those who lived in the reference group. In addition, I conducted the Wald test to examine whether the estimated odds ratio of HUHW neighborhoods to LULW neighborhoods was significantly different from the odd ratios of LUHW and HULW neighborhoods.

To account for the clustering of each individual within a household, I used clustered robust standard errors. Using the Bayesian information criterion (BIC) and R-squared value, I compared the fits of multiple models. The BIC is a criterion for model selection with different numbers of parameters. By introducing a penalty term for the number of parameters in the model, the BIC solves the overfitting problem caused by adding an excessive number of parameters. All analyses were conducted using STATA 9.2.

4.3. RESULTS

a. Descriptive Statistics

Table 4.3 presents descriptive statistics. The maximum distance from downtown indicates the spatial scope of this study. Distance was measured in miles, while regional job accessibility was represented with a relative scale. The unit of regional park accessibility was size of park per 1000 persons. In 2010, the population density of Washington, DC was 15.3 person/acre. The average population density of the focused study area (12.9 person/acre) was slightly lower than the density of the city and far larger than the average density of the DC Metropolitan area, as I only included fully developed urbanized areas in the metropolitan area. The 'less urban' neighborhood defined in this study implies a low-density development but not a rural area.

With respect to socio-economic characteristics, the proportion of females was well balanced with the proportion of males. I used a relative scale for household income. On average, household income was higher than $60k.

The Table 4.3 show that 33.5% of participants made one or more walking trips on the study day. By purpose of walking, 9.2% of participants walked for work, 38.0% walked for social-entertainment, and 18.8% walked for shopping-eating on the study day. The total number of participants was 1183. The numbers of participants who made trips for work, shopping-eating, and social-entertainment were 576, 527, and 510, respectively.

TABLE 4.3 Descriptive Statistics for Socio-Demographic Characteristics, outcomes and Environmental Exposures

Variable	Unit	Mean	S.D.	Min	Max
Neighborhood Location					
Regional job accessibility	Relative scale	43.1	28.7	2.6	90.9
Distance from the main core area	Miles	11.5	7.3	1.0	34.8
Distance from rail stations	Miles	4.3	4.5	0.0	26.4
Distance from highway	Miles	3.1	3.5	0.1	21.5
Regional park accessibility	Acres/1000 people	23.7	12.7	10.1	94.5
Neighborhood Built Environment					
Population density	Person/acre	12.9	14.6	0.3	114.5
Household density	Unit/acre	6.0	8.1	0.1	67.0
Employment density	Job/acre	4.7	11.5	0.0	128.5
Retail/service job density	Job/acre	3.0	7.4	0.0	80.5
Road density	feet/acre	171.5	75.0	33.1	405.9
Ratio of 3/4 way- intersections	%	79.1	14.0	52.6	100.0
Park Area	Acre	8.4	18.6	0.0	149.5
Socio-Demographic Characteristics					
Proportion of female	%	53.8	49.9	0.0	100.0
Mean age	year	50.7	17.0	16.0	92.0
Employed	%	64.7	47.8	0.0	100.0
Household size	Relative scale	2.7	1.2	1.0	5.0
Household income	Relative scale	3.1	1.1	1.0	4.0
Outcome					
Walked for any purpose	%	33.5	47.2	0.0	100.0
for to/from work	%	9.2	28.9	0.0	100.0
for social-entertainment	%	38.0	48.6	0.0	100.0
for shopping-eating	%	18.8	39.1	0.0	100.0

b. Principal Component Analysis

Table 4.4 is the results of PCA. A higher location component implies higher regional job accessibility, greater proximity to the main core area, metro stations, and highway ramps; and lower regional park accessibility. A higher local walkability component implies a more compact and mixed-use environment and a well-connected street pattern in the neighborhood but lower access to local parks. The Cronbach's alphas of five variables representing urban location and seven variables representing local walkability were 0.907 and 0.854.

The numbers of participants who lived in HUHW, HULW, LUHW, and LULW neighborhoods were 476 (40.2%), 137 (11.6%), 132 (11.2%), and 43 (37.0%), respectively (Table 4.5). Not surprisingly, highly walkable neighborhoods were more likely to be located close to the main core area (Figure 4.3), but some of the highly walkable neighborhoods were found in less urban locations. Likewise, not all less walkable neighborhoods were located in less urban locations. One of the main inquiries of our study is a comparison of walking trips between HULW and LUHW neighborhoods.

TABLE 4.4 PCA for Urban Location and Local Walkability Components

Component	**Variable**	**Component loading**
Urban Location	Regional Job Accessibility	0.475
	Network distance to the main core area	-0.509
	Network distance to Rail stations	-0.481
	Network distance to highway ramps	-0.396
	Regional Park Accessibility	-0.357
Cronbach Alpha		0.907
Local Walkability	Population density	0.435
	Household density	0.450
	Employment density	0.344
	Retail/service job density	0.351
	Road density	0.409
	Connectivity of segments	0.379
	Local park area	-0.237
Cronbach Alpha		0.854

TABLE 4.5 Neighborhood Classification (# of neighborhood =516, # of participants =1183)

	Walkable neighborhood		Auto-oriented neighborhood	
	# of Neighborhoods	# of Participants	# of Neighborhoods	# of Participants
Highly Urban	239	476	51	137
Less Urban	62	132	164	438

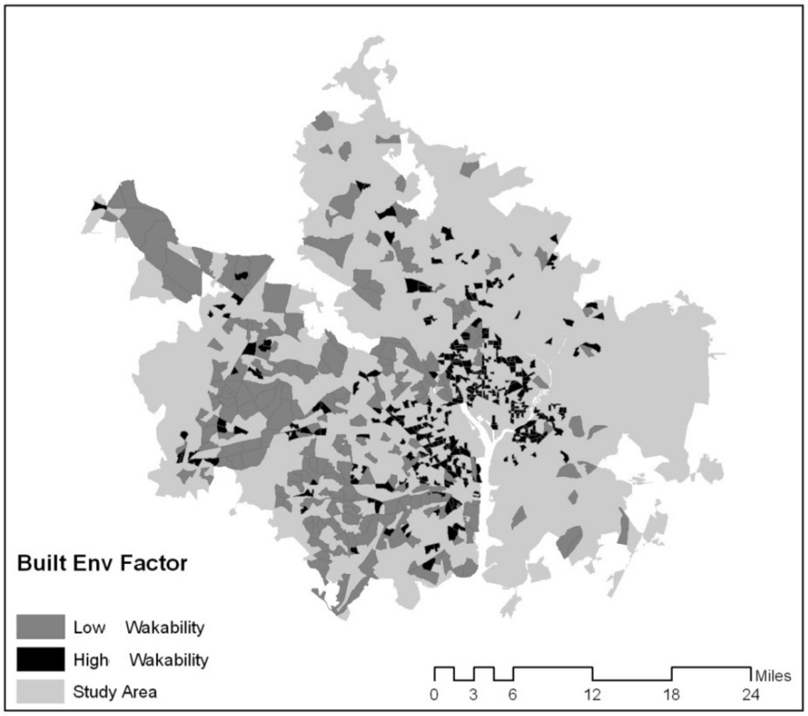


FIGURE 4.3 Built Environment Scores of the Selected Neighborhoods

c. Associations between Location, Built Environment and Walking

Table 4.6 shows that those who lived in HUHW and HULW neighborhoods were more likely to walk than those who lived in LULW neighborhoods. Although it was not significant at the 95% confidence level, residency in an LUHW neighborhood had a marginally positive association with walking. A Wald test indicated that those who lived in LUHW (χ^2=4.52) and HULW (χ^2=5.10) neighborhoods were less likely to walk than those who lived in HUHW neighborhoods. Figure 4.4 shows the odds ratios for the four groups. Residing in a walkable local environment or living in a highly urban location was positively associated with walking. If individuals lived in neighborhoods having both highly walkable and highly urban characteristics, the probability of walking relative to not walking was even higher. The odds of walking for the four groups were as follows: LULW < LUHW = HULW < HUHW.

In regard to work trips, those who lived in HUHW or HULW neighborhoods were more likely to walk than those who lived in LULW neighborhoods. However, this study could not find evidence indicating that the residents of LUHW neighborhoods walked more to/from work than the residents of LULW neighborhoods. A Wald test indicated that those who lived in LUHW neighborhoods walked to/from work less than the residents of HUHW neighborhoods (χ^2=5.79). The odds of walking to/from work for the HUHW and HULW groups were not significantly different (χ^2=1.92). In other words, living in a walkable neighborhood was not associated with the odds of walking to/from work. In terms of work-specific purposes, neighborhood location was more strongly associated with walking than the neighborhood built environment.

Analyses for shopping-eating walking showed a different pattern. The residents of HUHW and LUHW neighborhoods were more likely to walk for shopping-eating purposes than the residents of LULW neighborhoods. No significant difference was found between the residents of HULW and LULW neighborhoods in this regard. The odds of walking for shopping-eating for the HUHW and LUHW groups were not significantly different (χ^2=1.80) relative to the odds of not walking for this purpose. Living in a walkable neighborhood may encourage walking for shopping-eating purposes, but residential location defined on a regional scale may have only a limited effect on walking.

For social-entertainment walking, this study found that the residents of HUHW, HULW, and LUHW neighborhoods walked more than residents of LULW neighborhoods did. The odds of walking for social-entertainment for the HUHW group were not significantly different from those for the HULW (χ^2=0.06) or LUHW (χ^2=0.12) groups. Thus, either living in a highly walkable or highly urban neighborhood may encourage walking for social-entertainment. In contrast to the results for total walking, this study did not find that individuals living in highly walkable and highly urban neighborhoods walked more for social-entertainment than those living in neighborhoods having either highly walkable or highly urban characteristics.

