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Built environments and physical activity : improving understanding of the moderators

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Built environments and physical activity: Improving understanding of the moderators

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By

Ding Ding

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The Dissertation of Ding Ding is approved, and it is acceptable in quality and form for publication on microfilm and electronically:

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2012

DEDICATION

To my parents, my love to you is beyond words.

To my American parents Carolyn and Bill, you are the blessings of my life

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ABSTRACT OF THE DISSERTATION

Built environments and physical activity: Improving understanding of the moderators

by

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Doctor of Philosophy in Public Health (Health Behavior)

University of California, San Diego, 2012
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Background: Growing evidence supports the associations of neighborhood environments with physical activity. Understanding moderators of such associations is a critical gap in current research.

Objective: The dissertation aims to examine a series of potential moderators of the associations between neighborhood environments and physical activity. Selection of moderators was based on ecological models.

Methods: Secondary data from three separate studies were used. Chapter 2 used data from the Neighborhood Quality of Life study (NQLS), an observational epidemiological study of 2199 adults from selected neighborhoods in two U.S. regions. The moderators examined were psychosocial attributes about physical activity. Chapter 3 used data from the Senior NQLS study, a study of 880 seniors with similar design to that of NQLS. The moderator examined was the driving ability of seniors. Chapter 4 used data from the International Prevalence Study. Data were collected in 11 countries with standardized methodologies and instruments. The moderator examined was country. With each study, appropriate statistical models were selected based on the nature of data and the distribution of outcomes.

Results: In Chapter 2, psychosocial attributes (self-efficacy, social support, enjoyment, benefits, and barriers) were found to be moderators of neighborhood environments with leisure walking as the outcome, but not with transport walking or accelerometer-based physical activity as the outcome. All interactions consistently supported stronger neighborhood environments-leisure walking associations among those with less favorable psychosocial attributes. In Chapter 3, driving ability of seniors was found to be a moderator with leisure walking as the outcome, but not with transport walking or accelerometer-based physical activity or sedentary behavior as the outcome. Patterns of interactions were consistent, suggesting neighborhood environments-leisure walking associations among driving-able seniors, but not non-driving-able seniors. In Chapter 4, the associations of physical activity/walking with land use mix, sidewalks, and bicycle facilities were more consistent across countries, suggesting generalizability. Associations involving other neighborhood attributes were more variable across countries, suggesting country as a moderator of the association.

Discussion: There was evidence suggesting that psychosocial attributes, driving-ability, and country could modify associations between neighborhood environment attributes. Future studies should continue this inquiry with improved theories, conceptualization, and measurement instruments.

CHAPTER 1

Introduction

Built environments and Physical Activity

Regular physical activity offers numerous health benefits. It is effective in the primary and secondary prevention of chronic diseases, such as cardiovascular disease, diabetes, some cancers, and hypertension.[1, 2] Despite the health benefits of physical activity, the overall levels in the United States remain low. By report, more than half of the adult population did not meet recommended physical activity level and nearly a quarter did not engage in any leisure-time physical activity.[3] Based on accelerometer data, less than 5% of the US adults adhered to the physical activity recommendations.[4] Physical inactivity has led to enormous disease burden and is one of the leading preventable causes of death in the United States.[5]

Examinations of contributors to the declining rates of physical activity in the United States underline the importance of environmental change since around 1950, characterized by urban sprawls, scattered development, and car-dependent transportation.[6] In the past decade, mounting literature from public health, exercise science, leisure science, urban planning, transportation and other interdisciplinary and transdisciplinary areas has accumulated evidence for the associations of environments and physical activity.[7] This has led to a growing understanding of the role built environments play in physical activity and obesity prevention.[8, 9]

According to the Transportation Research Board and Institute of Medicine, built environments refer to “land use patterns, the transportation system, and design features that together provide opportunities for travel and physical activity.”[10] Although specific definitions and operationalization vary, built environments pertain to the physical form of a community, including elements such as land use patterns, street networks, the transportation system, landscaping, and traffic calming.[11]

Although the association between built environments and physical activity is conceptually apparent, the current empirical evidence is not yet consistent, as indicated by a large number of null associations summarized by recent reviews [12-14] and reviews of reviews.[15, 16] Since the area of built environments and physical activity is still in its infancy, limitations exist in the conceptualization and methodology of current research, including the operational definitions of environmental characteristics, conceptual models, measurement, and statistical analyses.[16-18]

To address limitations in current research, a recent study summarized gaps of research and future directions suggested by review papers on the built environment, physical activity, and obesity.[15] A few major areas of improvement were identified by various researchers, with the examination of potential moderators being the most cited suggestion. Potential moderators ranged from demographic characteristics, geographic location, to psychosocial attributes and the social environment. These potential moderators are conceptually important to understanding when, where, for whom, and under what circumstances built environments exert the most influence on physical activity.[19] Practically, understanding the moderators of the associations between built environments and physical activity helps prioritize subpopulations for whom environmental interventions may be the most effective. It also helps identify combinations of modifiable factors that are likely to lead to sustainable behavioral change.

Ecological Models

In the past two decades, there have been increasing applications of ecological models as a theoretical framework for understanding behavior and designing interventions for behavior change.[20] Ecological models emphasize multiple levels of influence on behavior and define behavior as a product of the interactions of individuals with the environment.[21]

Ecological models are particularly suitable for physical activity research as physical activity always takes place in a specific context.[22] Because of the explicit emphasis on multiple environmental influences, ecological models offer a wide range of opportunities for behavioral interventions.[21, 22] Compared to cognition-based physical activity interventions, which tend to target a small number of individuals, have small-to-moderate effect sizes,[23] and lack maintenance,[24] an ecological approach is likely to direct researchers to environmental and policy changes. Once implemented, these changes have the potential to achieve long-term, sustainable behavior change at the population level.[25] However, the potential effect of environmental and policy interventions may not be the same for all individuals.

One key principle of the ecological models is the interactions of contingencies across different levels of influence.[20, 26] In a real-world setting, individuals are influenced by multiple contingencies from different levels, and the multiplicative interactions of these contingencies are complex. Due to the conceptual and methodological challenge in testing these interactions, understanding cross-level interactions of influence remains a gap in the literature and a priority for future inquiry.

Overall objectives

The dissertation includes three analytical papers using three separate datasets, united by the overarching theme of understanding the moderators of the associations between built environments and physical activity. Paper 1 examines interactions between neighborhood built environments and psychosocial attributes in relation to physical activity among adults. Paper 2 aims to understand whether the associations of neighborhood environment s with physical activity and sedentary behavior are moderated by driving ability among older adults. Paper 3 explores cross-country variations in the associations of neighborhood environments with physical activity.

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CHAPTER 2

Interactive Effects of Built Environment and Psychosocial Attributes on Physical Activity: A Test of Ecological Models

Abstract

Background: The principle of cross-level interactions of influence on behavior in ecological models is seldom studied.

Purpose: To examine built environment × psychosocial interactive effects on physical activity.

Methods: Multi-level mixed regression analyses used data from the Neighborhood Quality of Life Study conducted in neighborhoods in two US regions (n=2199 adults). Outcomes were: 1) objectively measured moderate-to-vigorous physical activity, 2) reported transport walking, and 3) leisure-walking. Conceptually matched built environment variables were analyzed for domain-specific outcomes.

Results: With leisure walking as the outcome, built environment × psychosocial interactions were significant in 7 of 20 models tested. Directions of interactions were consistent, indicating a stronger built environment-leisure walking association in adults with less favorable psychosocial status. Little evidence supported such interactions with objectively measured moderate-to-vigorous physical activity or transport walking as outcomes.

Conclusion: The results imply that the built environment may exert stronger influence on adults who are not psychologically predisposed to be active.

Introduction

Ecological models emphasize multiple levels of influence on behaviors, such as intrapersonal, interpersonal, social, environmental, and policy.[1, 2] Compared to traditional cognition-based models, ecological models offer a wider range of intervention opportunities that have the potential for sustainable behavior change at the population level.[2, 3]

Ecological models are particularly suitable for physical activity research because physical activity occurs in specific places or contexts, and there is strong support for environmental effects or associations.[3-5] Ecological conceptualization of physical activity has extended the definition of physical activity from planned exercise to specific domains of activity for different functional purposes (i.e., occupational, recreational, transport, and household).[6] It is well accepted that ecological models should be domain- and context-specific. The conceptual congruity or "match" between environmental factors and domains of physical activity can improve explanatory value and utility of ecological models.[7, 8]

A core principle of ecological models is that influence from multiple levels can interact and exert synergistic effects on behaviors.[9, 10] Understanding these interactions is a major challenge for research, and testing such interactions is a priority for providing empirical evidence for principles derived from ecological models.[2, 11] Specifically, Sallis and colleagues recommended incorporating components of psychosocial theories into ecological models to specify hypotheses at particular levels.[12] In the context of physical activity, it is widely acknowledged that both the built environment[3, 13] and psychosocial characteristics[14] are potential correlates, and both should be targeted in interventions.[15] Understanding the interactions between the built environment and psychosocial attributes could guide the development of multi-level interventions that are being increasingly implemented for physical activity [15, 16] and obesity prevention.[17, 18] Understanding environment by psychosocial interactions could also inform the prioritization of subgroups of populations among whom psychosocial or environmental interventions could be most effective.

Only a small number of studies have examined environment × psychosocial interactions, and the findings were inconsistent. Cerin and colleagues found that access to sports/fitness facilities was more strongly related to physical activity among adults who reported lower enjoyment of, and self-efficacy for, moderate-to-vigorous physical activity.[19] Giles-Corti and Donovan tested interactions among individual, social, and environmental correlates, but did not find any significant interactions in relation to either walking or recreational physical activity.[20, 21]

The present paper examined interactions between neighborhood built environment and psychosocial variables in relation to physical activity among adults. Three physical activity outcomes were examined: 1) objectively measured moderate-to-vigorous physical activity (measured by accelerometer), 2) self-reported transport walking, and 3) self-reported leisure walking. Domain- and context-specific ecological models were used to guide variable selection and statistical analyses.

Methods

Study Design

The present cross-sectional analysis is part of the Neighborhood Quality of Life Study,[22] an observational epidemiological study designed to examine associations between neighborhood environment attributes and health behaviors and other outcomes. Data collection was conducted from 2001 to 2005 in two metropolitan areas in the United States: King County-Seattle, WA and Baltimore-Washington DC regions. These two areas were selected based on the availability of detailed parcel-level and road network data and variation in walkability.[22]

Neighborhoods (defined as clusters of census block groups) were selected based on a walkability index using data in geographic information systems[23] and census block group-level socioeconomic status (measured by Census 2000 median household income). Census block groups were deciled based on walkability and socioeconomic status, and those in walkability deciles 1-4 and 7-10, and socioeconomic status deciles 2-4 and 7-9 were selected as the sampling frame. After several selection procedures (e.g., site visits), a total of 32 neighborhoods (16 in each metropolitan area) were selected to represent wide variability in walkability balanced by socioeconomic status. More information about the study design and neighborhood selection has been provided elsewhere.[22]

Households were recruited within neighborhoods using contact information obtained from a marketing firm. An introductory letter was sent, followed by telephone calls. Eligibility criteria were 1) 20-65 years of age, 2) living in private dwellings, 3) English-speaking, and 4) ability to walk without assistance. If the initially contacted individual refused or was ineligible, another adult in the same household was invited. Upon returning a signed informed consent, participants were mailed an accelerometer followed by a survey one week later. Participants were given the option of completing the questionnaires by mail, online or telephone interview. A $20 monetary incentive was provided for participation. Among 8504 initially contacted eligible adults, 2199 completed the survey (26% participation rate). The Institutional Review Boards at San Diego State University and the Cincinnati Children's Hospital Medical Center approved the study.

Measures

Physical activity

Objective. Actigraph accelerometers (models 7164 and 71256; ActiGraph Inc; Pensacola, FL) were used for measuring moderate-to-vigorous physical activity.

Accelerometers have strong evidence of validity.[24] Participants were instructed to wear the accelerometer around the waist for seven complete days. Accelerometers recorded movement in one minute epochs. A valid hour contained no more than 30 minutes of consecutive ‘0’ counts and a valid day consisted of at least eight valid hours. Participants with less than five valid days or 66 valid hours across seven wearing days were asked to re-wear the accelerometer. Moderate-to-vigorous physical activity was determined by recorded counts of movement per minute above previously established “cut points”.[25] The average minutes per valid wearing day was the outcome variable.

Self-Report. Transport walking and leisure walking were assessed using the long version of the International Physical Activity Questionnaire, which was validated in 12 countries.[26] Questions were asked regarding frequency (i.e., number of days) and duration (i.e., minutes per day) of walking in the past seven days. Weekly minutes of walking for transport and leisure were calculated.

Neighborhood environment

Objective measures. A walkability index was calculated as a function of four environmental variables (intersection density, residential density, retail floor area ratio, land use mix) found to be associated with walking, especially transport walking.[23, 27, 28] Calculation of the index has been described in detail[23]. Measures of the four variables were obtained from parcel-based land use data, street centerline files and US census data that were incorporated into a GIS. Scores were normalized in each metropolitan area to calculate walkability using the formula: walkability = [(2×z intersection density) + (z net residential density) + (z retail floor area ratio) + (z land use mix)].[22, 23] For present analyses, walkability was computed for a 1 km street network buffer around each participant's home. The individual walkability index reflected characteristics that a participant would encounter by traveling the street network for 1 km in all directions and was expected to be related to moderate-to-vigorous physical activity and transport walking.

Data on public parks were obtained from county/local planning and recreation departments. Information on private recreation facilities was searched manually using online search engines and printed Yellow Pages.[29] Both public parks and private recreation facilities were geocoded using ArcView 3.2. The number of private recreation facilities within a 1 km street network buffer from a participant’s home and the number of public parks within or intersected by a 1 km buffer were calculated, and these variables were expected to be related to moderate-to-vigorous physical activity and walking for leisure.