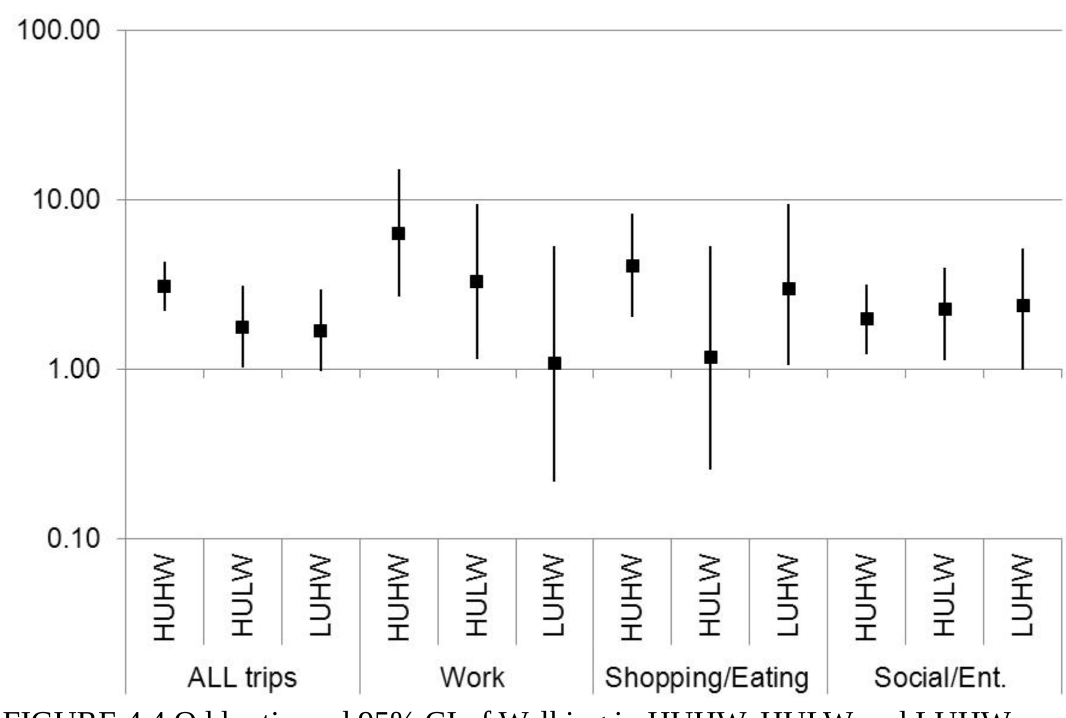


FIGURE 4.4 Odd ratio and 95% CI of Walking in HUHW, HULW and LUHW Neighborhoods versus Walking in LULW neighborhoods

TABLE 4.6 Adjusted Odds Ratio of Walking by Purpose Associated with Neighborhood Location and Local Walkability

	ALL trips (n=1183)			Work (n=576)			Shopping/Eating (n=527)			Social/Ent. (n=510)		
	OR	95% CI		OR	95% CI		OR	95% CI		OR	95% CI	
		Lower	Upper		Lower	Upper		Lower	Upper		Lower	Upper
HUHW	**3.10**	**2.26**	**4.27**	**6.33**	**2.71**	**14.79**	**4.10**	**2.07**	**8.13**	**2.00**	**1.24**	**3.11**
HULW	**1.78**	**1.04**	**3.04**	**3.29**	**1.16**	**9.33**	1.17	0.26	5.26	**2.25**	**1.15**	**3.92**
LUHW	1.70	0.99	2.93	1.08	0.22	5.22	**2.99**	**1.08**	**9.24**	**2.39**	**1.01**	**5.07**
LULW	(Reference)											
Female	0.88	0.69	1.13	0.99	0.55	1.78	0.97	0.61	1.56	0.80	0.55	1.16
Household size	0.91	0.81	1.03	1.14	0.87	1.51	**0.79**	**0.63**	**0.99**	0.86	0.73	1.02
Age	**0.72**	**0.52**	**1.00**	**2.67**	**1.35**	**5.29**	**0.31**	**0.17**	**0.57**	**0.40**	**0.25**	**0.66**
Household Income	**1.21**	**1.06**	**1.37**	1.10	0.85	1.42	**0.79**	**0.63**	**0.99**	1.00	0.81	1.22
Employment	1.14	0.84	1.53	1.33	0.63	2.81	1.00	0.58	1.70	1.32	0.87	2.00
Log likelihood			-717.2			-158.8			-218.7			-331
BIC			1498			374.7			493.5			718.4

4.4. DISCUSSION

The findings regarding total walking trips conform to my hypothesis. A neighborhood's location, defined on a regional scale, was associated with walking, and this association was separately identifiable from the association between the neighborhood built environment and walking. Even when the residential neighborhood had less walkable characteristics, residents in highly urban locations walked more than residents in LULW neighborhoods. The walkability of a neighborhood also had a separately identifiable association with walking. Thus, the combination of the two conditions—highly walkable and highly urban—may have a synergetic effect on walking.

The findings show that the relationship between the built environment and walking for work is different from the relationship between the built environment and walking for shopping-eating. Residents of walkable neighborhoods took more walking trips to work only when the neighborhood was located close to the main core area or regional job centers. It is noteworthy that even residents of walkable neighborhoods rarely had jobs within a walkable distance from home (i.e., a quarter to half-mile from their residence). A more common pattern of work trips involved the combination of walking with other modes of travel, such as bus or rail. Most of the public transportation networks are designed to serve areas close to downtown or regional job centers. Therefore, those who live farther from such areas may have fairly limited access to the public transportation system and therefore tend to give up walking as a mode of travel to/from work even when their residential neighborhoods have walkable characteristics.

In contrast to our findings, existing literature has reported an association between local built environment characteristics and walking to work (Suminski et al., 2005; Owen et al., 2007; Badland et al., 2008). I speculate that some of those findings may be partly explained by the higher than moderate level of covariance between the local built environment and neighborhood location. In our study area, approximately 75% of walkable neighborhoods were located close to the main core area. Only 25% of walkable neighborhoods were located in less urban areas. Without a clear distinction between a neighborhood's location and built environment factors, it may be difficult to identify the true environmental correlates of walking to work.

The results of walking for shopping-eating revealed a different pattern. Living in neighborhoods with dense, mixed-land use and well-connected street characteristics increases the chances of walking for shopping-eating. The walkable characteristics of neighborhoods reduce the average distance from home to destinations. A shorter distance between home and destinations increases the chance of selecting walking as a travel mode. However, neighborhood location defined at the regional scale was not associated with walking for shopping-eating.

Næss's (2005) and Vilhelmson's (1999) theoretical work may provide additional insight regarding the distinctive aspects of walking trips for work and shopping-eating. Based on Vilhelmson's definition, trips to work tend to be 'bounded trips' where both time and geographical location are fixed. Meanwhile, trips for shopping are 'non-bounded' or 'semi-bounded trips' where the time of the activity is flexible and the location may vary. For some non-bounded trips, people tend to choose the closest destination or a destination located outside the region. In contrast, patterns of bounded trips are to a much higher extent affected by the spatial distribution of facilities. Thus, urban structures or regional-scale environments are expected to have a stronger influence on bounded trips than non-bounded trips (Næss, 2005).

In the literature, a typical classification of walking by purpose is either utilitarian or recreational walking (Rodriguez et al., 2006; Lee, 2006; Forsyth et al., 2007), whereas I examined three specific purposes of walking: to/from work, shopping-eating, or social-entertainment. Notably, the purpose of walking classified in this study is a refined type of utilitarian walking, rather than a classification based on new criteria. Although a limited number of recreational walking trips, such as going to the gym, might be included in walking for social-entertainment, the majority of the walking trips I examined were walking trips for utilitarian purposes. Both walking trips to work and trips for shopping-eating are specific types of walking trips for utilitarian purposes, but this study found that the environmental correlates of walking trips to/from work showed a different pattern from environmental correlates of walking trips for shopping-eating and environment exposures. Thus, our study results may underscore the importance of developing a refined conceptual model in examining the association between walking and urban form. An investigation that is sensitive to the specific purpose of walking may be desirable in the effort to understand the association between walking and urban form.

This study has limitations. Among recent studies (Forsyth et al., 2007; Rodriguez et al., 2008; Cho et al., 2011), it has been common practice to use a seven-day travel diary to identify individuals' travel patterns and to detect the difference between weekend and weekday travel patterns. However, as NHTS 2009 data only provide information on one-day travel patterns, I used a relatively crude classification for outcomes: walked or not walked. For the same reason, I could not use other important characteristics of walking trips, such as frequency or duration. Living in high density areas may reduce total duration or length of walking trips as the distances between origin and destination are likely to decrease (Xu et al., 2010). Furthermore, because the distributions of duration or frequency of walking trips are highly skewed positively in many cases (Forsyth et al., 2007), appropriate outcome variables to be used in the analyses were limited.

This study found that neighborhood location was positively associated with walking for work purposes but was not associated with walking for shopping-eating purposes. However, as I used data only from the DC metropolitan area, the existence of similar patterns in other cities was not confirmed. In particular, the classification of neighborhood location in this study into the categories of highly urban location or less urban location is dependent upon regional context. It would be desirable to investigate further to test whether the results of this study are found across multiple regions, as such consistency would enhance the external validity of the findings.

The findings of our study have policy implications. The development of walkable neighborhoods may not be successful in encouraging walking trips to work without the provision of a proper level of access to the public transit system connecting regional job centers. On a practical level, however, it is important to be aware that New Urbanist communities in suburbs are hardly dense enough to justify frequent transit service (Gordon & Richardson, 1998). Indeed, researchers have addressed the possibility that there is a limited association between walking trips to work and walkable neighborhoods in the critique of the New Urbanist approach to community development. On the supply side, the benefits of New Urbanist street patterns in reducing automobile commuting can be diminished if communities are situated in spatially disconnected locations in suburbs (Cervero & Gorham, 1995). On the demand side, the policy assumption that workers will opt to live closer to their workplaces is questionable (Downs, 1992; Levine, 1998). Cervero (1996) stated that communities could experience improved jobs-housing balance despite the fact that most persons living in the communities work elsewhere because of housing costs. Households with a range of locational choices tend to seek lower residential densities at increasing distances from work (Levine, 1998). The motivation for living in highly mixed and dense neighborhoods can be proximity to local shopping and socializing opportunities rather than proximity to jobs.