Reported measures. The aesthetics and walking/cycling facilities subscales from the Neighborhood Environment Walkability Scale were included as an addition to objectively measured built environment variables. This instrument has good evidence of reliability and validity.[30] The aesthetics subscale included 6 items regarding neighborhood vegetation, cleanliness, and attractiveness (Cronbach’s alpha=0.802). The walking/cycling facilities subscale included 7 items concerning the presence, condition, and safety of sidewalks and bike paths in the neighborhood (Cronbach’s alpha=0.709). Items on both scales were rated on a 4-point scale ranging from "strongly disagree" to "strongly agree", and the mean score was used in analyses. The aesthetics scale was expected to be related to moderate-to-vigorous physical activity and leisure walking, and the walking/cycling facilities scale was expected to be related to all three outcomes.

Psychosocial variables

The study included measures of several of the most consistent psychosocial correlates of physical activity.[14] The measures were generally based on social cognitive theory.[31] Though these variables were developed mainly to explain leisure time physical activity, they were tested in relation to all outcome variables.

Self-efficacy. A subset of items from a validated scale was used (32). Participants were asked how sure they were about: 1) exercising vigorously when feeling sad or highly stressed, 2) sticking to vigorous exercise program when family and social life took a lot of time, and 3) setting aside time for regular vigorous exercise. Similar questions were asked about moderate exercise. Scores on the 6 items ranged from 1 (lowest) to 5 (highest), and the average was labeled self-efficacy for moderate-to-vigorous physical activity. The scale had good internal consistency (Cronbach's alpha=0.865).

Social support. A short version of a validated scale was used.[32] Participants were asked whether their family engaged in physical activity or offered to do physical activity with them or gave them encouragement to do physical activity. Parallel questions were asked about friends. Item scores ranged from 0 (never) to 4 (very often), and a mean of six items was computed (Cronbach's alpha=0.810).

Enjoyment. A 6-item scale was developed, with three parallel questions for vigorous and moderate physical activity. Items included general enjoyment of physical activity and enjoyment of the feeling while doing and after doing vigorous/moderate activities. Items were scored on a scale from 1 (strongly disagree) to 5 (strongly agree) with a higher score representing more enjoyment of moderate-to-vigorous physical activity. A mean score was computed (Cronbach's alpha=0.888).

Benefits. A 10-item scale was adapted from a validated instrument.[33] Participants were asked to rate each item on a scale from 1 (strongly disagree) to 5 (strongly agree). An example item was "if I participate in regular physical activity or sports, then I will feel less depressed and/or bored." Other items assessed benefits, such as improving self-esteem, meeting new people, and losing weight. The average scale score was used for analyses (Cronbach's alpha=0.886).

Barriers. A list of 15 potential barriers to regular physical activity was adapted from previously validated scales.[33] Items included lack of interest, self-discipline, time, energy, company, enjoyment, equipment, good weather, skills, facilities/spaces, good health, "how to" knowledge, feeling self-conscious, discouraged, and fears of injury. Ratings ranged from 0 (never) to 4 (very often). A mean was computed, with a higher score representing more barriers (Cronbach's alpha=0.879).

Social demographic variables

Participants reported age, gender, education attainment, family household income, ethnicity/race, marital status, and the number of people and motor vehicles in the household.

Data analysis

Multi-level mixed regression models were fitted using SPSS 17.0 to account for participants clustering within neighborhoods. The intraclass correlation coefficient (ICC) was reported for each outcome variable, denoting the proportion of variance attributable to neighborhood-level covariation among participants recruited from the same neighborhoods. Random intercept models were used with neighborhood entered as a random effect. Three physical activity outcome variables were examined: objectively measured moderate-to-vigorous physical activity, reported transport walking, and reported leisure walking. All outcome variables were log transformed to improve normality. All independent variables were grand-mean centered to improve interpretability.

In each model, one psychosocial variable, one built environment variable, and their interaction term were entered, adjusting for age, gender, education, ethnicity/race, marital status, the number of people in the household, and the number of motor vehicles per adult in the household as covariates, as well as neighborhood clustering as a random effect. Because the relationship between the built environment and physical activity is domain- and context-specific,[7, 8, 34] we used a framework from a recent review (Table 1)[35] to select and test built environment variables that were only in relation to conceptually matched physical activity outcomes. Therefore, walkability and walking/cycling facilities were tested for transport walking; private recreation facilities, public parks, walking/cycling facilities, and aesthetics were tested for leisure walking; and all built environment variables were tested for objectively measured moderate-to-vigorous physical activity. To detect possible curvilinear relationships between independent variables and the dependent variable, higher-order (e.g., squared term) main effects and interactions were entered in the model together with all lower order main effects and interactions. Higher order variables were removed from the model one at a time if they were non-significant. An alpha level of 0.05 was used to identify significant interaction terms. For significant interactions, line graphs were used to plot predicted geometric means of physical activity (anti-log minute) in relation to a built environment attribute. Two separate regression lines were plotted for individuals with high (one standard deviation above the mean) and low (one standard deviation below the mean) psychosocial characteristics.

Results

Participant Characteristics

Participants were on average 45±11 years of age, 52% were male, 74% were non-Hispanic white, 65% had a college degree, 56% were married, and 43% had an annual household income of $70,000 or more. On average, participants were living in a household of 2.7±1.4 people and had 1.0±0.5 motor vehicles per adult in the household. Based on accelerometer measures, participants engaged in an average of 33±24 minutes of moderate-to-vigorous physical activity per day. Descriptive statistics of independent variables and physical activity outcomes are presented in Table 1.

Built environment × psychosocial attribute interactions

A total of 25 models were tested with objective moderate-to-vigorous physical activity as an outcome (ICC=0.10). None of the built environment × psychosocial interactions was significant (Table 2). Ten models were tested using transport walking as an outcome (ICC=0.10). One interaction (neighborhood walkability × benefits of moderate-to-vigorous physical activity) was significant (β= -0.05, p=0.047, Table 3). Twenty models were tested with leisure walking as an outcome (ICC=0.02). Seven interactions were significant (Table 4): recreation facilities × self-efficacy (β= -0.04, p=0.006), recreation facilities × benefits (β= -0.07, p=0.003), recreation facilities × barriers (β= 0.06, p=0.006), public parks × benefits (β= -0.09, p=0.001), public parks × barriers (β= 0.07, p=0.017), walking/cycling facilities × social support (β= -0.14, p=0.049), neighborhood aesthetics × enjoyment (β= -0.19, p=0.036). No higher-order main effects or interaction effects were found in any model. All interactions with facilitating psychosocial variables had a negative direction, while both interactions involving psychosocial barriers had a positive direction, consistently suggesting a stronger built environment-walking association among those with less favorable psychosocial characteristics. Line graphs of each significant interaction are presented in Figure 1a to 1h.

Discussion

The present study demonstrated multiple significant interacting effects of the built environment and psychosocial attributes in relation to leisure walking. Findings provide limited empirical support for the principle of cross-level interactions of influence on behavior derived from ecological models.[1, 2]

All significant interactions followed a similar pattern in which the built environment appeared to have a stronger facilitating effect on walking among adults with a weaker psychosocial predisposition to be physically active. This can also be interpreted as associations of psychosocial characteristics with walking being less pronounced when the neighborhood environment supported walking. For example, in neighborhoods with fewer parks or private recreation facilities, participants with higher perceived benefits of moderate-to-vigorous physical activity spent about 15 minutes more per week walking for leisure than those with lower perceived benefits. However, in neighborhoods with more parks or private recreation facilities there was no significant difference in leisure walking time across subgroups with higher and lower benefits of moderate-to-vigorous physical activity (Figure 1-b, 1-d). Similarly, for adults with high perceived barriers to moderate-to-vigorous physical activity, time spent on leisure walking was more than 10 minutes higher among those with more parks and recreation facilities in the neighborhood. However, for adults with low perceived barriers, leisure walking remained high regardless of the number of parks or recreation facilities in the neighborhood (Figure 1-c, 1-e).

Most built environment attributes tested had significant main effects on objective physical activity and on self-reported transport and leisure walking, independent of psychosocial characteristics, as found in reviews[4, 5, 36] and previous analyses.[22, 37] A key finding from the present study was that several environmental associations were stronger among those with less favorable psychosocial attributes. In some cases (Figure 1-a, 1-b, 1-d), an activity-friendly environment almost completely compensated for a low psychosocial predisposition for physical activity. This pattern was generally similar to a few previous observational studies that examined built environment and psychosocial variables [19, 38, 39] and an intervention study that found a motivational intervention to be more effective in promoting walking in low aesthetic neighborhood conditions.[40] One interpretation is that activity-friendly neighborhood environment can help people overcome low psychosocial resources for physical activity. The pattern suggests that improving environment could be most helpful to those least inclined to be active. Perhaps improving activity-friendliness of neighborhoods can be an approach to reducing socioeconomic status or racial/ethnic disparities in physical activity.

Strength of evidence for the built environment × psychosocial interactions differed across physical activity outcomes. Only 8 out of 55 interactions tested were significant. Almost all significant interactions (7 of 8) involved leisure walking as the outcome, suggesting that significant results were not a random occurrence. The psychosocial measures were generally designed to explain leisure-time physical activity, which is thought to be mostly volitional and planned, thus more strongly influenced by theory-based psychosocial variables.[7] By contrast, transport walking may be more likely based on necessity (e.g., limited access to automobiles or public transit) or opportunity in the environment.[41]

It is notable that no significant interactions were found in relation to objectively measured moderate-to-vigorous physical activity. A possible explanation is that since most of the psychosocial and several environmental variables were particularly relevant to leisure walking, the interactive effects might be diluted by other domains of physical activity captured by accelerometers, including occupation and household. However, there were main effects of psychosocial factors, including perceived barriers (negatively) and self-efficacy (positively) related to moderate-to-vigorous physical activity in this sample.[37] The concentration of significant interactions related to leisure walking provides empirical confirmation of ecological models that are specific to physical activity domains, because the psychosocial variables were developed to explain leisure-time physical activity.[7] Within models explaining leisure walking, it was interesting that significant interactions involved all four built environment variables and all five psychosocial variables. Present findings highlight the dearth of psychosocial measures expressly developed to explain transport walking, so this is a research gap that needs to be filled.

The current study has several strengths. First, environmental attributes and physical activity measures were validated and conceptually matched, which enhanced the theoretical fidelity. Second, the study included both objective and reported physical activity measures. Third, despite minor differences, the overall patterns of interactions were similar across multiple environment × psychosocial interactions when leisure walking was the outcome. These internal replications increased confidence that results may be reflecting an important principle. The lack of significant interactions when transport walking was the outcome may provide evidence for divergent validity, since the psychosocial measures were better at explaining leisure-time physical activity, for which they were conceptually matched. Limitations of the study included the lack of psychosocial measures related to walking for transport, limited racial-ethnic diversity of the sample, lack of objective measures of some environmental variables, and lack of examination of subgroup-specific results.

Conclusions

The present study provided partial support for the principle of cross-level influence derived from ecological models,[2] which seldom has been examined.[19] There was strong evidence for neighborhood environment × psychosocial interactions, but only when the outcome was leisure walking. The consistent pattern of results was that environmental associations with walking were stronger when psychosocial scores were unfavorable. This implies that improving built environment could be most effective in helping adults who are least predisposed to be active, based on psychosocial variables like social support, barriers, and benefits. Present findings suggest that multi-level interventions that target environmental and individual change could be particularly effective, which is a principle of ecological models that has been rarely tested.[2] Because an environmental approach may be more effective among those with disadvantaged psychosocial predispositions, improved access to parks, recreation facilities, and sidewalks is a promising approach to reducing disparities in physical activity.

Table 2.1. Descriptive statistics of built environment, psychosocial variables, and physical activity outcomes

Built environment variables	Range	Mean	SD
Walkability (objective, sum of z-scores)	-5.0-13.4	0	3.2
Number of parks (objective, within 1km buffer)	0-13	3.3	2.8
Number of recreation facilities (objective, within 1km buffer)	0-27	2.5	3.6
Walking/cycling facilities (reported)	1-4	2.9	0.7
Neighborhood aesthetics (reported)	1-4	3.1	0.6
Psychosocial variables (all reported)			
Self-efficacy	1-5[a]	3.6	0.9
Social support	0-4[b]	1.4	0.9
Enjoyment	1-5[c]	4.0	0.8
Benefits	1-5[c]	4.2	0.6
Barriers	0-4[b]	1.3	0.7
	Median	Inter-quartile range	
Physical activity variables			
Total moderate-to-vigorous physical activity (objective, min/day)	27.3	15.1, 45.6	
Transport walking (reported, min/week)	60.0	0.0, 200.0	
Leisure walking (reported, min/week)	50.0	0.0, 140.0	

Table 2.2. Associations of built environment attributes, psychosocial variables, and built environment × psychosocial interactions with total moderate-to-vigorous physical activity, assessed by accelerometer[a]

		Walkability (W)			Recreation facilities (R)			Public parks (P)	
		β	*p*		*β*	*p*		*β*	*p*
Self-efficacy (SE)	W	0.03	<0.001	R	0.02	<0.001	P	0.02	0.014
	SE	0.21	<0.001	SE	0.21	<0.001	SE	0.21	<0.001
	W×SE	- 0.01	0.337	R×SE	- 0.01	0.981	P×SE	- 0.01	0.771
Social support (SS)	W	0.03	<0.001	R	0.02	<0.001	P	0.02	0.039
	SS	0.10	<0.001	SS	0.10	<0.001	SS	0.10	<0.001
	W×SS	- 0.01	0.540	R×SS	- 0.01	0.267	P×SS	- 0.02	0.785
Enjoyment (E)	W	0.03	<0.001	R	0.02	<0.001	P	0.02	0.024
	E	0.21	<0.001	E	0.20	<0.001	E	0.21	<0.001
	W×E	- 0.01	0.384	R×E	- 0.01	0.708	P×E	0.01	0.870
Benefits (Be)	W	0.03	0.001	R	0.03	<0.001	P	0.02	0.034
	Be	0.14	<0.001	Be	0.14	<0.001	Be	0.14	<0.001
	W×Be	0.01	0.958	R×Be	- 0.01	0.813	P×Be	- 0.01	0.434
Barriers (Ba)	W	0.03	0.001	R	0.02	<0.001	P	0.02	0.039
	Ba	- 0.33	<0.001	Ba	- 0.32	<0.001	Ba	- 0.33	<0.001
	W×Ba	0.01	0.117	R×Ba	0.01	0.194	P×Ba	0.01	0.137

	Walking/cycling facilities (F)			Neighborhood aesthetics (A)		
		β	*p*		*β*	*p*
Self-efficacy (SE)	F	0.02	0.369	A	0.06	0.044
	SE	0.20	<0.001	SE	0.20	<0.001
	F×SE	- 0.01	0.909	A×SE	- 0.03	0.549
Social support (SS)	F	0.04	0.143	A	0.08	<0.001
	SS	0.10	<0.001	SS	0.09	0.010
	F×SS	- 0.01	0.713	A×SS	- 0.01	0.715
Enjoyment (E)	F	0.02	0.362	A	0.06	0.038
	E	0.20	<0.001	E	0.20	<0.001
	F×E	0.02	0.594	A×E	- 0.01	0.630
Benefits (Be)	F	0.04	0.197	A	0.08	0.011
	Be	0.13	<0.001	Be	0.13	<0.001
	F×Be	- 0.02	0.618	A×Be	- 0.01	0.916
Barriers (Ba)	F	0.01	0.796	A	0.04	0.136
	Ba	- 0.33	<0.001	Ba	- 0.32	<0.001
	F×Ba	0.01	0.936	A×Ba	- 0.05	0.215

[a] All models adjusted for age, gender, education, ethnicity, marital status, number of people in the household, number of motor vehicles per adult in the household, as well as neighborhood clustering.

Table 2.3. Associations of built environment attributes, psychosocial variables, and built environment × psychosocial interactions with transport walking[a]

	Walkability (W)			Walking/cycling facilities (F)		
		β	*p*		*β*	*p*
Self-efficacy (SE)	W	0.21	<0.001	F	0.15	0.013
	SE	0.16	0.005	SE	0.14	0.013
	W×SE	0.01	0.528	F×SE	-0.04	0.667
Social support (SS)	W	0.21	<0.001	F	0.13	0.144
	SS	0.32	<0.001	SS	0.30	<0.001
	W×SS	- 0.01	0.773	F×SS	-0.53	0.496
Enjoyment (E)	W	0.21	<0.001	F	0.15	0.104
	E	0.20	0.001	E	0.18	0.004
	W×E	- 0.01	0.862	F×E	0.03	0.741
Benefits (Be)	W	0.21	0.546	F	0.17	0.060
	Be	0.05	<0.001	Be	0.01	0.896
	W×Be	**- 0.05**	**0.047**	F×Be	-0.13	0.283
Barriers (Ba)	W	0.21	0.022	F	0.15	0.092
	Ba	- 0.18	<0.001	Ba	-0.16	0.048
	W×Ba	0.03	0.222	F×Ba	-0.05	0.670

[a] All models adjusted for age, gender, education, ethnicity, marital status, number of people in the household, number of motor vehicles per adult in the household, as well as neighborhood clustering.

Bolded numbers indicate statistically significant interactions

Table 2.4. Associations of built environment attributes, psychosocial variables, and built environment × psychosocial interactions with leisure walking[a]

	Recreation facilities (R)			Public parks (P)		
		β	*p*		*β*	*p*
Self-efficacy	R	0.04	0.025	P	0.04	0.024
(SE)	SE	0.30	<0.001	SE	0.31	<0.001
	R×SE	**- 0.04**	**0.006**	P×SE	- 0.02	0.360
Social support	R	0.03	0.076	P	0.04	0.032
(SS)	SS	0.53	<0.001	SS	0.54	<0.001
	R×SS	- 0.02	0.240	P×SS	- 0.01	0.519
Enjoyment	R	0.04	0.019	P	0.04	0.030
(E)	E	0.28	<0.001	E	0.29	<0.001
	R×E	- 0.03	0.134	P×E	- 0.01	0.685
Benefits	R	0.03	0.037	P	0.04	0.051
(Be)	Be	0.17	0.051	Be	0.17	0.046
	R×Be	**- 0.07**	**0.003**	**P×Be**	**- 0.09**	**0.001**
Barriers	R	0.04	0.015	P	0.04	0.034
(Ba)	Ba	- 0.41	<0.001	Ba	- 0.42	<0.001
	R×Ba	**0.06**	**0.006**	**P×Ba**	**0.07**	**0.017**

	Walking/cycling facilities (F)			Neighborhood aesthetics (A)		
		β	*p*		*β*	*p*
Self-efficacy	F	0.22	0.006	A	0.44	<0.001
(SE)	SE	0.30	<0.001	SE	0.28	<0.001
	F×SE	0.18	0.825	A×SE	- 0.07	0.438
Social support	F	0.20	0.012	A	0.39	<0.001
(SS)	SS	0.53	<0.001	SS	0.51	<0.001
	F×SS	**- 0.14**	**0.049**	A×SS	- 0.01	0.905
Enjoyment	F	0.22	0.007	A	0.44	<0.001
(E)	E	0.28	<0.001	E	0.24	<0.001
	F×E	- 0.05	0.612	**A×E**	**- 0.19**	**0.036**
Benefits	F	0.24	0.003	A	0.48	<0.001
(Be)	Be	0.13	0.143	Be	0.10	0.255
	F×Be	- 0.05	0.703	A×Be	- 0.06	0.621
Barriers	F	0.20	0.014	A	0.44	<0.001
(Ba)	Ba	- 0.40	<0.001	Ba	- 0.37	<0.001
	F×Ba	0.06	0.607	A×Ba	- 0.07	0.532

[a] All models adjusted for age, gender, education, ethnicity, marital status, number of people in the household, number of motor vehicles per adult in the household, as well as neighborhood clustering.

Bolded numbers indicate statistically significant interactions

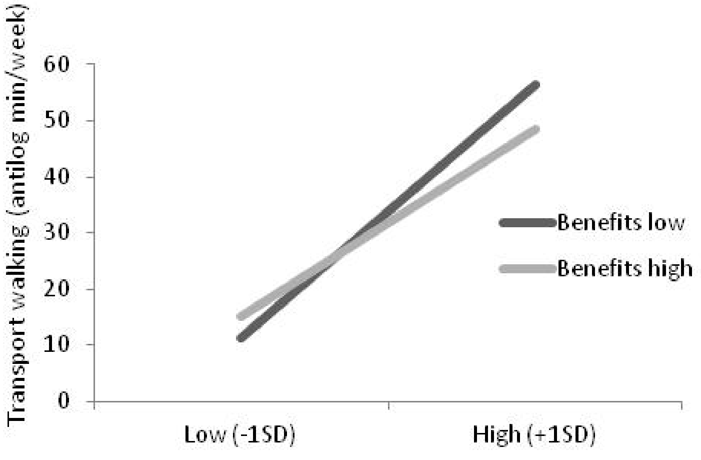

Figure 1-a Neighborhood walkability

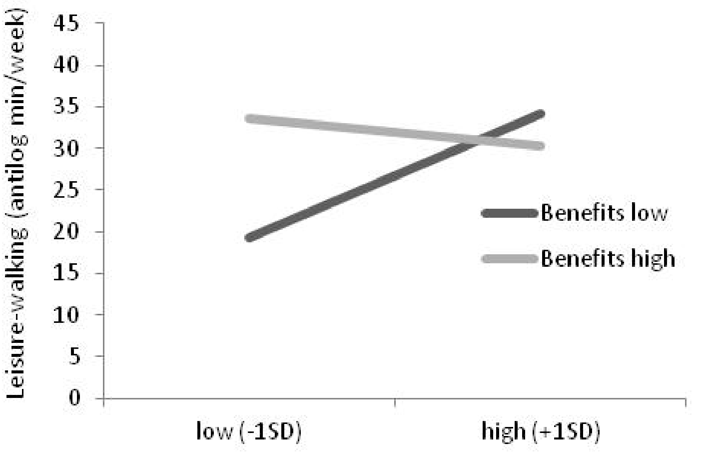

Figure 1-b Park counts

Figure Caption

Figure 2.1. (1a-1h) Plotting significant built environment × psychosocial attribute interactions with leisure walking as the outcome