However, this does not necessarily imply the limitation of the New Urbanist approach; instead, it may indicate the necessity of an expansive perspective (Ellis, 2002). Weitz (2003) argued that adopting jobs-housing balance policies in comprehensive plans, integrating jobs-housing balance into land-use regulations, and ensuring qualitative balance in large-scale development can be effective planning strategies for achieving "true" jobs-housing balance.

Policy for modifying the local built environment to favor walkable characteristics in order to encourage walking trips may need to be reevaluated from a regional perspective. A neighborhood with walkable characteristics (i.e., dense, highly mixed land-use and well-connected streets) may be utilized not only by its residents, but also by individuals living outside the neighborhood. If a walkable neighborhood has weak connections with other neighborhoods in the same region, the unbalanced distribution of jobs, retail facilities, and services in urban areas may discourage walking trips to access the walkable neighborhood from other neighborhoods. The net effect of a walkable neighborhood in a region is an important subject for policy evaluation.

4.5. CONCLUSIONS

This study examined the relationship between the neighborhood built environment, neighborhood location, and walking for various purposes. The results indicated that the association of neighborhood location with walking was separately identifiable from the association of the neighborhood built environment with walking. Living close to job centers and the regional transportation system increased the likelihood of walking to/from work. Living in walkable neighborhoods was positively associated with walking for shopping-eating. For social-entertainment purposes, both neighborhood location and the built environment were associated with the likelihood of walking.

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V. What If You Live in The Wrong Neighborhood? The Influence of Residential Neighborhood Type Dissonance on Walking and Physical Activity

5.1. INTRODUCTION

Urban form is believed by many to influence individuals' health outcomes by promoting physical activity (Handy et al., 2002; Lee and Moudon, 2004). Accordingly, many studies have examined the associations between the environment of a neighborhood and the physical activity of residents. A common criticism of physical activity and environment studies to date, however, has been that they are not successful in accounting for neighborhood self-selection (Saelens and Handy, 2008). In regard to studies examining the built environment and behavior, neighborhood self-selection arises when those who prefer to travel by a motorized mode select auto-oriented areas for their residence, whereas those who are willing to engage in transportation-purpose physical activity (walking or jogging) select pedestrian-friendly environments in which to live. If the association between the built environment and physical activity is mainly a result of the neighborhood self-selection process, neighborhood self-selection may be viewed as a source of bias to be eliminated in correlational analyses (Levine, 2005). However, previous studies have commonly reported that the built environment is significantly associated with travel behaviors or physical activity, even after controlling for neighborhood self-selection. Thus, the influence of the built environment on behavior is constituted both as the influence of the built environment itself and the influence of neighborhood self-selection (Cao et al., 2009).

One of the important reasons why differences in physical activity cannot be fully explained by neighborhood self-selection is the dissonance between the preferences individuals have for neighborhood environments and the neighborhoods in which they actually reside. Because of undersupplied forms of development (Talen, 2001), limited monetary resources (Lu, 1998) and information (Rodriguez et al., In press), or dynamics in the life course (Schwanen and Mokhtarian, 2004), considerable mismatches can exist between preferences and residential choices. The literature indicates that at least one-quarter of U.S. residents live in neighborhoods they do not prefer in terms of the neighborhoods' walkable features (Schwanen and Mokhtarian, 2004; Frank et al., 2007). The dissonance between preferences and actual place of residence may be an important factor in physical activity and behavioral patterns.

In this study, I examined agreement between preferences and actual residential locations to define groups of residents that were mismatched (dissonant) and well matched (consonant) with their neighborhoods. I then compared their physical activity outcomes and walking. In particular, I hypothesized that those who lived close to the core of the city but sought to live in suburbs could be expected to walk less than those who preferred living in the city and lived there. Whether dissonant residents walk more or less than consonant residents in downtown/suburban neighborhoods is a matter of empirical debate. Investigating this issue will also contribute to understanding the role of self-selection in the environment-behavior relationship.

5.2. BACKGROUND

Many scholars have speculated on the possible overestimation or underestimation of the causal influence of urban form on physical activity resulting from not taking into account the neighborhood self-selection factor (Saelens and Handy, 2008; Cao, 2010). Most studies of urban form and physical activity have adopted a cross-sectional design. Because changing environments in desirable ways generally requires large amounts of time and high budgets, assessments of the before-and-after impact of urban form have been limited mainly to the evaluation of local transportation investments (Frank and Engelke, 2001). By nature, cross-sectional studies have a limitation in identifying causal relationships. Without results from longitudinal studies, it is difficult to understand whether neighborhood design influences physical activity or activity preferences influence the choice of neighborhood (Saelens and Handy, 2008). Mokhtarian and Cao (2008) proposed a longitudinal structural equation modeling approach as theoretically ideal to control for neighborhood self-selection, but cost and complexity make it unfeasible in most cases. Mokhtarian and Cao concluded that, ironically, the more sophisticated the approach to treating self-selection, the more difficult it becomes to answer questions about the true impacts of urban form. In theory, the inclusion of instrumental variables can be a means of identifying causal relationships. However, in practice, it is difficult, if not impossible, to find appropriate instrumental variables that are correlated with the endogenous explanatory variable and not significantly correlated with the error term of the original equation (Winship and Morgan, 1999).

As a realistic alternative, a popular approach to controlling self-selection in cross-sectional studies has been the inclusion of residential preference variables in analytical models (Cao et al., 2006; Schwanen and Mokhtarian, 2005a). However, this approach has an intrinsic limitation because preferences measured in the present may differ from those that led to a prior choice of residential environment (Mokhtarian and Cao, 2008). Furthermore, through a consolidation process, preference for a chosen decision may increase once it is firmly determined (Svenson, 1992). Thus, it is difficult to understand the determinants of neighborhood self-selection if the individuals involved already live in the selected neighborhood.

If the neighborhood self-selection process is the only complete mechanism that explains physical activity, people will select the neighborhoods that physically support their preferred type of activity without exception, and the characteristics of these neighborhoods promote their preferred type of activity. However, we have little justification for the belief that these assumptions hold in reality (Levine, 2005). A neighborhood self-selection process involves many factors other than neighborhood preferences. Schwanen and Mokhtarian (2004) suggested that residential mismatches between preferences and actual choices arise from complex residential choice processes and dynamics in life course and attitudes. Disagreement among household members, limited monetary resources, travel time to work, and dwelling size can make the choice process complex, and ultimately the decision may be incongruent with individuals' preferences concerning the physical features of environments. Dynamic changes in residential preference over time also generate dissonance. Having a child is an especially important factor that promotes a transition from a pro-urban attitude to a pro-suburban attitude (Talen, 2001). Furthermore, environmental characteristics supporting physical activity or walking represent only one aspect of the built environment. In selecting a residential neighborhood, people consider other physical attributes—such as aesthetics, historical features, or house type—that are believed to be irrelevant to physical activity or walking. Therefore, how one defines the preference toward physical attributes of neighborhoods and whether one chooses to live in the preferred type of neighborhood may be more important than whether individuals prefer pedestrian or auto-oriented neighborhoods.

As a considerable level of mismatch between preferences and choice is likely to exist, it seems reasonable to expect that those who prefer highly urban neighborhoods but live in suburban neighborhoods act differently from those who eagerly seek to live in such neighborhoods (Cao, 2010). A handful of studies have examined the relative influence of neighborhood mismatch and neighborhood locations on travel behaviors (Schwanen and Mokhtarian, 2004; Schwanen and Mokhtarian, 2005a; Schwanen and Mokhtarian, 2005b; Levine et al., 2005; Frank et al., 2007).

Schwanen and Mokhtarian conducted a series of studies on the subject of neighborhood-type dissonance using data from the San Francisco Bay Area. In their studies, they introduced the concept of residential match and mismatch. A residential matching group was composed of true urbanites who preferred urban land use and lived in urban areas as well as true suburbanites who preferred suburban areas and lived in such areas. A residential mismatched group was composed of dissonant urban dwellers who preferred suburban land use but lived in urban areas and dissonant suburban dwellers who preferred urban land use but lived in suburban areas. The researchers found that, for commute mode choice, the influence of the residential location prevailed over the traveler’s preferences in the suburban neighborhood. In the urban neighborhood, the relative contributions of preferences and residential locations were balanced (Schwanen and Mokhtarian, 2005a). With regard to the weekly distance traveled by private vehicle

(Schwanen and Mokhtarian, 2005b), residential location had a stronger influence than preferences toward the environment in general. Both of the studies found that dissonant urban residents were more likely to commute by private vehicle than consonant urbanites were but were not quite as likely to do so as true suburbanites.

Similarly, Frank et al. (2007) classified participants into four groups based on their neighborhood's walkability and their preferences. Then they conducted descriptive analyses to compare the mean percent walked and the mean vehicle miles driven within each of the four groups. The study indicated that walkable environments may result in increased walking and reduced vehicle use, but neighborhood dissonance largely weakened those associations regardless of neighborhood location.

Unlike studies of travel behavior, no study has examined the effects of residential mismatch on recreation-related activity or physical activity. In particular, environmental correlates of physical activity are important for those who are interested in public health outcomes. Our hypotheses are based on a simple conceptual framework. I defined preference concerning environmental characteristics in terms of two categories: pro-urban locational features or pro-suburban locational characteristics.

If personal preferences toward environmental characteristics are more strongly associated with an individual's behavior, consonant groups are more likely to be active than dissonant groups, regardless of their actual residential locations. If the physical characteristics of neighborhood locations are more strongly associated with behavioral outcomes, those who live close to the main core of the city will be more active than those who live in the suburbs, regardless of their preferences toward environmental characteristics.