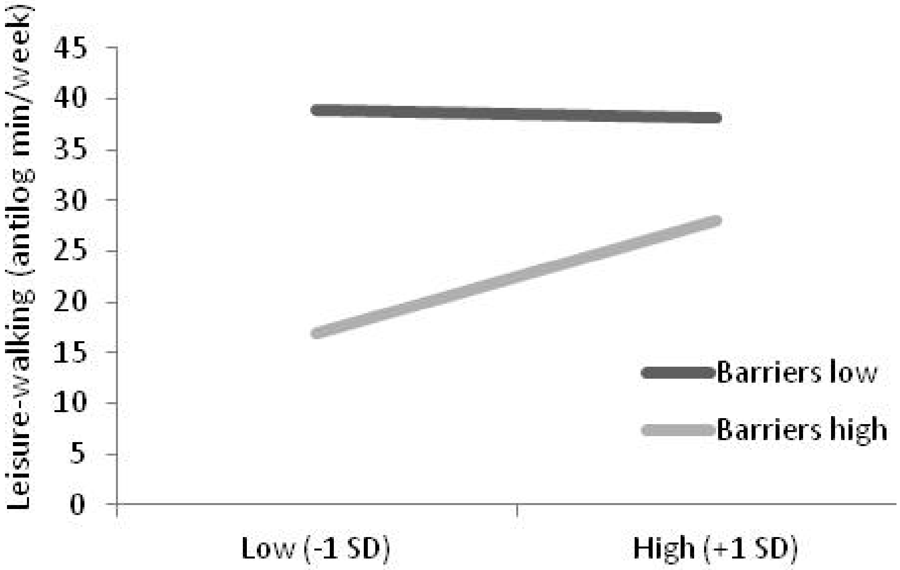

Figure 1-c Park counts

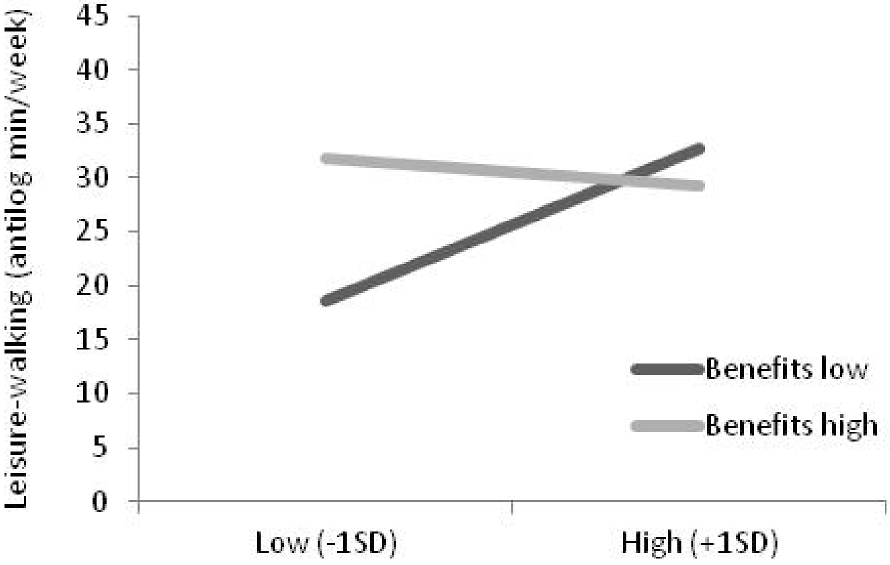

Figure 1-d Counts of recreation facilities

Figure 2.1 continued

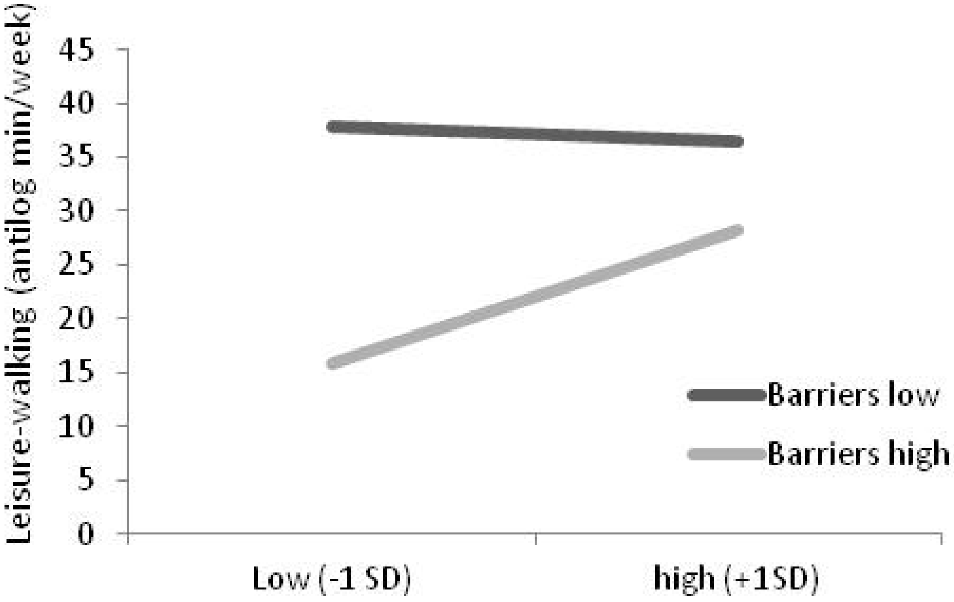

Figure 1-e Counts of recreation facilities

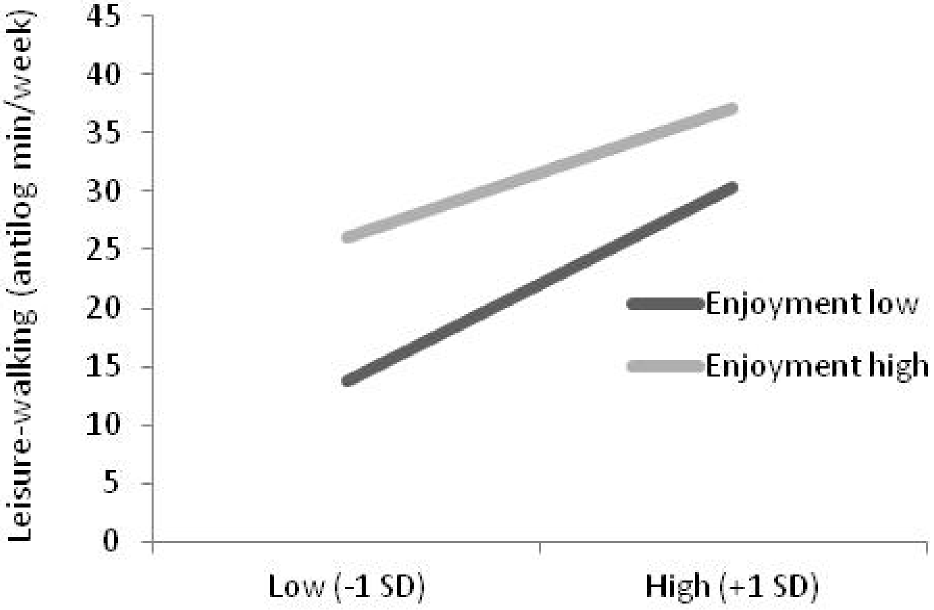

Figure 1-f Neighborhood aethetics

Figure 2.1 continued

Figure 1-g Neighborhood aethetics

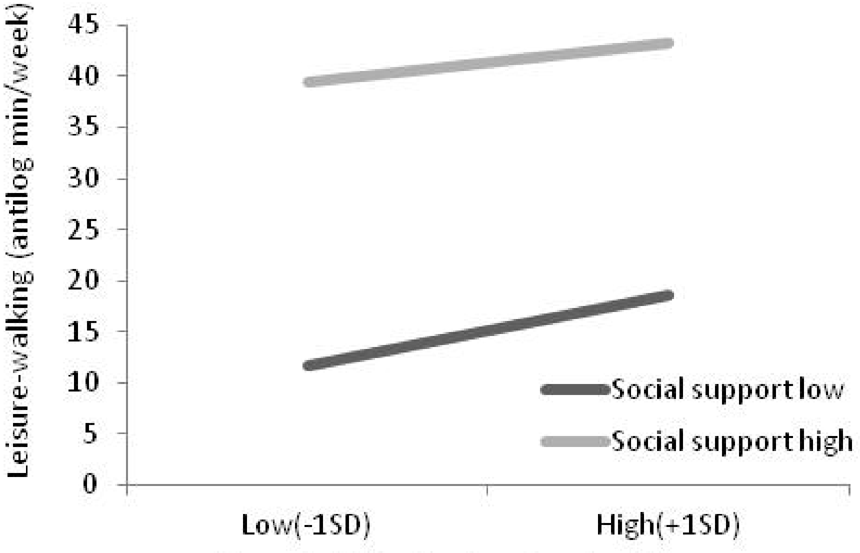

Figure 1-h Walking/cycling facilities

Figure 2.1 continued

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CHAPTER 3

Neighborhood environment, physical activity and sedentary behavior among older adults: Does the relationship differ by driving status?

Abstract

Background: There is a dearth of research on built environments and physical activity among seniors and most studies did not consider potential moderators. Some seniors do not drive and their physical activity may be more dependent on neighborhood environments.

Purpose: To examine driving status as a potential moderator of the association between neighborhood environments and physical activity among seniors.

Methods: Seniors from selected neighborhoods completed a written survey and wore accelerometers. Neighborhood environments were measured by geographic information systems and validated questionnaires. Driving ability was defined as having a driver's license, having a car in the household, and feeling comfortable to drive. Outcome variables included accelerometer-based total physical activity and self-reported transport and leisure walking. Multi-level generalized linear regression was used to model associations of each environmental variable with an outcome, specifying an environment by driving status interaction, adjusted for demographic characteristics, living situation, health conditions, and lower-extremity function. Significant interactions were further explored by stratified analyses.

Results: Non-driving-able seniors (n=154) were more sedentary but more likely to report transport and leisure walking than driving-able seniors (n=726). With objective physical activity, only objective walkability and reported land use mix were significant and the associations tended to be stronger among driving-able seniors (p

for interaction=0.061). For reported transport walking, almost all environmental attributes tested were significant among both driving-able and non-driving-able seniors. With leisure walking as the outcome, however, almost all environmental attributes were significant among driving-able seniors but none were significant among non-driving able seniors (five significant interactions at $p<0.05$).

Discussion: Driving ability moderated the association of neighborhood environments with leisure walking, in which associations were only significant among driving able seniors.

Introduction

Most industrialized nations have experienced demographic shifts characterized by population aging. The trend of aging is projected to continue at an accelerated rate in the 21st century.[1] Despite numerous health benefits of physical activity, older adults remain the least active age group.[2] In a recent study, based on national data of objectively measured physical activity, only 2.4% of US adults aged 60 or older met the recommended physical activity levels.[3]

Increasing evidence from multiple disciplines has underlined the importance of built environments to physical activity.[4-6] Due to functional declines and fears of moving outdoors,[7, 8] some attributes of built environments may be especially important to older adults,[9] particularly to those with mobility impairments.[10] However, only a small number of studies examined attributes of neighborhood environments in relation to physical activity among older adults and findings were mixed.[11, 12] Overall, neighborhood environments had more consistent associations with reported physical activity than with objectively measured physical activity.[11] Specifically, a relatively large number of studies supported associations of physical activity with access/proximity to recreation facilities[9, 13-17] and with land use features.[9, 18, 19] Reviews have recommended that to advance the field, future research on built environments and physical activity should include tests of potential moderators of the association.[20]

Sedentary behavior is ubiquitous and is an independent risk factor for multiple health outcomes.[21] The association of neighborhood environments with sedentary behavior is less known: a small number of studies have provided equivocal findings and no conclusions for associations can be drawn.[22-24] Improving understanding of environmental correlates of sedentary behavior is important to reducing sedentary behavior in specific settings and has been identified as an important research question.[25]

For older adults, transportation mobility is critical to quality of life.[26] Based on the 2001 National Household Travel Survey, older adults depended on personal vehicles for 89% of their traveling needs.[27] Although most seniors continue to drive at an old age, some eventually give up or self-regulate driving as aging progresses.[28] Driving seniors with age-related illnesses and functional declines are at higher risk for traffic related injuries and fatalities.[29] On the other hand, seniors who cease driving experience transportation deficiency [30] and face social exclusion and challenges in independent living.[31, 32] They are at risk for deteriorating physical and mental well-being and quality of life.[33] This “driving dilemma” for seniors in the United States is a consequence of land use patterns and transportation policies that have encouraged car dependence and limited options for travel among non-drivers.[34]

Considering the different transportation options for drivers and non-drivers, it is yet to be examined whether attributes of neighborhood environments play an equally important role in physical activity and sedentary behavior among drivers and non-drivers. A study of rural Japanese women found that convenient bus service was positively associated with physical activity among non-drivers, but not drivers.[35] Based on this finding, one can hypothesize that attributes of neighborhood environments may be more important to non-driving seniors since their activities are likely to be confined to the immediate neighborhood. This potential moderating effect may be more likely with leisure-time physical activity than with transport physical activity outcomes. Because leisure-time physical activity is more volitional: driving seniors living in less-activity friendly neighborhoods may drive to other locations for physical activity, therefore their activity may be less influenced by the immediate neighborhood environments.

In this study, we examined whether driving status moderated the associations of neighborhood environments with physical activity and sedentary behavior among seniors. We used objectively assessed physical activity and sedentary behavior measures as well as reported domain-specific walking behavior (i.e., for leisure and errands). Additionally, we compared and described characteristics of driving and non-driving seniors.

Methods

Procedures

The current analysis is part of the Senior Neighborhood Quality of Life Study (SNQLS), an observational epidemiological study designed to examine the relationship of neighborhood environments with multiple health and wellbeing outcomes among seniors (66 years of age or older). The study design was very similar to that of the Neighborhood Quality of Life Study,[36] and details of the study design and procedures have been published elsewhere.[9, 10] Briefly, senior adults were recruited from 228 census block groups in Seattle-King County, WA, and Baltimore-Washington, DC regions. These census block groups were selected to represent variation in socioeconomic status (measured by 2000 census median household income) and neighborhood environment attributes (measured by a walkability index). The walkability index was calculated using parcel-level land use data, state centerline data and Geographic Information Systems (GIS).[37]

Two samples were recruited from selected census block groups (i.e., neighborhoods): an independent living sample and a congregate living sample. For the independent living sample, investigators obtained basic demographic and contact information of residents from a marketing firm and sent out introduction letters to randomly selected households with residents in the target age range. For the congregate living sample, investigators contacted the resident liaison to develop a recruitment plan, and the liaison helped identify interested residents or facilitated materials distribution and communication with residents. All participants had to be 66 years of age or older, able to complete written surveys in English, free of medical conditions that affected walking for 10 feet at a time, having lived in the current neighborhood for three months or more, and not planning to move within 12 months. After obtaining written informed consent, participants were sent a survey package, an accelerometer, and instructions. Participants were provided with an incentive of $25 for completing an assessment. For the independent living sample, 719 out of 3359 eligible contacts returned the initial survey, resulting in an enrollment rate of 21.4%. For the congregate living sample, 164 out of 252 eligible contacts returned the survey (enrollment rate of 65.1%). The higher enrollment rate in the congregate sample may be a result of having a resident liaison to make recruitment more personal to seniors. All study procedures were approved by the Institutional Review Boards at Stanford University and San Diego State University.

Measurement

Independent variables

Objectively measured attributes of neighborhood environments. A GIS-derived walkability index was calculated for a 500 meter buffer around participants' homes as a composite score of four neighborhood characteristics known to facilitate walking for transportation: net residential density, land-use mix, retail floor area ratio, and intersection density.[37] The total number of public parks within a 500 meter buffer was determined using parcel-level land use data and lists from local park agencies.[38]

The total number of private recreation facilities within a 500m buffer was determined using manually searched and geocoded information about private recreation facilities (e.g., gyms, dance studios). The two numbers were summed to represent the number of locations for recreational physical activity.

Reported attributes of neighborhood environments. The Neighborhood Environment Walkability Scale (NEWS) was used to measure aspects of neighborhood environments expected to be associated with physical activity. NEWS has good reliability and validity[39, 40] and has been validated against GIS measures.[41] Subscales included residential density (6 items), land use mix-diversity (26 items), land use mix-access (6 items), street connectivity (3 items), walking/bicycling infrastructures (4 items), aesthetics (4 items), traffic safety (3 items), pedestrian safety structures (7 items), and personal safety (7 items). A NEWS item regarding proximity to bus or train stops was used as a separate variable. A micro-scale summary score was created by averaging subscale scores on walking/bicycling infrastructure, aesthetics, traffic safety, pedestrian safety structures, and proximity to bus/train stops. The micro-scale summary complemented the macro-level walkability index. Compared to macro-scale land use features, micro-scale characteristics refer to smaller “details” in the environment that usually can be changed more easily and inexpensively.[42]

Outcome variables

Objectively measured physical activity. Actigraph uniaxial accelerometers (model 7164 or 71256) were used to objectively assess physical activity. Accelerometers provide valid measures of physical activity [43] and have been widely used in research.[3] Participants were instructed to wear the accelerometer during waking hours for seven consecutive days. Movement was recorded in one minute epochs. A valid hour included no more than 30 consecutive “0”s, and a valid wearing day included at least 8 valid hours. Participants were asked to wear the accelerometer again if their data included less than five valid wearing days or less than 66 valid wearing hours across 7 days. Sedentary time, light, moderate, and vigorous physical activities were determined based on previously established cut-points.[44] Three accelerometer-based activity outcomes were used: 1) moderate-to-vigorous physical activity (≥1953 counts/min) per valid wearing day, 2) total physical activity, measured by mean counts per minute across all valid wearing days, and 3) sedentary behavior, measured by percentage of wearing time within the sedentary “threshold” (<101 counts/min) across all valid wearing days.

Reported physical activity. Walking was measured using two items from the Community Healthy Activities Model Program for Seniors, a questionnaire with reasonably good reliability and validity.[45] Participants reported frequencies during a typical week in the past four weeks that they walked to do errands, and the number of times they walked leisurely for exercise or pleasure. Both types of walking behaviors were dichotomized as “any” if participants reported walking for at least once per week and “none” if otherwise.

Potential moderator: Driving ability

Driving ability pertains to individual and environmental conditions that allow a senior to drive whenever needed. Three variables were considered essential for driving: driver’s license, car availability, and capability to drive. Seniors who reported having a driver’s license, having a car in the household, and felt comfortable driving for at least 1 mile from home were defined as “driving-able.” Seniors who did not meet all three criteria were classified as “non-driving-able” because the absence of any one condition would critically impede driving.