5.3. METHODS

a. Study Areas and Study Participants

Data was collected from two related projects assessing the relationship between residential environments and behaviors in two U.S. areas: the northern sector of Minneapolis–St Paul metropolitan area and Montgomery County, Maryland in the Washington DC metropolitan area. Although the two projects were conducted independently, they followed a similar research design and shared common exposure and outcome measures. The combination of data from two sites would offer the ability to compare results between sites and enhance the external validity of the findings (Rodriguez et al., 2008).

For the Twin Cities, a stratified cluster design was used. One hundred thirty neighborhood areas, each 805*805 meters, were identified and stratified into high, medium or low categories across the dimensions of gross population density and street connectivity. To maximize variability, the study randomly selected 36 areas that ranked high or low on each of the two dimensions. In the second stage, approximately 20 residents were randomly sampled from each area for an original sample size of 716 persons in total. Inclusion criteria included aged 25 year or older, primary residence in one of the 36 neighborhoods, not out of town during week of data collection, and self-reported ability to walk unaided for 20 minutes (Oakes et al., 2007; Forsyth et al., 2007).

Montgomery County, Maryland contains 318 CAZs (Community Analysis Zone). Each of the CAZs was characterized according to their development characteristics (density of population, employment, open space and housing), motorized activity (proximity to bus and rail, population percentage taking transit commuting to work in

2000, and roadway and bus route density), and pedestrian infrastructure (sidewalk connectivity, sidewalk coverage and population percentage walking or cycling to work in 2000). A built environment score was then used as a basis to classify zones into one of three types of built environments using factor and cluster analysis: high (30 zones), middle (135 zones) and low (153 zones) supportive of walking. Two zones were then selected at random from the high group, two from the middle group and one from the low group. 293 participants in Montgomery County enrolled in the studies between January 2005 and September 2006.

Among a total of 1008 individuals (715 is the Twin Cities and 293 in Montgomery County), 612 in the Twin Cities and 255 in Montgomery County completed questionnaire for socio-demographic characteristics, neighborhood selection, and walking and physical activity patterns.

b. Variables

Neighborhood Location

Five measures were used to identify neighborhood location (Table 5.1). First is the distance from main core area of each metropolitan area, which is expected to be associated with the density of the neighborhood and the intensity of development. The main core area in DC Metropolitan area was defined as Dupont Circle metro-station. In Twin Cities, two main core areas were defined; Minneapolis Convention Center in Minneapolis and State Capitol in St. Paul. A shorter network distance to the core area was used. Network analysis in ArcGIS 9.2 was used to calculate network distances from the selected core area to the center of each neighborhood.

The second measure to characterize neighborhood locations is regional job accessibility. The scope of the region for working was defined based on commuting distances. Since more than 80 percent of commuting distances are less than 20 miles (Transportation Statistics Annual Report, 2008) in the United States, all census-defined Traffic Analysis Zones (TAZ) within 20 miles from the focused study areas were used for calculating regional accessibility measures.

TABLE 5.1 Neighborhood Location Variables and Dimensions

Dimensions	Variables	Source
Regional job center	Distance from downtown	TIGER 2009
	Regional job accessibility	CTPP 2000/Census 2000
Regional transportation system	Distance from rail stations (Montgomery County only)	Census 2000/TIGER 2009
	Distance from highway	Census 2000/TIGER 2009
Regional park system	Regional park accessibility	Tele Atlas North America 2008

Among the various approaches used to measure accessibility, the gravity approach has been widely adopted because it provides the great advantages of being easily understandable, less demanding on data, and able to show spatial variations (Baradaran and Ramjerdi, 2001). However, the gravity approach also has limitations. First, the estimation of accessibility using the gravity approach is largely dependent on the value of the distance decay parameter, but the parameter cannot be determined with empirical data. Second, gravity measures quickly increase to infinity when the distances approach zero because the functional form relies on a negative exponential function.

As an alternative, a Gaussian function, which is widely used in statistics describing normal distributions, was used for calculating regional job accessibility. I used Gaussian distribution as a distance-weight function. The graph of a Gaussian function is a symmetrical bell curve, and the basic functional form of Gaussian distribution is

$$f(x_{ij}) = ae^{-\frac{(x_{ij}-b)^2}{2c^2}}$$

e: Euler's number
a: the height of the curving function
b: the position of the center of the peak
c: the width of the bell
X_{ij}: the distance between census block *i* and *j*

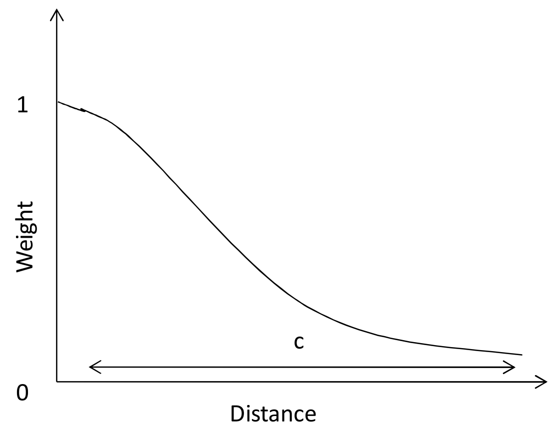


FIGURE 5.1 Gaussian Distribution as a Distance-Weight Function

In calculating job accessibility, the values of *a* and *b* are set to 1 and 0, respectively, and the value of *c* is determined by the standard deviation of distances between census block groups and jobs. Regional job accessibility of census block *i* is the sum of distance-weighted number of jobs within a region. Higher accessibility value indicates better access to jobs in a region. The primary data source that this study used to identify job locations was the Census Transportation Planning Package (CTPP) 2000, Part II, at the TAZ level.

The third and fourth measures are the shortest network distance to a rail station and to a highway ramp. Accessibility of the neighborhood in a region depends largely on the regional transportation infrastructure, because proximity to the regional transportation infrastructure makes it easier to reach various destinations within a short amount of time. A relative location from rail and highway networks is important regional transportation infrastructure to represent the geographic locations of neighborhoods. However, as a commuter rail system has not been operated in the Twin Cities until June 2004, I did not consider the shortest distance to a rail station in the analysis of the Twin Cities. Using network analysis in ArcGIS 9.2, the network distances from the center of each neighborhood to the closest rail station and highway ramp were calculated.

The fifth measure was regional park accessibility. Park and recreational services are essential infrastructure elements in planning (Mertes and Hall, 1995). Our calculation of this measure was based on methods proposed by Mertes and Hall (1995). First, each park was classified as one of four classes based on size: neighborhood park (<20 acres), community park (<50 acres), large urban park (<200 acres), and regional park (>200 acres). The service areas for these classes were ½ mile, 3 miles, 5 miles, and 10 miles, respectively. The LOS of each park was defined as the size of the park divided by the population located within the service area of the park. The regional park accessibility of a neighborhood was defined as the sum of LOS of each park classification.

Regional park accessibility = LOS of neighborhood parks within ½ mile + LOS of community parks within 3 miles + LOS of large urban parks within 5 miles + LOS of regional parks within 10 miles

Preference for Residential Location

Participants were asked to indicate their reasons for moving. Participans in both study sites filled out the Neighborhood Quality of Life Study (NQLS) survey developed by Sallis and Saelens (2003). For each question, participants selected a response on a 5-point Likert-type scale ranging from ‘strongly disagree’ to ‘strongly agree’, with higher scores indicating more important environmental characteristics. Items relevant to participants' preference for living in a highly urban location included those pertaining to 'closeness to job or school', 'closeness to public transportation', 'desire for nearby shops and services', and 'access to freeways' (Table 5.2). The numerically coded answers were summed to represent preferences for residential locations.

Access to freeways and closeness to job is not necessarily features of highly urban locations. However, our exploratory analysis showed that the distance to the closest highway ramps (Montgomery; τ=0.57, Twin Cities; τ=0.68) and regional job accessibility (Montgomery; τ=-0.83, Twin Cities; τ=0.-0.76) were highly correlated with the network distance to the main core of the city. Further, participants' responses regarding access to freeways and closeness to job or school were positively correlated with desire for nearby shops and services and closeness to public transportation.

TABLE 5.2 Preferences for Residential Location (from NQLS Survey)

Question: Main reason for selecting current residential location					
	Strongly disagree			Strongly agree	
closeness to job or school	1	2	3	4	5
closeness to public transportation	1	2	3	4	5
desire for nearby shops and services	1	2	3	4	5
access to freeways	1	2	3	4	5

Outcomes

This study used six outcome measures from two data sources. First, data on physical activity outcomes were derived from the International Physical Activity Questionnaires (IPAQ), which assessed the frequency and duration of activity over the preceding seven days. Reported transportation-related, recreation-related and total physical activity were transformed into metabolic equivalent (MET) values to facilitate the measurement of the energy cost of physical behaviors. The value of 1 MET represents the typical energy cost at rest of an average individual. The variables used from IPAQ were (1) transportation-related physical activity METs/week, (2) leisure-related physical activity METs per week, and (4) total physical activity METs per week.

The second data source was travel diaries. In both study sites, participants used slightly different travel diaries. Participants in the Montgomery County site used a location diary (Cho et al., 2011). This diary required participants to fill in trip start and arrival times, mode of travel, and location of activity in a closed-ended format. The participants in the Twin Cities site used a modified form of the National Household Transport Survey (NHTS) (Forsyth et al., 2007). Perhaps the main difference between the two types of diary is the protocol for filling in a chain of subsequent travel events. The NHTS diary was designed to enable the recording of a multi-mode travel event in a single row, such as walk-car or bus-walk, whereas the location diary was designed to fill out each trip separately by mode of travel. The variables derived from the travel diary were (1) mean number of walking trips per day, and (2) the proportion of by walking.

Socio-Demographic Characteristics

We used five socio-demographic variables: gender, age, marital status, employment, and household income. Gender (female: 1), marital status (married: 1), employment (employed: 1) were binary variables. Household income was converted into four categorical values: less than $30k, $30k-$60k, $60k-$100k, and more than $100k.

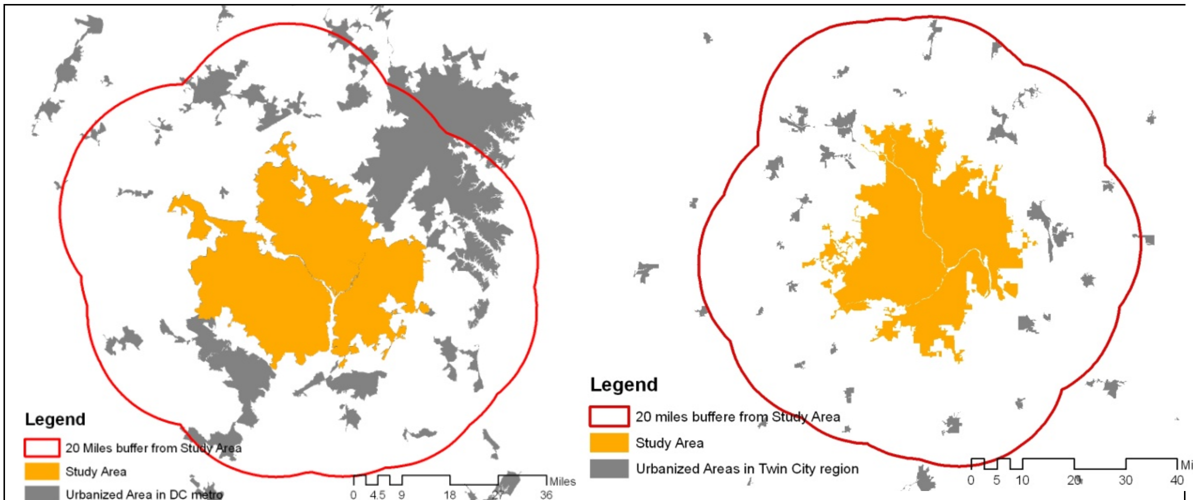
c. Analytical Methods

Principal Component Analysis (PCA)

The five variables representing neighborhood location (Table 5.1) are likely to be highly spatially correlated. Given the limited number of participants in the study, it is useful to condense these variables into a smaller set of variables that eliminate redundancy and correlation in the data (Song and Knaap, 2007). PCA was used to reduce strongly associated variables into a single factor. Typically, a scale is considered reliable if its Cronbach's alpha is 0.70 or higher, although Nunnally and Bernstein (1994) claimed that values greater than 0.80 are highly desirable. I estimated component scores to represent the location of a neighborhood.

One of the principles of the analysis was that the location of each neighborhood must be defined by considering all of the neighborhood locations in a metropolitan region, as the concept of neighborhood location in this study implies the location of a neighborhood relative to certain urban facilities in a metropolitan region. Accordingly, the five neighborhood location variables were calculated for 2193 and 1798 census block groups located within the focused study areas in DC region and the Twin Cities, respectively. (Figure 5.2) I used the census block group in which a participant resided to represent that participant's neighborhood. Because the average sizes of census block groups in the selected DC and the Twin Cities study region were 0.43 and 0.53 square miles, respectively, the size of census block groups corresponded well with the concept of a walkable radius of a quarter- to half-mile.

Using the estimated component loading on each manifest variable, the component scores of 4004 census block groups were calculated.



(c) Montgomery County, MD | (d) Twin Cities, MN

FIGURE 5.2 Selected Study Areas in Montgomery County, MD and the Twin Cities, MN

Classification of Residential Preferences and Actual Residential Locations

As the estimated component scores indicating actual neighborhood locations were standardized values, with the mean centered on zero, I defined neighborhoods in highly urban locations as those having scores higher than mean values (i.e., positive component scores) and neighborhoods in suburban locations as those having negative scores.

Residential preferences were also reduced to two dimensions: participants having higher than median values were classified as pro-highly urban location, and participants having lower than median values were defined as pro-suburban location.

Based on actual residential location and preference for living in urban locations, the participants in each neighborhood were classified into one of four groups: true urbanites (TU) who prefer living in highly urban locations and actually live in highly urban areas, dissonant urbanites (DU) who prefer living in suburban locations but live in highly urban areas, dissonant suburbanites (DS) who prefer living in highly urban locations but live in suburban locations, and true suburbanites (TS) who prefer living in suburban locations and live in suburban areas. This classification is identical with Schwanen and Mokhtarian's approach (2005a). TS was a reference group. Three physical-activity and three walking-outcome variables were regressed on the classification of residents and socio-demographic factors.

Ordinal Logistic Regression

Ordinal logistic regression models were used to minimize the impact of measurement error, as the measurement of behavioral patterns was not thought to be sufficiently precise (Oakes et al., 2007). Outcome measures were classified in terms of five ordered categories based on percentiles.

I conducted a Brant test for each model in order to test the proportional odds assumption. Because participants at the two study sites were spatially clustered, all models used robust standard errors. I compared models with and without the neighborhood location variable for each site. Thus, this study employed four models for each outcome variable.

Using the Bayesian information criterion (BIC), I compared the fit of multiple models. The BIC is a criterion for model selection with different numbers of parameters. By introducing a penalty term for the number of parameters in the model, the BIC solves the overfitting problem caused by adding an excessive number of parameters. The analysis was conducted using STATA 9.2. I used a 95% level of confidence to determine statistical significance.

5.4. RESULTS

a. Classification of Residential Preferences and Actual Residential Locations

Table 5.3 contains the results of this exploratory factor analysis for 2193 and 1798 census block groups in the focused study area of DC and the Twin Cities metropolitan areas. The standardized Cronbach's alphas of the location factor were 0.880 and 0.846 for the DC and Twin Cities areas, respectively. A higher location component implies higher regional job accessibility, lower regional park accessibility and proximity to the main core area, rail stations, and highway ramps. Based on our definition of regional park accessibility, neighborhoods close to the main core are tend to have lower level of service, because population density of the neighborhoods are higher and large-scale parks are more concentrated at the edges of cities. The standardized Cronbach's alphas of the location component were 0.880 and 0.870 for the DC and Twin Cities areas, respectively. The estimated component loadings in the two sites had relatively consistent values, which suggest that the component score conveyed consistent meanings across two study sites.

TABLE 5.3 PCA of Neighborhood Location Factor

	Montgomery Co.	Twin Cities
Regional job accessibility	0.485	0.528
Network distance to the main core	-0.521	-0.565
Network distance to rail/metro stations	-0.481	-
Network distance to highway ramps	-0.375	-0.446
Regional park accessibility	-0.347	-0.450
Cronbach Alpha	0.880	0.870

Estimated neighborhood location scores are mapped in Figure 5.3. Overall, the spatial patterns of location scores take concentric forms; thus, neighborhoods located closer to the main core are of the region are more likely to have higher scores. However, as the scores account for job and park locations and the regional transportation system, the patterns are different from the pattern of distance from downtown.

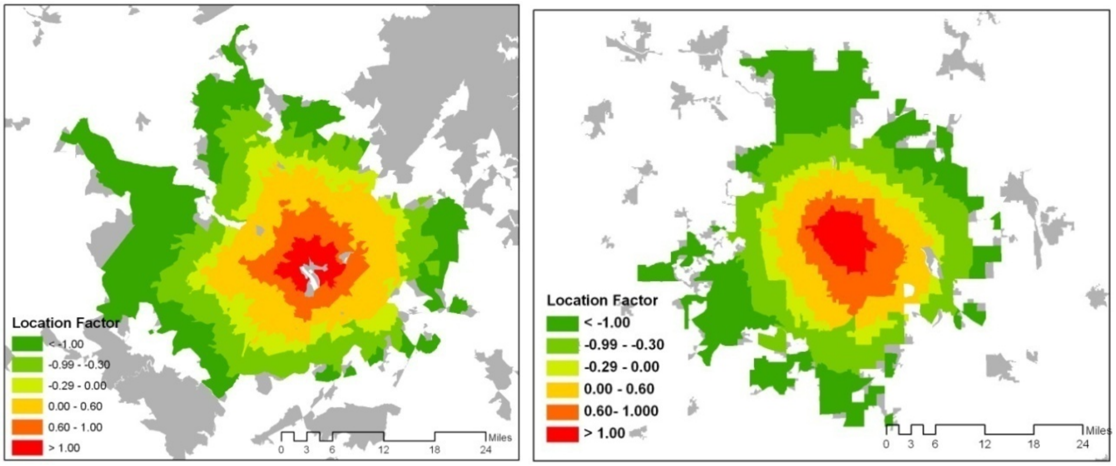


FIGURE 5.3 Neighborhood Location Scores in DC (left) and the Twin Cities (right)

Accordingly, 136 participants in Montgomery County and 353 participants in the Twin Cities were classified as urban residents who live in the neighborhood with positive component scores, whereas 119 in Montgomery County and 259 in the Twin Cities were defined as suburban residents who live in the neighborhood with negative component scores. The mean location scores for urban and suburban residents in Montgomery County were 0.85 and -0.97, respectively. The corresponding scores in the Twin Cities were 0.52 and -0.43. Thus, the variability of location scores among Montgomery County participants was greater than among participants in the Twin Cities.

Overall 143 participants in Montgomery County and 339 participants in the Twin Cities were classified as having a preference for a highly urban location, and the remaining 112 and 273 at the Montgomery County and the Twin Cities, respectively, were defined as preferring a suburban location. The mean response scores for preferring highly urban and suburban residences in Montgomery County were 16.1 and 10.7, respectively. The scores for these groups in the Twin Cities were 14.7 and 8.8, respectively.

Table 5.4 shows the number of participants classified into group. Among the participants, 35% of those in Montgomery County and 47% of those in the Twin Cities were dissonant residents—either dissonant urbanites or dissonant suburbanites. The dissonance level was somewhat higher than the level reported in other studies (Cao, 2008; Schwanen and Mokhtarian, 2004).