Covariates

Geographic location (Seattle-King County vs. Baltimore-Washington DC), reported demographic characteristics (age, gender, educational attainment, race/ethnicity, marital status), living situation (independent vs. congregate living), years at the current address were adjusted for as covariates. In addition, medical history and mobility impairment were adjusted for. Medical history was an index of having the following conditions: visual impairments, hearing problems, confusion, and depression. Mobility impairment was measured using the validated 11-item advanced lower extremity function subscale from the Late-Life Function and Disability Instrument.[46, 47]

Data analyses

Data analyses used the combined sample of independent and congregate living seniors because the characteristics of driving-able and non-driving-able seniors were similar in both samples (Table 5), and the environmental attribute× driving ability interaction effects did not differ by living situation. Due to the structure of data with individuals nested within census block groups, multi-level modeling was used. For continuous outcomes (accelerometer-based physical activity and sedentary behavior variables), mixed linear regression was used. Unstandardized regression coefficients were reported, representing adjusted mean differences in the outcome with one-unit differences in independent variables. For dichotomous outcomes (transport walking and leisure walking), mixed generalized linear regression models were fitted specifying a binary logit link. The exponents of unstandardized regression coefficients were reported, which can be interpreted similarly to odds ratios. All models adjusted for covariates and census block group number as a random effect cluster variable. Models with sedentary behavior as the outcome also included total accelerometer wearing time across all valid wearing days as an additional covariate, as sedentary time measured by accelerometer was sensitive to total wearing time.

When testing driving ability as a moderator, one neighborhood environment variable was entered together with driving ability and an interaction term of the two in each model, adjusted for all covariates. Stratified analyses examined associations of neighborhood attributes with physical activity and sedentary behavior outcomes separately for driving-able and non-driving-able seniors. An alpha of 0.05 was used for tests of main effects and 0.10 was used for tests of interactions. All statistical analyses were conducted in IBM SPSS 19.0.

Results

Descriptive statistics

The final study sample included 880 seniors aged 66 to 97 years (mean age=75 years, 56% women, 30% non-white) with complete survey data, of whom 726 were driving-able and 154 were not driving-able. Descriptive statistics of driving-able and non-driving-able seniors are presented in Table 1. Compared to driving-able seniors, non-driving-able seniors were older, more likely to be women, non-white, without a college degree, without a partner, and living in congregate living facilities. Additionally, non-driving-able seniors were more likely to have visual impairment, hearing problems, confusion, and poorer lower-extremity function. Non-driving-able seniors were also more likely to reside in higher-walkable neighborhoods by both objectively measured walkability index and self-reports (i.e., NEWS residential density, land-use mix, and street connectivity subscales), and neighborhoods that were closer to parks and recreation facilities and with better access to public transit and better infrastructure for walking and bicycling. However, non-driving-able seniors reported their neighborhoods to be less safe.

Physical activity and sedentary behavior by driving status

In unadjusted models, non-driving-able seniors had less moderate-to-vigorous physical activity, less total physical activity, and more sedentary time. In adjusted models, non-driving-able seniors still had more sedentary time but the differences in objective physical activity outcomes were no longer significant (Table 2). In both unadjusted and adjusted models, non-driving-able seniors were more likely to report transport walking and leisure walking for at least once a week in the past 4 weeks.

Neighborhood environment, physical activity, and sedentary behavior by driving status

Of all the neighborhood environment × driving status interactions tested, only one was significant for an accelerometer-based outcome: walkability × driving status related to moderate-to-vigorous physical activity (*p*=0.061). For the transport walking outcome, walking/bicycling infrastructure had a significant interaction with driving status (*p*=0.051). For the leisure walking outcome, several interactions were significant, involving street connectivity (*p*=0.012), walking/bicycling infrastructure (*p*=0.060), traffic safety (*p*=0.048), pedestrian safety structures (*p*=0.008), and overall micro-scale sum score (*p*=0.013). All but one significant interactions followed similar patterns in which the neighborhood environment –physical activity associations were stronger among driving-able seniors than non-driving-able seniors.

Considering that the small number of non-driving-able seniors may limit the power to detect statistically significant interactions, all tests of associations were stratified by driving status in subsequent analyses. Overall, associations of neighborhood environment and accelerometer-based outcomes were similar for driving-able and non-driving-able seniors (Table 3). Objectively assessed walkability and reported land use mix-access were associated with total and moderate-to-vigorous physical activities, among driving-able seniors only. Reported land use mix-diversity had positive and significant (or near significant) associations with both physical activity outcomes among driving-able and non-driving-able seniors. Reported street connectivity was negatively associated with moderate-to-vigorous physical activity among non-driving-able seniors, and negatively associated with sedentary time among driving-able seniors. Few micro-scale environmental attributes had significant associations with any of the three objective outcomes.

As Table 4 shows, several environmental attributes were significantly associated with transport walking in a positive direction among both driving-able and non-driving-able seniors. These attributes included walkability, residential density, land use mix-diversity, land use mix-access, walking/cycling infrastructure, aesthetics, pedestrian safety structures, transit access, and overall micro-scale attributes. For leisure walking, several environmental attributes were significant among driving-able seniors only, including walkability, land use mix-diversity, land use mix-access, street connectivity, walking/cycling infrastructures, aesthetics, pedestrian safety structures, and overall micro-scale attributes. No environmental attribute was significantly associated with leisure walking among non-driving-able seniors at the $p< 0.05$ level.

Discussion

The original hypothesis that built environments may play a stronger role in physical activity and sedentary behavior among non-driving-able seniors was not supported. The potential moderating effects differed by domains of physical activity and there were more significant built environments × driving ability interactions with the leisure walking outcome. Several significant neighborhood environment × driving status interactions were found and all showed a stronger neighborhood environment-leisure walking association among driving-able seniors than among non-driving-able seniors. Thus, a main finding was that driving ability was a moderator for the association between neighborhood environments and leisure walking.

With the leisure walking outcome, five of the 13 tested interactions were significant and the direction of interactions was counter to the hypothesis, as leisure walking was related to neighborhood environments among driving-able seniors only. It is unknown why leisure walking was not related to any environmental characteristics in the expected direction among non-driving seniors. One possible explanation is that since non-driving-able seniors were older, had poorer health and lower-extremity function, they might be more inclined to walk for leisure in protected areas, such as the home, yards, and public indoor places. In fact, the instrument used for assessing leisure walking explicitly prompted seniors to include treadmill walking. Walking in these private or indoor places is less likely to be related to outdoor neighborhood environments. By contrast, the higher-functioning driving-able seniors may be more influenced by neighborhood environments because they had more choices in settings to do their leisure walking, including outdoors in the neighborhood, if it was suitable. Future studies should include measures for location-specific physical activity and take into account particular contexts where physical activity takes place.[48]

Only two significant interactions were found with other physical activity outcomes. Specifically, objective walkability was positively associated with accelerometer-based total moderate-to-vigorous physical activity among driving-able seniors and not among non-driving-able seniors. Walking/bicycling infrastructure was positively associated with transport walking among both driving-able and non-driving-able seniors but the association was almost twice as strong among non-driving-able seniors. These interactions are interesting and should be further explored by future studies. In the context of the current study, they should be interpreted with caution to avoid type 1 errors. In this study, most associations of neighborhood environments with objective physical activity and reported transport walking appeared similar in both samples (Table 3, 4), suggesting little evidence for moderating effects with these outcomes.

Overall, more environmental attributes were significantly associated with reported walking than with objective physical activity measured by accelerometers. This pattern of associations is consistent with the synthesis of studies among seniors,[11] and is similar to findings from a recent semi-quantitative review among other age groups.[49] Conceptually, many attributes of neighborhood environments (e.g., sidewalks, pedestrian safety structures) are more relevant to walking, particularly to walking in the neighborhood, than to total physical activity, which includes domains that are less likely to be related to neighborhood environments, such as occupational, and household physical activity.[50-52] This behavior-specific approach was recommended for research in built environments and physical activity.[53]

Among all environmental attributes tested in the study, walkability and land-use mix (a key component of the walkability index; [37] were associated with the most physical activity outcomes. Such a walkability-physical activity association was replicated within the study across different measurement modes for environmental attributes and physical activity. The consistency of association suggests internal validity and adds to the evidence base for the association between walkability and physical activity.[54] Interestingly, although walkability has been conceptualized as being imperative to transport walking, not leisure walking,[51] this study found walkability and components of walkability to be associated with leisure walking as well. A similar finding was also reported by a previous paper using a portion of the present data.[9] These “conceptually unmatched” associations suggest that walkable neighborhoods not only provide routes and destinations for active travel,[55] but also prompt and reinforce leisure walking.

In this study, we also examined the associations between neighborhood environments and objectively assessed sedentary behavior among driving-able and non-driving-able seniors. There was little evidence suggesting a neighborhood environment main effect or a moderated effect by driving ability. This finding has added to the currently inconclusive knowledge base for neighborhood environments and sedentary behavior.[25] Conceptually, one would expect little direct association between the two, although one study argued that leisure-time sedentary activity, such as TV viewing, may be a competing choice for time that would otherwise be allocated to physical activity, and therefore may be influenced by neighborhood environments that affected physical activity.[22] However, such hypothesis may be difficult to test with total sedentary time as the outcome, as is the case in the current study. Because sedentary behavior constitutes a large proportion of one’s time, it is likely to be influenced by multiple factors outside the neighborhood. Specifying a domain-specific sedentary behavior outcome, such as leisure-time, may provide more focused tests of hypothese.[56]

The present study found that non-driving-able seniors were a distinctive group as compared to driving-able seniors. Non-driving-able seniors were more likely to be older, women, minorities, without a college degree, and without a partner. Most of these demographic characteristics of non-drivers were consistent with the literature.[57] The lack of driving ability could signify deteriorating health and impaired mobility, as indicated by lower-extremity function and key medical conditions. Based on objective measures, non-driving-able seniors were less physically active than driving-able seniors, and the inactivity was mostly due to health and physical functions, as the difference in accelerometer-based physical activity diminished once lower-extremity functions and key medical history were adjusted for. Based on self-report, non-driving-able seniors walked more, both for errands and for leisure, possibly due to lack of other transportation options. Non-driving-able seniors were also more likely to live in neighborhoods with activity-friendly environmental features. Since temporal order could not be determined from the current study, it is unknown whether seniors relocated to walkable neighborhoods after giving up driving or they gave up driving because they lived in neighborhoods where they did not need a car for daily activities. More specific questions about driving (or self-regulation of driving) need to be asked to understand the associations between neighborhood environments and driving.

Limitations

Despite methodological strengths, such as including both objective and reported measures for neighborhood environments and physical activity and using multi-level statistics to adjust for clustering, this study has several limitations. Firstly, this study did not directly assess driving behavior. Instead, three related variables (a driver's license, access to a car, and feeling comfortable to drive) were used to conceptualize "driving ability". Although in the transportation literature, having a valid driver's license is often used to crudely define a driver,[57] from a behavioral perspective, a license alone does not enable one to drive. We conceptualized the construct of "driving ability" to take into account different scenarios when seniors could not drive freely. It is a conservative measure and possibly has better sensitivity of identifying non-driving-able seniors at the expense of specificity. However, this measure was not directly validated. Future studies should directly ask participants to report recent driving behavior.

Secondly, the conceptualization of driving status as a potential moderator was based on the assumption that non-drivers were less mobile and had fewer transportation options. Although this assumption was generally supported by the literature,[30] it is possible that seniors who were classified as “non-driving-able” in this study had easy access to a vehicle as a rider (through social networks or transportation service), therefore having similar mobility to drivers. Future studies should consider other modes of transportation and examine overall mobility in addition to driving mobility.

Third, this study did not include location-specific physical activity measures. Therefore it was impossible to determine whether the location of physical activity matched that of environmental attributes. This may explain some non-significant associations that were conceptually important, such as neighborhood environments with leisure walking among non-driving-able seniors. Future studies should include combined GPS, GIS and accelerometry measures[58] or ask about walking and other physical activity that take place in the neighborhood.

Conclusions

This study examined driving ability as a potential moderator for the association of neighborhood environments with physical activity and sedentary behavior among seniors. There was some evidence suggesting moderating effects with the leisure walking outcome but little evidence with other physical activity and sedentary behavior outcomes. The patterns of interactions, where neighborhood environments had stronger associations with leisure walking among driving-able seniors, were not as expected. Most attributes of neighborhood environments were related to transport walking regardless of driving ability. This highlights the importance of an activity-friendly neighborhood environment to active aging of all seniors. To better understand the complex relationships among neighborhood environments, physical activity, and transportation mobility among seniors, future studies should identify transportation options of non-driving seniors and the locations where driving and non-driving seniors are active.

Table 3.1. Characteristics of driving able and non-driving able seniors in Senior Neighborhood Quality of Life Study

	Driving able seniors (n=726)[a]	Non-driving able seniors (n=154)[b]
Continuous variables	Mean (SD)	Mean (SD)
Age	74.6 (6.4)***	78.8 (7.6)
Body mass index	26.6 (4.7)	26.0 (5.1)
Lower-extremity function (lowest:0-highest:100)	57.7 (17.4)***	42.8 (18.4)
Neighborhood walkability	-0.38 (2.60)***	1.86 (3.70)
Residential density (unit: 100)	2.34 (0.83)	2.98 (1.27)
Land use mix-diversity[c]	2.31 (0.80)*	2.45 (0.88)
Land use mix-access[c]	2.69 (0.60)***	2.89 (0.62)
Street connectivity[c]	2.95 (0.66)*	3.07 (0.67)
Walking/cycling infrastructures[c]	2.74 (0.85)***	2.88 (0.78)
Neighborhood aesthetics[c]	3.13 (0.66)	3.12 (0.76)
Traffic safety[c]	2.74 (0.69)	2.64 (0.70)
Pedestrian safety structures[c]	2.65 (0.45)	2.65 (0.48)
Transit access	3.20 (1.00)*	3.42 (0.94)
Micro-scale sum score[c,d]	2.89 (0.48)	2.94 (0.50)
Personal safety[c]	3.42 (0.60)***	3.11 (0.70)
Categorical variables	%	%
Women	51.2***	81.2
Non-Hispanic White	71.3*	63.6
Completed college	49.5**	36.4
Married/living with a partner	57.4***	24.0
Independent living	87.6***	51.9
Visual impairment	6.1***	18.2
Hearing problems	13.2*	20.8
Confusion	9.9**	18.8
Depression	10.6	14.3
Having parks within 500m from home	59.0***	78.6
Having recreation facilities within 500m from home	42.1***	59.1

[a] n=712 for accelerometer-related outcomes; [b] n=149 for accelerometer-related outcomes

[c] Based on Neighborhood Environment Walkability Scale, scores range 1 to 4, with higher number representing more activity-friendly attributes; [d] Mean score of walking/cycling facilities, aesthetics, traffic safety, pedestrian safety structures, and transit stops

*p<0.05, **p<0.01, ***p<0.001 for comparisons between driving able and non-driving able seniors.