TABLE 5.4 Samples classified by preference for residential neighborhood location and actual neighborhood location

Montgomery County	**Prefer highly urban**		**Prefer suburban**		**Total**
	n	**%**	**n**	**%**	
Living highly urban	79	31.0	57	22.4	136
Living suburban	33	12.9	86	33.7	119
Total	112		143		255
Twin Cities					
Living highly urban	185	30.2	134	21.9	319
Living suburban	154	25.2	139	22.7	293
Total	339		273		612

b. Descriptive Comparison between Urban and Suburban Residents

Table 5.5 compares physical activity outcomes and socio-economic characteristics by neighborhood type. Comparing mean values for physical activity outcomes with a *t* test might not be the most appropriate method, as distributions are often positively skewed (Forsyth et al., 2007). More sophisticated models for physical activity outcomes will be described in the analysis of residential mismatch. In this section, I examine differences in mean values between highly urban and suburban residents.

With regard to four IPAQ variables representing energy expenditure, urban residents in Montgomery County expended more than twice as much energy as did suburban residents for transportation purposes. This study could not find this association in the Twin Cities. Suburban residents in the Twin Cities were slightly more active than urban residents in terms of recreational walking. In Montgomery County, however, the difference between the two groups was not statistically significant. Total physical activity for the two groups was similar.

Without considering the purpose of walking activity, three outcomes derived from the travel diary indicate that urban residents walked more than suburban residents did in Montgomery County. In Montgomery County, urban residents were more likely to select the walking mode of travel, took more walking trips, and walked for a longer duration. In the Twin Cities, urban residents were more likely to select the walking mode of travel, but the differences in the number of walking trips and total duration of walking were not statistically significant.

The demographic profiles of residents in urban and suburban locations were similar in terms of gender proportion and employment status. Residents who live in suburban locations earned slightly more than residents who live in urban locations did, and a higher proportion of suburban residents were married. In the Twin Cities, residents who live in urban locations were younger than residents who live in suburban locations. Overall, residents of Montgomery County were older and earned more than residents of the Twin Cities did.

c. Neighborhood Location, Preference, and Physical Activity

Table 5.6 shows the adjusted odds ratios for physical activity outcomes. I tested the odds ratios for three outcomes for each site; thus, the table contains the results of six models. The reference group was true suburbanites. The ordinal logistic regression models included five confounders: age, gender, marital status, employment status, and household income. Brant tests showed that the proportional odds assumption was met in five of the models. The proportional odds assumption was not met in the model for recreational-purpose physical activity in the Twin Cities.

TABLE 5.5 Descriptive statistics for socio-demographics and outcome variables (Minneapolis–St. Paul, MN and Montgomery County, MD)

Variable	**Unit**	**Montgomery County, MD**			**Twin Cities, MN**		
		Suburban N=119	**Urban N=136**	**t**	**Suburban N=293**	**Urban N=319**	**t**
Energy Expenditure							
Transport physical activity	MET min per week	168.3	364.0	-3.73 **	288.2	395.6	-1.63
Recreational physical activity	MET min per week	1287.8	1336.3	-0.31	993.8	728.2	2.94 *
Total physical activity	MET min per week	2818.1	3130.4	1.01	4832.9	4601.0	0.49
Walking trips							
Share of walk mode	%	15.4	28.8	-5.50 **	12.2	15.5	-2.44 *
Duration of walking	min/day	19.1	30.6	-3.12 **	13.2	12.8	0.27
Number of walking	#/day	0.85	1.60	-4.65 **	0.60	0.73	-1.91
Socio-economic characteristics							
Age	year	51.3	50.1	0.63	48.2	44.5	3.41 **
Female	%	62.2	69.1	-1.16	65.9	64.3	0.42
Married	%	68.1	46.3	3.57 **	68.6	48.6	5.11 **
Income	Ordinal value	3.40	3.07	3.06 **	2.58	2.09	6.42 **
Work	%	74.0	63.2	1.84	70.0	73.7	-1.02

* p<0.05; ** p<0.01

In the Montgomery County models, results indicated that true and dissonant urbanites were more likely to be active than true or dissonant suburbanites. With regard to energy expenditure for transportation purposes, true and dissonant urbanites had 3.62 and 3.80 higher odds than true suburbanites, respectively. This study could not find a significant difference between true suburbanites and dissonant suburbanites for transportation-purpose physical activity. The four groups I investigated did not show any differences in energy expenditure for recreation-purpose physical activity and total physical activity. Recreation-purpose physical activity was positively associated with household income but negatively associated with employment status.

In the Twin Cities models, true urbanites had 1.87 higher odds of expending higher level of energy related to transportation physical activity than true suburbanites. Dissonant suburbanites had odds ratio slightly higher than 1 for transportation-purpose physical activity, but difference was not statistically significant. In regard to recreation-purpose physical activity and total physical activity, no significant difference between residential groups was found. Males expended more energy on transportation, recreation, and total physical activity than females. Household income was negatively associated with transportation-purpose physical activity but positively associated with recreation-purpose physical activity. In the six models I investigated, I could not find any evidence indicating that dissonant suburbanites were more active than true suburbanites.

d. Neighborhood Location, Preference and Walking

Table 5.7 shows the adjusted odds ratios for walking outcomes. We tested the odds ratios for three outcomes for each site; thus, the table contains the results of six models. The reference group was true suburbanites. Brant tests showed that the proportional odds assumption was met in five models. The proportional odds assumption was not met in the model for duration of walking in Montgomery County.

In the Montgomery County models, true and dissonant urbanites had 3.76 and 3.60 higher odds than true suburbanites with respect to the proportion by walking. They also had 3.12 and 2.94 higher odds than rue suburbanites in terms of number of walking trips. No difference was found between dissonant suburbanites and true suburbanites. For three walking outcomes, males consistently walked more than females.

In the Twin Cities models, we found much weaker associations. The only statistically significant finding was an association between the number of walking trips and true urbanites. True urbanites had a 1.52 higher odds ratio for the number of walking trips. No association was found in regard to socio-demographic factors.

TABLE 5.6 Associations between Neighborhood Location, Preference, and Physical Activity

	Transport physical activity				Recreational physical activity				Total physical activity			
	Montgomery		Twin Cities		Montgomery		Twin Cities		Montgomery		Twin Cities	
	OR	95% CI	OR	95% CI	OR	95% CI	OR	95% CI	OR	95% CI	OR	95% CI
True urbanites	3.62	[1.99,6.58] **	1.87	[1.19,2.93] **	0.94	[0.52,1.69]	0.81	[0.55,1.19]	0.85	[0.46,1.57]	0.90	[0.56,1.45]
Dissonant urbanites	3.80	[1.74,8.34] **	1.06	[0.67,1.68]	1.12	[0.57,2.20]	1.09	[0.71,1.68]	0.70	[0.34,1.41]	0.87	[0.54,1.42]
Dissonant suburbanites	1.28	[0.64,2.54]	1.53	[0.97,2.40]	0.92	[0.40,2.11]	1.36	[0.89,2.08]	1.16	[0.58,2.31]	1.31	[0.83,2.07]
True suburbanites		(reference)										
Age	0.99	[0.97,1.00]	0.99	[0.98,1.00]	0.99	[0.97,1.00]	1.00	[0.99,1.01]	1.00	[0.98,1.02]	1.00	[0.98,1.01]
Female	0.64	[0.40,1.05]	0.48	[0.35,0.67] **	1.06	[0.64,1.76]	0.65	[0.47,0.90] **	1.05	[0.65,1.70]	0.62	[0.44,0.88]
Married	1.13	[0.65,1.95]	0.83	[0.59,1.18]	0.72	[0.41,1.27]	0.65	[0.46,0.92] *	0.76	[0.44,1.30]	0.82	[0.56,1.21]
Income	0.97	[0.73,1.31]	0.80	[0.66,0.97] *	1.63	[1.24,2.15] **	1.85	[1.54,2.22] **	1.18	[0.89,1.57]	0.91	[0.75,1.11]
Work	0.99	[0.58,1.68]	0.87	[0.61,1.25]	0.47	[0.29,0.76] **	0.74	[0.53,1.02]	0.71	[0.42,1.20]	0.64	[0.38,1.10]
LL	-370		-753		-401		-954		-408		-709	
BIC	807		1577		868		1986		882		1492	
Brant[†]	0.97		0.13		0.51		0.04		0.27		0.44	

[†] Brant indicates p>chi2. To meet proportional odd assumption, the value should be larger than 0.05

* p<0.05; ** p<0.01

TABLE 5.7 Associations between Neighborhood Location, Preference, and Walking

	Share of walk mode				Duration of walking				Number of walking			
	Montgomery		Twin Cities		Montgomery		Twin Cities		Montgomery		Twin Cities	
	OR	95% CI	OR	95% CI	OR	95% CI	OR	95% CI	OR	95% CI	OR	95% CI
True urbanites	3.76	[2.16,6.56] **	1.33	[0.90,1.98]	2.10	[1.22,3.64] **	1.12	[0.77,1.63]	3.12	[1.77,5.52] **	1.52	[1.09,1.91] *
Dissonant urbanites	3.60	[1.51,8.58] **	0.94	[0.61,1.44]	1.81	[0.88,3.74]	1.00	[0.65,1.53]	2.94	[1.38,6.26] **	1.00	[0.65,1.52]
Dissonant suburbanites	1.35	[0.67,2.70]	0.98	[0.66,1.45]	1.09	[0.48,2.44]	1.03	[0.68,1.57]	1.37	[0.69,2.72]	1.03	[0.69,1.53]
True suburbanites		(reference)										
Age	0.99	[0.97,1.01]	1.00	[0.99,1.01]	0.99	[0.97,1.00]	1.01	[1.00,1.02]	0.98	[0.96,1.00]	1.00	[0.99,1.01]
Female	0.36	[0.21,0.63] **	1.01	[0.75,1.37]	0.56	[0.34,0.92] *	1.01	[0.74,1.37]	0.50	[0.30,0.83] **	1.04	[0.77,1.40]
Married	0.61	[0.34,1.10]	0.81	[0.59,1.12]	0.78	[0.46,1.34]	1.03	[0.76,1.41]	0.74	[0.42,1.28]	0.88	[0.63,1.21]
Income	1.11	[0.83,1.47]	0.85	[0.70,1.02]	0.92	[0.69,1.23]	0.99	[0.82,1.18]	0.98	[0.73,1.31]	0.95	[0.79,1.15]
Work	1.08	[0.66,1.80]	0.71	[0.50,1.01]	0.81	[0.47,1.40]	0.74	[0.51,1.07]	1.17	[0.68,2.00]	0.80	[0.57,1.13]
LL	-388		-959		-401		-965		-391		-965	
BIC	842		1994		869		2007		849		2007	
Brant†	0.08		0.24		0.02		0.1		0.12		0.93	

† Brant indicates p>chi2. To meet proportional odd assumption, the value should be larger than 0.05

* p<0.05; ** p<0.01

5.5. DISCUSSION

This study examined the extent to which patterns of individual physical activity differ by level of dissonance between residential preferences and residential locations. Our initial expectation was that, for transportation-purpose physical activity and walking, those who lived in highly urban locations would be more likely to be active than those who lived in suburban areas, regardless of their preference for neighborhoods. In contrast, for recreation-purpose physical activity, those who preferred suburban locations were expected to be more active than those who preferred highly urban locations, regardless of actual residential location. Some of the findings accorded with expectations, but others did not.