Table 3.2. Sedentary behavior and physical activity among driving-able and non-driving-able seniors

Objective outcomes	n	Unadjusted mean (95%CI)	Adjusted mean^a (95%CI)
Moderate-to-vigorous physical activity (min/day)			
Driving able	712	13.7 (12.5, 14.8)***	10.9 (9.2, 12.8)
Non-driving able	149	6.5 (3.9, 9.0)	11.0 (8.3, 13.7)
Total physical activity(counts/min)			
Driving able	712	189.0 (181.9, 196.1)***	172.1 (161.6, 182.7)
Non-driving able	149	130.8 (115.2, 146.4)	162.2 (146.6, 177.8)
Sedentary time (% all wearing time)			
Driving able	712	64.2 (63.5, 64.8)***	65.0 (63.9, 66.0)*
Non-driving able	149	68.1 (66.7, 69.5)	66.6 (65.0, 68.2)

Reported outcomes	n	%	Unadjusted odds ratio (95%CI)	Adjusted odds ratio^b (95%CI)
Walking for leisure				
Driving able	726	69.5	1.00	1.00
Non-driving able	154	80.5	1.96 (1.26, 3.07)**	2.28 (1.37, 3.80)***
Walking for errands				
Driving able	726	37.0	1.00	1.00
Non-driving able	154	62.3	2.84 (1.97, 4.01)***	3.57 (2.14, 5.95)***

^{a}Based on multi-level linear models. ^{b}Based on multi-level generalized linear models with a binary logit link. ^{a,b} Adjusted for age, gender, marital status, ethnicity, living situation, educational attainment, study site (Seattle vs. Baltimore), years in current location, key medical conditions, and lower-extremity functions. All models also included block group number as a random effect. The model with sedentary time also adjusted for total valid accelerometer wearing time.

*p<0.05, **p<0.01, ***p<0.001 for comparisons between driving able and non-driving able seniors

Table 3.3. Unstandardized regression coefficients (95% CI) for the associations of neighborhood attributes and accelerometry outcomes among driving able and non-driving able seniors[a]

	Total physical activity (counts/ min)		Moderate-to-vigorous physical activity (min/day)		Sedentary time (% all wearing time)	
	Driving able (n=712)	Non-driving able (n=149)	Driving able (n=712)	Non-driving able (n=149)	Driving able (n=712)	Non-driving able (n=149)
Objective						
No. parks and						
recreation	10.8	14.8	1.1	-0.9	- 0.4	- 4.5
facilities (Ref=0)	(-6.7, 28.3)	(-22.8, 52.4)	(-1.9, 4.1)	(-6.3, 4.5)	(-2.0, 1.2)	(-10.1, 1.1)
1	12.0	27.8	2.4	2.5	- 0.6	- 4.0
	(-3.8, 27.2)	(-7.1, 62.8)	(-0.3, 5.0)	(-2.7, 7.2)	(-2.0, 0.8)	(-9.2, 1.2)
2+						
Walkability	3.2*	1.1	0.7**	0.1	- 0.1	- 0.3
	(0.6, 5.8)	(-1.9, 4.1)	(0.3, 1.2)	(-0.4, 0.5)	(-0.3, 0.1)	(-0.7, 0.2)
Report						
Residential density	1.5	0.3	0.8	0.5	0.2	- 0.2
(100 housing unit)	(-7.1, 10.1)	(-8.1, 8.6)	(-0.7, 1.7)	(-0.8, 1.7)	(-0.6, 1.0)	(-1.4, 1.1)
Land use mix-	11.2**	9.2	2.5***	1.9*	- 0.3	- 0.2
diversity[b]	(2.9, 19.6)	(-3.3, 21.7)	(1.1, 4.0)	(0.1, 3.6)	(-1.1, 0.5)	(-1.9, 1.5)
Land use mix-	9.7†	9.2	2.0*	1.6	- 0.3	- 0.8
access[b]	(-1.4, 20.8)	(-8.0, 26.3)	(0.1, 3.9)	(-0.8, 4.1)	(-1.3, 0.7)	(--3.5, 3.0)
Street	2.6	-9.8	-0.7	-2.5*	- 0.9*	0.7
connectivity[b]	(-6.8, 12.0)	(-25.6, 6.1)	(-2.3, 1.0)	(-4.7, -0.2)	(-1.8, -0.1)	(-1.3, 2.8)
Walking/cycling	0.9	0.7	0.4	0.8	- 0.02	0.7
infrastructures[b]	(-6.9. 8.6)	(-13.4, 14.7)	(-0.9, 1.7)	(-1.2, 2.8)	(-0.7, 0.7)	(-1.2, 2.5)
Neighborhood	5.1	-5.6	0.3	-0.3	- 0.02	0.7
aesthetics[b]	(-4.9, 15.2)	(-20.3, 9.1)	(-1.5, 2.0)	(-2.4, 1.8)	(-0.9, 0.9)	(-1.2, 2.6)
Traffic safety[b]	-0.01	-13.7†	-0.01	-1.2	0.4	1.3
	(-0.5, 0.5)	(-29.3, 1.7)	(-1.6, 1.6)	(-3.5, 1.0)	(-0.4, 1.3)	(-0.6, 3.3)
Pedestrian safety	-3.0	0.9	0.8	0.1	0.9	0.8
structures[b]	(-17.3, 11.3)	(-20.9, 22.8)	(-1.7, 3.3)	(-3.0, 3.2)	(-0.4, 2.2)	(-1.9, 3.5)
Transit access[b]	3.0	2.3	1.1†	0.9	- 0.04	- 0.5
	(-3.5, 9.6)	(-9.1, 13.6)	(-0.1, 2.2)	(-0.7, 2.5)	(-0.6, 0.6)	(-2.0, 0.9)
Overall micro-	2.6	-5.8	1.4	0.3	0.3	1.0
scale attributes[c]	(-11.4, 16.5)	(-27.9, 16.3)	(-1.0, 3.8)	(-2.8, 3.5)	(-0.9, 1.6)	(-1.9, 3.8)
Personal safety[b]	2.0	-10.8	-0.2	0.5	0.5	2.0†
	(-9.5, 13.2)	(-27.8, 6.1)	(-2.2, 1.8)	(-1.9, 2.9)	(-0.6, 1.5)	(-0.2, 4.2)

[a] Multi-level linear models adjusted for age, gender, marital status, ethnicity, living situation (independent vs. congregate), educational attainment, study site (Seattle vs. Baltimore), years in the current location, number of key medical conditions, and mobility impairment. All models also included block group number as a random effect cluster variable. The model with sedentary time adjusted for total valid accelerometer wearing time in addition to all other covariates

[b] Based on Neighborhood Environment Walkability Scale, scores range 1 to 4, with higher number representing more activity-friendly attributes

[c] Mean score of walking/cycling infrastructures, aesthetics, traffic safety, pedestrian safety structures, and transit access

†p<0.10, *p<0.05, **p<0.01, ***p<0.001 (shaded cell indicates significant environmental attribute × driving status interactions)

Table 3.4. Odds ratios (95%CI) for the associations of neighborhood attributes and reported walking among driving able and non-driving able seniors[a]

	Transport walking (yes vs. no)		Leisure walking (yes vs. no)	
	Driving-able (n=726)	Non-driving-able (n=154)	Driving-able (n=726)	Non-driving-able (n=154)
Objective				
No. parks and recreation facilities (Ref=0)				
1	0.49† (0.93, 2.89)	0.82 (0.14, 4.81)	1.07 (0.70, 1.67)	0.61 (0.09, 3.94)
2+	4.44*** (2.72, 7.24)	3.71 (0.76, 18.17)	1.36 (0.92, 1.99)	1.08 (0.19, 6.23)
Walkability	1.34*** (1.23, 1.46)	1.57*** (1.25, 1.97)	1.11** (1.03, 1.20)	1.01 (0.86, 1.19)
Report				
Residential density (100 housing unit)	1.80*** (1.38, 2.34)	1.75* (1.08, 2.80)	1.19 (0.94, 1.49)	1.03 (0.68, 1.58)
Land use mix-diversity[b]	2.59*** (1.99, 3.35)	4.01*** (2.18, 7.39)	1.35* (1.07, 1.68)	1.02 (0.57, 1.86)
Land use mix-access[b]	5.99** (4.10, 8.76)	4.66*** (2.10, 10.38)	1.49* (1.12, 1.99)	1.35 (0.60, 3.03)
Street connectivity[b]	1.51** (1.14, 2.10)	1.36 (0.67, 2.75)	1.34* (1.04, 1.72)	0.51 (0.23, 1.17)
Walking/cycling infrastructures [b]	1.65*** (1.30, 2.12)	3.94*** (1.95, 15.64)	1.25* (1.03, 1.52)	0.68 (0.34, 1.35)
Neighborhood aesthetics[b]	1.34* (1.01, 1.80)	2.29* (1.17, 4.48)	1.30* (1.01, 1.68)	1.03 (0.51, 2.08)
Traffic safety[b]	1.20 (0.90, 1.58)	1.13 (0.59, 2.18)	1.22 (0.95, 1.55)	0.46† (0.21, 1.01)
Pedestrian safety structures[b]	2.29*** (1.48, 3.56)	2.61* (1.02, 6.69)	1.93*** (1.32, 2.83)	0.43 (0.15, 1.28)
Transit access[b]	1.63*** (1.32, 2.01)	2.01** (1.21, 3.32)	1.12 (0.94, 1.31)	0.80 (0.46, 1.38)
Overall micro-scale attributes[c]	3.10*** (1.99, 4.85)	7.03*** (2.39, 20.49)	1.73** (1.21, 2.51)	0.41 (0.13, 1.27)
Personal safety[b]	1.08 (0.77, 1.54)	1.46 (0.69, 3.06)	0.84 (0.63, 1.15)	0.52 (0.23, 4.26)

[a] Multi-level generalized linear models with a binary logit link, adjusted for age, gender, marital status, ethnicity, living situation (independent vs. congregate), educational attainment, study site (Seattle vs. Baltimore), number of months in current location, number of key medical conditions, and mobility impairment. All models also included block group number as a random effect cluster variable.

[b] Based on Neighborhood Environment Walkability Scale, scores range 1 to 4, with higher number representing more activity-friendly attributes

[c] Mean score of walking/cycling infrastructures, aesthetics, traffic safety, pedestrian safety structures, and transit access

†p<0.10, *p<0.05, **p<0.01, ***p<0.001 (shaded cells indicate significant environmental attribute × driving status interactions)

Table 3.5. Descriptive statistics of driving able and non-driving able seniors by living situation

	Independent living		Congregate living	
Continuous variables Mean (SD)	Driving-able (n=636)	Non-driving-able (n=80)	Driving-able (n=90)	Non-driving-able (n=74)
Age	73.9 (6.0)***	77.9 (7.4)	79.5 (7.3)	79.7(7.8)
Body mass index	26.6 (4.7)	25.6 (5.2)	26.6 (5.3)	26.3 (5.1)
Lower-extremity function (lowest:0-highest:100)	58.8 (17.2) ***	44.4 (17.5)	50.0 (16.6)**	41.2 (19.4)
Neighborhood walkability	-0.4 (2.5)***	1.9 (3.6)	0.1 (2.9)**	1.8 (3.9)
Residential density (unit: 100)	2.3 (0.7)***	3.0 (0.7)	2.7(1.2)	3.0 (1.2)
Land use mix-diversity[a]	2.3 (0.8)	2.5 (0.9)	2.3 (0.7)	2.4 (0.8)
Land use mix-access[a]	2.7 (0.6)**	2.9 (0.6)	2.8 (0.5)	2.8 (0.6)
Street connectivity[a]	3.0 (0.7)	2.9 (0.7)	3.0 (0.6)	3.1(0.7)
Walking/cycling infrastructures[a]	2.8 (0.8)	2.7 (0.8)	3.0 (0.8)	3.0 (0.7)
Neighborhood aesthetics[a]	3.1 (0.8)	3.1 (0.7)	3.0 (0.7)	3.2 (0.7)
Traffic safety[a]	2.6 (0.7)	2.7 (0.7)	2.7 (0.8)	2.7 (0.7)
Pedestrian safety structures[a]	2.6 (0.5)	2.6 (0.5)	2.7 (0.4)	2.7 (0.4)
Personal safety[a]	2.7 (0.8)	2.8 (0.8)	3.0 (0.8)	2.9 (0.7)
Micro-scale sum score[a,b]	3.1 (0.6)	3.1 (0.8)	3.3 (0.7)	3.2 (0.7)
Categorical variables (%)				
Women	50.4%***	75.0%	56.7%***	87.8%
Non-Hispanic White	28.2%*	38.8	32.2%	33.8%
Completed college	49.9%	41.3%	46.7%*	31.1%
Married/living with a partner	59.7%***	33.8%	41.1%***	13.5%
Visual impairment	5.2%***	17.5%	12.2%	18.9%
Hearing problems	12.4%*	22.5	18.9%	18.9%
Confusion	9.4%	15.0%	13.3%	23.0%
Depression	10.7%	13.8%	10.0%	14.9%
Having parks within 500m from home	58.6%**	77.5%	62.2%*	79.7%
Having recreation facilities within 500m from home	41.0%**	56.3%	50.0%	62.2%

[a] Based on Neighborhood Environment Walkability Scale, scores range 1 to 4, with higher number representing more activity-friendly attributes; [b] Mean score of walking/cycling facilities, aesthetics, traffic safety, pedestrian safety structures, and transit stops

*p<0.05, **p<0.01, ***p<0.001 for comparisons between driving able and non-driving able seniors.