One of the notable points concerned the inconsistent results from the two study sites. With regard to transportation-purpose physical activity, true and dissonant urbanites of Montgomery County were more active than true suburbanites. However, in the Twin Cities, only true urbanites were slightly more active than true suburbanites. The same results were found with respect to the number of walking trips. Thus, for Montgomery County residents, participants living in highly urban locations were more active regardless of their preference for neighborhood type. Meanwhile, for the Twin Cities, participants living in highly urban locations were more active than suburbanites only when they preferred living in urban locations.

This result might be due to the different contextual characteristics of the two study sites. The consistent component loadings on the manifest location variables for the two sites suggested similarities in correlation structure but did not necessarily indicate a consistent mean structure for the two study sites. Overall, the DC metropolitan area is more urbanized than the Twin Cities metropolitan areas. As more jobs are concentrated in the DC area, the average job accessibility of Montgomery County was 1.4 times greater than the Twin Cities. Thus, a considerable number of neighborhoods identified as highly urban locations in the Twin Cities might not be classified as such when compared with neighborhoods in Montgomery County. In other words, urban locations in the Twin Cities might have represented moderately urban locations, whereas those in Montgomery County might have represented strongly urban locations. Perhaps a certain threshold in the degree of urbanity exists, resulting in an autonomous association with transportation-related walking or physical activity. Therefore, in a moderately urban location, both conditions—living in an urban location and having a preference for living in an urban neighborhood—should be met to be associated with travel behaviors. Meanwhile, in strongly urban locations, participants might have been active for transportation-related behavior regardless of their preferences for neighborhood type.

One of the consistent findings was no significant difference in physical activity or walking trips between true suburbanites and dissonant suburbanites. This result is consistent the finding of Schwanen and Mokhtarian (2005b) that, in suburban neighborhoods, the conditioning influence of the environment prevails over residents' preferences regarding their residential environment. These researchers pointed out that the difference between urbanites and suburbanites may result from the degree of choice available to the residents of each type of neighborhood. It is not surprising that dissonant urbanites are less likely to walk than true urbanites are, as they are still inclined to select private vehicles. However, for dissonant suburbanites, no selectable modes of travel other than private vehicles are available for trips, even though these individuals are inclined to walk or use transit systems. Thus, dissonant suburbanites may constitute the subgroup that benefits the most from relocating to walkable neighborhoods in urban locations.

With respect to recreation-purpose physical activity or total physical activity, this study could not find any meaningful associations with neighborhood locations or preference for neighborhood environment. Some studies (Rodriguez et al., 2006; Forsyth et al., 2007; Oakes et al., 2007) have suggested a possible substitution relationship between transportation and recreational-purpose activity, but this study could not find such relationships in the results. Many studies have attempted to uncover associations between urban form and recreational activity, but, in contrast to transportation-purpose activity, little or no evidence of the association has been found (Saelens and Handy, 2008). More research has reported that social relationships, personal motivation, and socio-demographic characteristics might have a greater influence than physical characteristics of the environment on recreation-related physical activity (Rutt and Coleman, 2005; Hoehner et al., 2005; Lee et al., 2006). Our results also showed that a higher household income was positively associated with recreation-purpose physical activity in both sites.

To date, measures of urban form used in the literature were developed with the primary purpose of capturing correlates with transportation activity, rather than recreational activity (Owen et al., 2007). The lack of conceptual models for explaining recreational activity as distinct from transportation activity makes it difficult to develop a plausible hypothesis about the associations between urban form and recreational activities (Rutt and Coleman, 2005). In contrast to transportation activity, quality of pedestrian infrastructure and aesthetics may be associated with recreation-purpose activity (Saelens and Handy, 2008), but those microscopic features were not considered in this study.

There is a need for theoretical models for the examination of environmental factors that are likely to be more conducive to recreational activity.

The association between environmental exposure and total physical activity is important, particularly to those who are interested in public health outcomes. The results of our study, however, suggest that planning interventions to reduce obesity rates by modifying the built environment is a very complicated process. Given that recreation-purpose and other types of physical activity are not associated with environmental factors, a realistic approach for the physical urban planner may be modifying environments in a way that encourages transportation-purpose activity. However, the connection between urban form and total physical activity is still tenuous (Lovasi et al., 2008).

The limitations of the study are mainly related to construct validity. First, for defining the preference for residential locations, four questions on a 5-point Likert scale on the NQLS survey were used. Compared to previous studies examining the preference for residential neighborhoods or attitude toward environmental characteristics (Frank et al., 2007; Schwanen and Mokhtarian, 2007), the survey I used was not designed to facilitate the accurate identification of specific preferences concerning the environment. Perhaps this is one of the reasons for the relatively high level of dissonance indicated in this study. In particular, I found a 47% dissonance rate in the Twin Cities. Such a high dissonance rate is partly attributable to the sampling method. As half of the dense neighborhoods were intentionally selected in low street connectivity areas (Forsyth et al., 2007), a sizable portion of neighborhoods in suburban locations, by our definition, have highly urban built environment characteristics such as high density or high connectivity. In sum, it was challenging to define a highly urban location or a pro-urban attitude in a valid and reliable way.

Second, this study found a considerably higher level of total physical activity in the Twin Cities than in Montgomery County. From our understanding, there is little basis for the belief that participants in the Twin Cities were significantly more active than participants in Montgomery County. Although data were collected from two research projects that followed a similar research design, the two projects were conducted independently. Both studies used IPAQ to measure self-reported physical activity. However, specific methods for the calculation of total physical activity may have differed, and the manner in which staff and participants were trained might have affected the participants' response.

From a policy perspective, the findings underscore the importance of interventions enhancing the match between actual residential location and preference in order to encourage transportation-purpose activity or walking. Dissonant suburbanites are potentially active travelers once they have an opportunity to relocate to a neighborhood in a highly urban location. Although members of this group desired to live close to jobs, public transportation, or shopping facilities, they lived in a suburban location for other practical reasons. This finding implies that interventions that are excessively focused on modifying the built environment may be misguided. Dissonant suburbanites may reside in neighborhoods in suburban locations because of disagreement among household members, limited monetary resources (Schwanen and Mokhtarian, 2004), having a child (Talen, 2001), aversion toward multiculturalism (Fennelly and Federico, 2008), or the desire to enroll children in higher-quality public schools (Fennelly and Orfield, 2008). Ideally, dissonant suburban residents will move into the city if neighborhoods in a highly urban location become more attractive and livable in every aspect. However, resolving these issues is often far beyond the control of the physical urban planner. The inclusion of sociologists and community-based participatory approaches may be important for the next wave of interventions to promote walking (Forsyth et al., 2008).

Strategies for relocating a pro-suburban population to a highly urban location might or might not be successful. In highly dense and compact metropolitan areas, such a policy might be useful. However, the study results did not indicate that in less populated regions, dissonant urbanites were more active than true suburbanites in terms of walking or transportation-purpose physical activity. Indeed, interventions designed for a consonant suburban population might not need to be very different from those for a dissonant suburban population because preference for environmental characteristics of residential neighborhoods is not an unchangeable trait. Planning interventions for non-physical elements of the city are essential. Such interventions could involve improving the quality of the public school system, reducing crime rates, and providing affordable housing and desirable jobs.

With respect to recreation-purpose or total physical activity, my study did not reveal meaningful associations between neighborhood location and behaviors. I speculate that a residential neighborhood-based approach may not be the most appropriate way to investigate association between participants' environmental exposure and recreation-purpose or total physical activity. Recent studies have adopted diverse approaches to this subject. Methods such as analyzing activity path (Guo and Ferreira, 2008; Rodriguez et al., forthcoming), identifying walking trips with GPS (Stopher et al., 2008; Cho et al., 2011) and accelerometer (Troped et al., 2008; Troped et al., 2010), connecting park characteristics and behavior (McKenzie et al., 2006; Shores and West, 2008; Shores and West, 2010), and analyzing locations of food outlets (Moore et al., 2008; Sallis and Glanz, 2009) may provide more sophisticated and plausible causal concepts that may aid in understanding associations between physical activity and urban form. These approaches may be more appropriate in revealing the environmental determinants of outdoor behaviors.

Given the weak associations among total physical activity, residential location, and preference for residential neighborhoods, it is challenging to derive substantial planning implications for healthy communities. Finding similar associations, Forsyth et al. (2008) argued that analyzing empirical data from current U.S. cities may not reveal that the characteristics of urban form promote total physical activity, as U.S cities have evolved to support sedentary behavior. Thus, even for neighborhoods in highly urban locations, proximity to job centers or transportation infrastructure may not be significant enough to influence individuals' activity levels. In Asian cities, recreational facilities and community parks tend to be located in more populated areas in order to maximize the number of people served. Perhaps a comparison with the characteristics of Asian cities will make the association more manifest.