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CHAPTER 4

Neighborhood environments and physical activity in 11 countries: Do associations differ by country?

Abstract

Background: Most studies about neighborhood environments and physical activity were conducted in a single country, primarily high-income countries. The generalizability of findings was to be determined.

Purpose: To examine whether the associations between attributes of neighborhood environments and physical activity differ by country.

Methods: Population representative samples from11 countries were surveyed using comparable methodologies and measurement instruments. Neighborhood environment × country interactions were tested in logistic regression models adjusted for age and gender. Country-specific associations were reported.

Results: Significant neighborhood environment × country interactions existed with all seven neighborhood environment variables. Land-use mix, bicycle facilities and sidewalks had the most consistent associations with physical activity outcomes. Residential density and crime-related safety had the least consistent associations across countries

Conclusion: Despite some overall differences in the associations between neighborhood environments and physical activity across countries, there was evidence supporting the generalizability of the associations involving some attributes of neighborhood environments.

Introduction

Regular physical activity reduces the risk for adverse health outcomes such as coronary heart disease, stroke, metabolic syndromes, type 2 diabetes, and some cancers.[1, 2] Despite numerous benefits of physical activity, many adults are not sufficiently active in developed nations such as the United States, Sweden, and Australia.[3, 4] Based on the World Health Organization estimates, physical inactivity accounts for a substantial proportion of the global burden of non-communicable diseases,[5] and is the fourth leading risk factor of global mortality.[6]

Population-level physical activity varies greatly by country.[7, 8] The reasons for such cross-country differences are not well understood. Improving the understanding of these differences could help guide country-specific interventions to promote physical activity. As postulated by ecological models,[9, 10] behavior, such as physical activity, is under multiple levels of influence, including the built and social environments.[11, 12] Reviews of empirical evidence suggest that neighborhood design features, such as land use mix and street connectivity, are strongly related to physical activity, primarily walking.[13-15] Recreation environments, such as parks and exercise facilities, are associated with leisure-time and overall physical activity.[16, 17] Findings regarding neighborhood traffic, crime, incivilities, and aesthetics are more equivocal.[14, 18]

To date, most studies on built environments and physical activity were conducted in single countries, primarily the United States and other high-income countries. A number of review papers identified this as a limitation and called for more geographic diversity in study locations.[16, 17, 19] A multiple-country approach is important to improving understanding of built environments and physical activity. First, environmental data collected within a single country have limited variability and may lead to underestimation of associations. Pooled analyses address this limitation by modeling environmental attributes and physical activity in multiple countries.[20] Second, studies of multiple countries allow for comparing associations across countries, which provides tests of generalizability and helps identify promising interventions that are most relevant to a specific country.[21] Conceptually, the effects of environmental attributes may vary by country as a result of cultures and other meta-contingencies[22, 23] that are uniquely present in a country.[24-26] This can be conceptualized as cross-level interactions in ecological models.[10, 27] For example, it is reasonable to hypothesize that a pedestrian-friendly environment may be more important to transport walking in countries where most people own a car and have choices for both active and passive transportation. The role of built environments may be less critical in countries where most people have no transportation options other than walking.

To improve geographic variation of studies, researchers from the United States, Australia, Belgium, and Sweden conducted studies with comparable designs to examine associations of neighborhood walkability with physical activity.[25, 28-30] Most findings from these studies supported the association of built environments with physical activity. Meanwhile, increasing literature emerged from countries in Asia,[31, 32] South America,[33] and Africa.[21] The general association of built environments with physical activity was supported by these studies despite some inconsistency.[34] Previous analyses from the same study pooled data from 11 countries and found more significant associations than most single-country studies. However, this approach could not address the generalizability of findings in each country.

The present study aims to address this generalizability issue by examining whether associations between neighborhood environments and physical activity differed by country. By examining country as a potential moderator, this approach also addressed a critical area of improvement frequently cited by studies—that is, improving understanding of moderators of the associations between built environments and physical activity.[19] Data were collected from 11 countries in five continents using common methodologies, making it possible to compare associations across countries.[8] Specifically, we first tested country× neighborhood environment interactions in relation to overall physical activity and walking. Then, we calculated country-specific estimates and compared patterns of associations across countries.

Methods

Sampling and procedures

The International Prevalence Study (IPS) was a collaborative project involving investigators from about 20 countries. The primary aim of the study was to determine nationally representative prevalence of physical activity for international comparison. Investigators were invited through the World Health Organization, the U.S. Centers for Disease Control and Prevention, and various other global health, non-communicable disease, and physical activity networks. Interested investigators needed to demonstrate capacity and agree to follow rigorous protocols to ensure comparability of data collection methods across countries. A description of the research protocols and inclusion criteria was published elsewhere.[8] Of the 24 countries that expressed interest, 20 met the inclusion criteria and conducted data collection, and 11 included an environmental survey: Belgium, Brazil, Canada, Colombia, Hong Kong (SAR, China), Japan, Lithuania, New Zealand, Norway, Sweden, and the United States. Informed consent was provided in verbal or written format from all participants and ethics approval was obtained from every participating country.

Sampling, recruitment, survey translation/adaptation, and data collection followed established protocols while allowing for minor modification in local settings.[8] In each country, the study sample was required to be 18-65 years of age (18-40 in Japan) and representative of the overall population in a country or a significant region within a country (i.e. with a population of > 1,000,000). Households were randomly selected within each country/region, and individuals within households were selected at random or by most recent birthday. Data collection was conducted in spring or fall 2002/2003 to reduce seasonal variation in physical activity. Questionnaires were either self-administered or administered by interviewers through phone or face-to-face interviews. Surveys were back-translated to English and approved before data collection.

Measures

Environmental attributes

Attributes of neighborhood environments were measured using items from the Physical Activity Neighborhood Environment Survey (PANES).[20, 35] The reliability of the questionnaire was supported in several countries.[35] Neighborhoods were defined as the area within a 10 to 15 minutes' walk from home. Seven common items were asked in all 11 countries and were used in the current analysis. Participants reported the main type of housing in their neighborhood (e.g., apartment, townhouse, single family home) as a proxy measure for residential density. Having shops and other retail destinations in the neighborhood was used as a marker for land-use mix. The presence of transit stops near home was asked because public transportation often involves walking.[36] The presence of sidewalks, bicycle facilities, and free or low-cost recreation facilities were asked as they provide opportunities and locations for physical activity. Participants reported whether crime in the neighborhood made it unsafe to go on walks at night. Except for the question on housing type, the original response options ranged from 1 (strongly agree) to 4 (strongly disagree) and were recoded as “strongly agree/agree” vs. “disagree/strongly disagree”. The item on main housing type in the neighborhood was recoded to contrast detached single-family homes (i.e., lower residential density) from the rest (higher residential density). Based on conceptual and empirical literature,[17, 37] we hypothesized that higher residential density, shops near home, transit stops, sidewalks, bicycle facilities, low-cost recreation facilities, and low crimes were activity-friendly features that should be positively associated with physical activity. We reversed coding when necessary to reflect the expected direction of associations.

Physical activity

The International Physical Activity Questionnaire (IPAQ) short format was used to assess the frequency and duration of past-week walking, moderate-intensity, and vigorous-intensity physical activity that lasted for at least 10 minutes. Questions were designed to measure physical activity across all domains, including occupational, transport, domestic, and leisure-time. Evaluation of the short IPAQ in 12 countries concluded that the questionnaire had good one-week test-retest reliability and fair-to-moderate criterion validity when compared against accelerometer total counts,[38] although IPAQ tends to overestimate physical activity.[39]

The scoring of IPAQ followed the protocol (www.ipaq.ki.se).[40] Weekly minutes of walking, moderate, and vigorous activity were calculated by multiplying the frequency (days/week) and average time (minutes/day) of each activity in the past week. To account for both time and intensity of different activities, weekly minutes of walking, moderate, and vigorous physical activity were weighted on energy requirements defined in metabolic equivalents (METs) to create a product term (MET-minutes/week). The following formulas were used: MET-minutes of walking = minutes of walking × 3.3 METs, MET-minutes of moderate physical activity = minutes of moderate physical activity × 4 METs; MET-minutes of vigorous physical activity = minutes of vigorous physical activity × 8 METs. Participants meeting any of the following criteria were classified as meeting overall physical activity recommendations: 1) 3 days of vigorous physical activity for ≥ 20 minutes/day; 2) 5 days of moderate physical activity or walking for ≥30 minutes/day; 3) 5 days of any combination of walking, moderate, or vigorous physical activity that totaled 600 MET-minutes/week. Participants who engaged in walking for at least 150 minutes per week (regardless of the number of days) were classified as meeting recommendations for walking.[41]

Data analysis

Because most questions about environments were particularly relevant to urban neighborhoods, analyses were restricted to participants living in towns or cities with populations ≥30,000. Data from each country were pooled and weighted to account for differential probabilities of sample selection within each country, and to improve the representativeness of the samples. Logistic regression was used to examine associations of each environmental variable with a dichotomous physical activity outcome. All models were adjusted for age and gender, as they were the only demographic variables collected in all 11 countries. To examine whether the association of a neighborhood attribute with physical activity differed by country, neighborhood attribute × country (dummy coded) interaction terms were included in each model. A significant interaction (p<0.05) indicated that the association of this environmental attribute with physical activity in the comparing country is different from that in the reference country. Finding of a significant interaction was followed by country-stratified analyses. Forest plots were used to display the odds ratios and 95% confidence intervals for all neighborhood environments-physical activity associations in each country. Statistical analyses were conducted in SPSS 19.0 (SPSS Inc.).

Results

Descriptive statistics of the age, gender, physical activity, and neighborhood environment characteristics of the weighted samples are presented in Table 1. Overall, age and gender distributions in all countries were well balanced, with the exception of Japan, where young people and men were over represented. The percentage of participants who met the overall physical activity recommendations ranged from 9.2% in Japan to 60.5% in the USA. The percentage of participants meeting the walking recommendation ranged from 32.7% in Japan to 85.4% in Hong Kong. All attributes of neighborhood environments varied across countries.

In all models tested, there were significant neighborhood environment attribute × country interactions. Therefore, country-specific associations of neighborhood environments with physical activity are presented in Figure 1.

Residential density

With meeting overall physical activity recommendations as the outcome, no association was significant in the expected direction (i.e., higher residential density associated with higher odds of meeting recommendations). In fact, the associations in Japan (OR=0.52, 95%CI: 0.34-0.79) and Lithuania (OR=0.57, 95%CI: 0.42-0.78) were in the opposite direction (Figure 1a). With walking as the outcome, higher residential density was associated with higher odds of meeting recommendations for walking in Colombia (OR=1.29, 95%CI: 1.05-1.59), and the association was near significant ($0.05<p<0.10$) in Norway (OR=1.39, 95%CI: 0.97-2.01) and Sweden (OR=1.46, 95%CI: 0.95-2.24). Odds ratios in Hong Kong could not be calculated due to the lack of variance in main housing types (only 3 out of 1100 lived in neighborhoods where the main type of housing was single-family homes).

Shops near home

In almost all countries, the associations of having shops near home and physical activity/walking were positive as expected (Figure 1b). With overall physical activity as the outcome, associations in Brazil (OR=1.69, 95%CI: 1.04-2.75), Japan (OR=3.10, 95%CI: 1.39-6.92), New Zealand (OR=1.40, 95%CI: 1.01-1.94), and the USA (OR=1.21, 95%CI: 1.03-1.42) reached statistical significance. With walking as the outcome, associations in Hong Kong (OR=1.62, 95%CI: 1.02-2.57), Japan (OR=2.29, 95%CI: 1.58-3.31), Lithuania (OR=1.38, 95%CI: 1.03-1.85), and the USA (OR=1.25, 95%CI: 1.06-1.46) reached statistical significance.

Public Transit

Having public transit stops near home had a positive and significant association with meeting overall physical activity recommendations in Belgium (OR=2.43, 95%CI: 1.25-4.40) and Japan (OR=5.78, 95%CI=1.39-6.92) (Figure 1c). Such associations with walking were also significant in Belgium (OR=2.07, 95%CI: 1.22-3.53) and Japan (OR=20.71, 95%CI: 6.33-67.71). There was a positive and near-significant association with walking in Hong Kong (OR=2.00, 95%CI: 0.94, 4.28).

Sidewalks

Having sidewalks present in the neighborhood had a positive and significant association with meeting overall physical activity recommendations in Colombia (OR=1.32, 95%CI: 1.04-1.68), Japan (OR=3.60, 95%CI: 2.13-6.08), and Sweden (OR=3.92, 95%CI: 1.05-14.63) (Figure 1d). There was a positive association between the presence of sidewalks and meeting recommendations for walking in Colombia (OR=1.52, 95%CI: 1.17-1.96), Hong Kong (OR=2.16, 95%CI: 1.01-4.64), Japan

(OR=1.92, 95%CI: 1.49-2.48), and Lithuania (OR=1.77, 95%CI: 1.27-2.46). In Norway, the presence of sidewalks had an unexpected inverse association with meeting overall physical activity recommendations (OR=0.65, 95%CI: 0.43-0.99).

Bicycling facilities

Having bicycling facilities (e.g., bike lanes) present in the neighborhood was positively associated with meeting overall physical activity recommendations in most countries (Figure 1d), and such associations reached statistical significance in Colombia (OR=1.31, 95%CI: 1.14-1.53), Hong Kong (OR=1.88, 95%CI: 1.14-1.53), Japan (OR=1.77, 95%CI: 1.15-2.74), Lithuania (OR=1.50, 95%CI: 1.20-1.89), New Zealand (OR=1.35, 95%CI: 1.01-1.80), and the USA (OR=1.28, 95%CI: 1.09-1.50). Bicycling facilities also had positive and significant associations with meeting walking recommendations in Hong Kong (OR=1.65, 95%CI: 1.14-2.39), Lithuania (OR=1.55, 95%CI: 1.23-1.94), and the USA (OR=1.19, 95%CI: 1.01-1.39), and positive and near-significant associations in Canada (OR=1.39, 95%CI: 0.98-1.97) and Colombia (OR=1.18, 95%CI: 0.98-1.41). Bicycling facilities had an inverse association with walking in Brazil (OR=0.71, 95%CI: 0.53-0.96).