Another perspective of the research is to examine whether specific types of people are more sensitive to urban form characteristics (Forsyth el al., 2009). Forsyth et al. (2009) showed that the behavioral patterns of the less healthy and the unemployed or retired were sensitive to the environmental characteristics of residential neighborhoods and that environmental interventions may not increase physical activity across a population. Focusing on groups that have limited mobility for physiological, social, or economic reasons is a promising approach in the effort to uncover the characteristics of immediate surrounding and behavioral patterns.

5.6. CONCLUSION

This study involved the comparison of walking and physical activity outcomes for four residential subgroups. The results showed that, for transportation-related outcomes, participants living in a highly urban location and preferring a highly urban environment were more likely to be active than those who lived in a suburban location and preferred a suburban environment. In a highly dense region, participants living in a highly urban location were more active than those who lived in a suburban location, regardless of their preferences. The results suggested that, for transportation-related outcomes, the influence of preferences might be overridden by the characteristics of neighborhood locations in a highly dense region. This study could not find any influence of preference for residential location or actual residential location on recreational-purpose or total physical activity. Modifying the built environment in a way that encourages transportation activity may not be an effective means of increasing total physical activity and reducing obesity rates in the population.

VI. CONCLUSION AND SUMMARY

A series of papers in my thesis have been based on the assumption that a neighborhood's location may influence walking or physical activity, and that this influence is separately identifiable from the influence of the neighborhood built environment.

I would summarize the main findings of each paper as follows. The introductory paper (Chapter II) showed that the neighborhood built environment and neighborhood location had a strong association after controlling for potential confounding effects of socio-demographic factors. The first paper (Chapter III) indicated that a neighborhood's location was associated with walking and transportation-purpose physical activity even when the neighborhood built environment was controlled. But it was not associated with total physical activity or recreation-purpose physical activity. The results of the second paper (Chapter IV) suggested that walking for commuting purposes might be more strongly associated with neighborhood location, whereas shopping-eating purpose walking had a stronger association with the neighborhood built environment. In the third paper (Chapter V), the association between neighborhood location and transportation-purpose outcomes became more manifest when residents' preference for neighborhood type accorded with their actual residential locations.

In the four research papers, 2050 participants' behavioral data and 3991 aggregated neighborhood data were used. Notably, my dissertation found several common results across these four papers. One of the consistent findings was a weak association between the environment, on either the local or the regional scale, and total physical activity. Although total physical activity and its correlates with environmental exposure are a very important subject for those who are interested in public health outcomes, these studies have not shown strong evidence supporting this hypothesis. Transportation-purpose physical activity was associated with physical features of walkable neighborhoods and residential locations, but transportation-purpose physical activity was only 7-10% of total physical activity. More than 90% of variations could not be explained by environmental characteristics around participants' residences. Perhaps a research design focused on the characteristics of residential neighborhoods is not appropriate. Recreational activity may occur around parks or trails. Occupational activity may occur around a workplace. The activity within a home may be strongly associated with architectural characteristics of the residence. Thus, conducting an investigation that is sensitive to the specific type of activity and its immediate context may be a more promising approach in exploring relationships between urban form and behaviors.

Second, neighborhood location may play as one of the necessary conditions rather than a sufficient condition for increasing walking. This point was addressed in Næss's work (2005) as well. He asserted that although the location of a residence is one of several conditions determining travel behaviors, it does not produce a causal effect alone. In Chapter IV, I found that those who live in a highly urban location walked more for shopping-eating purposes only when the neighborhood built environment had walkable characteristics. Residing in a highly urban location may increase walking for commuting, but this association becomes more manifest when the condition of living in a walkable neighborhood is met. In Chapter V, the results showed that those who lived in a highly urban location were active for transportation purposes only when they preferred living in a highly urban location in the Twin Cities.

Third, I used data from two study sites in Chapter II, III and V, but the results were not consistent across the two study sites. Inconsistency in findings across the two sites is not surprising, as the regional contexts of the two study areas are different. However, with regard to interpretation, such an inconsistency made it difficult to derive reliable and generalizable implications. In Chapter III and paper V, differences in sample design may be among the reasons for this inconsistency. For the Twin Cities, 36 zones were sampled from zones representing the four extreme category combinations (high density, high block size; high density, low block size; low density, high block size; low density, low block size), after which participants were recruited from these 36 zones. Meanwhile, for Montgomery County, participants were recruited from five larger zones, which were selected from high-, middle-, and low-walkability zones. Additionally, the inconsistency may be attributable to the fact that the two projects were independently conducted.

Finally, my dissertation found very consistent covariance structures in the variables representing neighborhood built environments and neighborhood locations across the two study sites. Though the two study cities were situated in completely different regional settings, the results of PCA in Chapter II indicated a remarkable similarity in the way urban form characteristics combined. In urban form studies, developing reliable and valid scales to compare environmental characteristics of multiple cities is important. It would be premature to generalize our findings from two cities to other cases in southern or far-west regions. An intriguing research question is whether other cities in the United States or other countries have consistent covariance structures in urban form characteristics.

The papers have several common limitations. First, as the association between neighborhood location and behavior was moderate, the association between the two was not reliable across statistical models, even when the same dataset was used. For instance, neighborhood location in the Twin Cities was positively associated with the proportion of by walking in Chapter II. However, when preference for residential location was considered simultaneously in paper V, I could not find significant associations between neighborhood location and the proportion of walking trips. Again, neighborhood location may be associated with travel behaviors only when other conditions, such as residing in a walkable neighborhood or preferring residence in a highly urban location, are met.

Second, I used behavioral data from two research projects and the 2009 NHTS. Admittedly, any of these is an ideal dataset to examine the main inquiries of our study. The Montgomery County and the Twin Cities datasets were originally designed to explore the association between the built environment and behaviors at neighborhood-scale; thus, they have a limited ability to explain the role of neighborhood location on a regional scale. The 2009 NHTS dataset may be more appropriate to investigate the role of neighborhood location with respect to sampling neighborhoods, but it does not provide detailed information about participants' preferences for residential location, built environment characteristics, and behavioral outcomes other than travel activity. Time and budget constraints hindered an independent study appropriately designed to examine the specific research questions of our study.

Third, I speculate that the role of neighborhood location may largely depend on the definition of study regions. In my dissertation, the focused study areas were the urbanized areas in the core county (i.e., DC in Washington, DC area, Ramsey County in the Twin Cities) and spatially adjacent counties to those. The rationale for this definition was that it offered enhanced simplicity in representing spatial urban structure. In other words, the study areas were selected in such a way that they represented a nearly mono-centric structure. For the same reason, counties in the Baltimore area and small towns and communities in the suburbs were not included in the study regions. However, this approach may have reduced the variability in neighborhood locations within study regions, which, in turn, may have made it difficult to show the role of neighborhood location in a larger regional context.

Fourth, I used the term “urban” or “suburban” to characterize participants’ residential locations. In my study, “urban” indicates relative proximity to job centers or transportation infrastructure in a given region. However, the definition of “urban” or “suburban” location can differ with context. For instance, the Regional Development Framework of the Twin Cities (Metropolitan Council, 2007) defines urban areas and rural areas, each of which occupies approximately half of the region. In its growth plan, an urban area is identical to the lands located within the Metropolitan Urban Service Area. Meanwhile, the Montgomery County Planning Department has defined an urban area as one in which streets are designed for a pedestrian environment and basic commercial services and transit service are provided at higher levels than in the surrounding suburban development (2009-2011 Growth Policy, Montgomery County Planning Department). Thus, the definition of urban area in the plan is similar with “urban built environments” in my study. Throughout my four papers, I have tried to use the terms “urban location” and “urban built environment” in a consistent manner, but I am aware that the definitions of these terms that I employ are somewhat different from their definitions in other contexts.

Finally, I defined neighborhood location as the location of a neighborhood relative to urban facilities in a region, using five variables representing a neighborhood's locational characteristics. Although each element of neighborhood location has unique implications, I had to simplify these elements and use a relatively a crude classification of neighborhood location (i.e., either residing in a highly urban location or a less urban location). A higher than moderate level of correlation within the five location variables made it difficult to reveal the relationship between each element of neighborhood location and behavior. The relative location of a neighborhood within a region can address various relationships between a neighborhood and a region, as well as between neighborhoods in a region. Is the neighborhood closely connected with adjacent neighborhoods through a rail system? Is the built environment of the neighborhood similar to that of adjacent neighborhoods? How the neighborhood is spatially related to networks of bike lanes? What is the main role of the neighborhood within the urban structure—is it a regional transportation node, a local retail center, or an administrative or civic center? Methods of defining locational characteristics of a neighborhood need to be refined to reveal the true implications of location in behavioral studies.

Despite the limitations described above, I expect that my study may provide unique contributions to practitioners and researchers. From a practical perspective, the study suggests that walkable neighborhood development in suburbs may not be as successful as planners expect. Without the provision of better public transportation service to suburban neighborhoods, physical attributes supporting walking may have limited effects on walking for commuting. Providing housing in a highly urban location with alternative forms of development may be useful, particularly when accompanying a policy of relocating pro-urban residents of suburbs to urban location.

From a research perspective, my study suggests that the relative location of a neighborhood may be associated with transportation-related behavioral outcomes, and that this association is separately identifiable from the influence of the neighborhood built environment. The causal relationship between neighborhood location and built environment is a promising research topic, as a neighborhood's location defined on the regional scale can be one of the determinants of the built environment at the local level. My dissertation found that environmental characteristics had a weak association with recreation-purpose or total physical activity. A research design investigating the association between purpose-specific activity and its immediate context may be more desirable. Further, developing conceptual theory to explain the association between each type of physical activity and urban form is an important research topic for future studies.

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