Recreation facilities

As Figure 1e presents, having free or low-cost recreation facilities in the neighborhood was associated with higher odds of meeting overall physical activity recommendations in Lithuania (OR=1.45, 95%CI: 1.15-1.82) and the USA (OR=1.24, 95%CI: 1.04-1.47), and higher odds of meeting recommendations for walking in Lithuania (OR=1.58, 95%CI: 1.26-1.98) and Hong Kong (OR=1.41, 95%CI: 0.99-2.03), though the association in Hong Kong was near-significant. The association of recreation facilities with walking was in an unexpected inverse association in Japan (OR=0.76, 95%CI: 0.60-0.98).

Safety from crime

Most associations of crime-related safety with physical activity/walking were in an inverse association where better safety was associated with less overall physical activity in Colombia (OR=0.76, 95%CI: 0.63-0.92), Japan (OR=0.61, 95%CI: 0.40-0.93), with less walking in Colombia (OR=0.79, 95%CI: 0.64-0.97), New Zealand (OR=0.66, 95%CI: 0.49-0.89), and Norway (OR=0.46, 95%CI: 0.27-0.80). The only expected association was that better safety was significantly associated with higher odds of meeting physical activity recommendations in Lithuania (OR=1.40, 95%CI: 1.08-1.83).

Summary of findings

As Table 2 presents, three environmental attributes had the most consistent associations with physical activity/walking outcomes across countries: shops near home (significant with overall physical activity in four countries, with walking in four countries), sidewalks (significant with overall physical activity in three countries, with walking in four countries), and bicycle facilities (significant with overall physical activity in six countries, with walking in three countries). For both residential density and safety, there was only one positive association, and more associations were in an unexpected direction.

Across countries, more environmental attributes were significantly associated with physical activity or walking in Japan, Lithuania, and the USA. None of the seven environmental attributes tested had a significant association with physical activity or walking in an expected direction in Canada and Norway.

Discussion

This study aimed to determine whether associations of neighborhood environments with physical activity differed by countries. Based on representative samples from 11 countries, we used standardized methodologies that allowed for cross-country comparison. Results showed distinctive patterns of associations in different countries. Although the main hypothesis of country being a moderator of the associations between neighborhood environments and physical activity was supported, the current study raised questions about why certain neighborhood characteristics were more important to physical activity in some countries than others.

Overall, the presence of shops, sidewalks and bicycle facilities near home were the most supported neighborhood attributes across countries. Particularly, the association of shops with physical activity/walking was in the expected positive direction in almost all countries and the association was statistically significant in four countries with each outcome. This suggests that mixed land use was an important environmental attribute that is likely to benefit neighborhood residents in a wide range of countries. This finding echoed that from a recent meta-analysis where land-use diversity and destinations within walking distance were the strongest correlates of walking.[15]

The presence of sidewalks and bicycle facilities was associated with physical activity and walking in several countries, although the associations were occasionally in an unexpected direction. Sidewalks were significantly associated with at least one physical activity outcome in six countries and were associated with both outcomes in Colombia and Japan. There were no obvious explanations for these distinctive patterns and for the unexpected association in Norway. Bicycle facilities were significantly associated with meeting overall physical activity recommendations in six countries and were the most supported correlate for this outcome. However, the mechanism for this association is unknown because bicycle use for transport and leisure was not directly measured. Interestingly, bicycle facilities were more likely to be predictive of physical activity in countries where bicycling is a minimal mode of transportation, such as the United States,[42] Hong Kong,[43] and New Zealand,[44] and not predictive of physical activity in European countries where bicycling is much more common.[45] European countries generally have better infrastructure, policies, programs, and social norms for bicycling.[46] In the current study, European countries had the highest overall prevalence of bicycle facilities (Table 1). It is possible that in these countries even neighborhoods without such facilities have other infrastructure or policies to make bicycling accessible and safe; therefore simply having bicycle lanes or trails may not be predictive of physical activity. Bicycle facilities were more likely to be related to total physical activity than to walking, providing some evidence of discriminant validity.

Public transit access is a less examined environmental attribute. In this study, presence of transit stops was significantly associated with both physical activity outcomes in Belgium and Japan, but not in other countries. One possible explanation is that in most countries responses about transit access were mostly favorable. In eight countries more than 90% of the participants reported having a transit stop within walking distance. The lack of variance could limit the power to detect significant associations. Public transit access in the United States had the lowest prevalence and the highest variance; but it was still unrelated to physical activity or walking. Given that public transit use is so rare in the United States,[45] access to public transit may be almost irrelevant to traveling choice. To enrich current data and improve variance to allow for more meaningful tests of associations, future studies should examine other aspects of public transit, such as pricing, frequency, and quality of service.[47]

The presence of low-cost recreation facilities had very inconsistent associations with physical activity and walking across countries. The definition of recreation facilities may differ greatly by country and people from different countries may be more likely to use different types of facilities (e.g., public vs. private). In addition to the overall question, future studies may include more specific questions about types of recreation facilities.

Regarding residential density, we found more associations with physical activity in the unexpected direction than in the expected direction. Although residential density is an important component of walkability,[48] it is usually considered as an intermediate variable for other attributes, such as land-use mix, because a large number of residents are required to support local business.[15] The current study, together with a recent meta-analysis,[15] suggests that mixed land use may be a better indicator of neighborhood walkability than simply having a high population density.

Crime is a frequently cited barrier to physical activity, but its association with physical activity has been inconsistent.[49] As the most subjective environmental measure in this study, it is very likely that people from different countries regarded crime and safety differently. Also, different types of crime, emotional responses, and coping strategies (e.g., constrained vs. protective behavior) may also affect the association between crime/safety and physical activity and all these factors may differ by country or culture. Future studies should test more complex, multi-variable models and compare psychometric properties of crime/safety measures across countries.

This study raised several methodological questions. First, it is important to note that associations with overall physical activity and with walking outcomes were not always similar, and sometimes even in the opposite directions. This suggests that sometimes conclusions about associations between neighborhood environments and physical activity were dependent on the physical activity outcomes examined. Conceptually, neighborhood environments should be more relevant to physical activity that takes place within the neighborhood. Future studies should adopt location- and domain-specific physical activity measures to improve the understanding of the mechanism of associations. Second, although using standardized measures is the premise of cross-country comparisons, it is important to note that sometimes such measures may fail to account for specific situations within the country and possibly lead to skewed data distribution. One example is that in a densely populated city like Hong Kong, the question about single-family houses had almost no variance. Another example is that in most countries more than 90% of the participants provided positive responses to the public transit question. For analyses of a particular geographic area, it is important to adapt instruments to the local situation to ensure the relevance of questions and the variance in the response. Third, the association between neighborhood environments and physical activity is complex and environmental attributes are likely to interact with one another. Therefore, it is important to examine combinations of environmental attributes that are the most likely to influence physical activity.[50] Because of the unique situation in each country, the combinations of potential environmental correlates may differ and this should be examined by future studies.

Limitations

The geographic variation, population representativeness, standardized methodology and measures have provided a unique opportunity for cross-country comparisons. However, this study has several limitations. First, physical activity was only measured by the IPAQ short form, which often led to overestimated physical activity compared to objective measures.[39] Furthermore, it is unknown whether the degree of overestimation was different across countries. Because the IPAQ short form did not ask physical activity in specific domains (e.g., occupational, transport, domestic, and leisure-time), it was impossible to test more specific and conceptually matched hypotheses. Second, there were only two shared covariates across countries and the models tested were under-specified. Including key variables such as socioeconomic status would allow for more complex conceptual and statistical models that include mediators, moderators, and confounders.[51] Third, it could not be determined whether the significant country× neighborhood environment interactions were a result of functionally different associations, differences in variability within country, or cross-cultural differences in interpreting and answering the same questions. This should also be examined by future studies.

Conclusions

In this study, we found that the overall associations of neighborhood environments with physical activity differed by country. Across the 11 counties, some environmental attributes, such as land-use mix, sidewalks, and bicycle facilities, had more consistent associations with physical activity, suggesting generalizability of findings across countries. Other attributes, such as residential density and safety, had inconsistent associations across countries, and the aggregate associations were near null.[20] With low-cost recreation facilities and public transit, associations were minimal in most countries, but strong in particular countries. However, there were no obvious explanations for such distinctive patterns of associations. Future studies should continue to examine the generalizability of the environments-physical activity associations. Priority areas of improvement may include adopting objective measures and more specific reports, testing better-specified and conceptually matched models, and examining differential response bias to improve comparability of survey instruments across countries.

Table 4.1. Descriptive statistics of the weighted samples in 11 countries (2002-2003)

	Belgium (n=348)	Brazil (n=876)	Canada (n=634)	Colombia (n=2692)	Hong Kong (n=1100)
Demographic characteristics					
Age (yr): M(SD)	42.3 (12.0)	35.6 (12.4)	39.3 (12.5)	36.7 (12.5)	39.5 (10.8)
Women (%)	44.4	49.5	44.8	51.5	53.1
Physical activity (PA) outcomes (%)					
Meeting PA recommendations	26.5	27.6	59.6	54.3	40.0
Meeting walking recommendations	40.4	38.5	61.9	75.5	85.4
Environmental characteristics (% (SD))					
High residential density	66.4 (47.3)	12.0 (32.6)	39.8 (49.0)	78.9 (40.8)	99.7 (6.05)
Shops near home	63.1 (48.3)	85.0 (35.8)	67.1 (47.0)	92.2 (26.8)	88.4 (32.0)
Transit stop near home	74.6 (43.6)	94.8 (22.2)	85.2 (35.6)	95.9 (20.0)	96.4 (18.5)
Sidewalks present	83.5 (37.2)	24.8 (43.5)	79.7 (40.2)	88.5 (32.0)	96.9 (17.7)
Facilities to bicycle	78.1 (41.4)	33.4 (47.2)	68.0 (46.7)	40.6 (49.1)	37.2 (48.4)
Low-cost recreation facilities	78.2 (41.4)	28.1 (45.0)	86.0 (34.8)	50.9 (50.0)	72.9 (44.5)
Crime-related safety	75.8 (42.9)	34.8 (47.7)	79.0 (40.8)	24.2 (42.8)	63.7 (48.1)

	Japan (n=1221)	Lithuania (n=1245)	New Zealand (n=797)	Norway (n=500)	Sweden (n=440)	USA (n=2560)
Demographic characteristics						
Age (yr): M(SD)	32.2 (5.5)	39.0 (12.7)	38.2 (12.4)	38.8 (12.9)	40.2 (12.4)	37.5 (13.1)
Women (%)	30.9	57.9	47.9	50.4	57.6	52.8
Physical activity (PA) outcomes (%)						
Meeting PA recommendations	9.2	51.1	55.2	41.0	34.9	60.5
Meeting walking recommendations	32.7	52.9	58.6	58.2	52.8	55.8
Environmental characteristics (% (SD))						
High residential density	70.8 (45.5)	84.3 (36.4)	24.4 (43.0)	58.1 (49.4)	70.4 (45.7)	40.2 (49.0)
Shops near home	82.8 (37.8)	82.2 (38.2)	73.4 (44.2)	83.9 (36.8)	77.0 (42.1)	59.0 (49.2)
Transit stop near home	90.6 (29.3)	90.6 (29.3)	91.4 (28.1)	97.4 (15.9)	97.1 (16.9)	68.4 (46.5)
Sidewalks present	58.1 (49.4)	86.3 (34.4)	94.5 (22.8)	76.9 (42.2)	95.4 (20.9)	74.6 (43.5)
Facilities to bicycle	24.5 (43.0)	46.9 (49.9)	45.4 (49.8)	72.3 (44.8)	79.9 (40.1)	56.5 (49.6)
Low-cost recreation facilities	59.4 (49.1)	53.8 (49.9)	87.2 (33.5)	76.4 (42.5)	78.8 (40.9)	69.1 (46.2)
Crime-related safety	67.3 (46.9)	25.0 (43.3)	57.3 (49.5)	84.8 (36.0)	60.8 (48.9)	66.8 (47.1)

Table 4.2. Summary of associations between neighborhood environments and physical activity in 11 countries

	Attributes of neighborhood environments															
Country	Density		Shops		Transit stop		Side-walks		Bicycle facilities		Rec facilities		Safety		Total[a]	
	PA	W	PA	W	PA	W	PA	W	PA	W	PA	W	PA	W	PA	W
Belgium	0	0	0	0	+	+	0	0	0	0	0	0	0	0	1	1
Brazil	0	0	+	0	0	0	0	0	0	-	0	0	0	0	1	0
Canada	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Colombia	0	+	0	0	0	0	+	+	+	0	0	0	-	-	2	2
Hong Kong	NA[c]	NA[c]	0	+	0	0	0	+	+	+	0	0	0	0	1	3
Japan	-	-	+	+	+	+	+	+	+	0	0	-	-	0	4	3
Lithuania	-	0	0	+	0	0	0	+	+	+	+	+	+	0	3	4
New Zealand	0	0	+	0	0	0	0	0	+	0	0	0	0	-	2	0
Norway	0	0	0	0	0	0	-	0	0	0	0	0	0	-	0	0
Sweden	0	0	0	0	0	0	+	0	0	0	0	0	0	0	1	0
USA	0	0	+	+	0	0	0	0	+	+	+	0	0	0	3	2
Total[b]	0	1	4	4	2	2	3	4	6	3	2	1	1	0	18	15

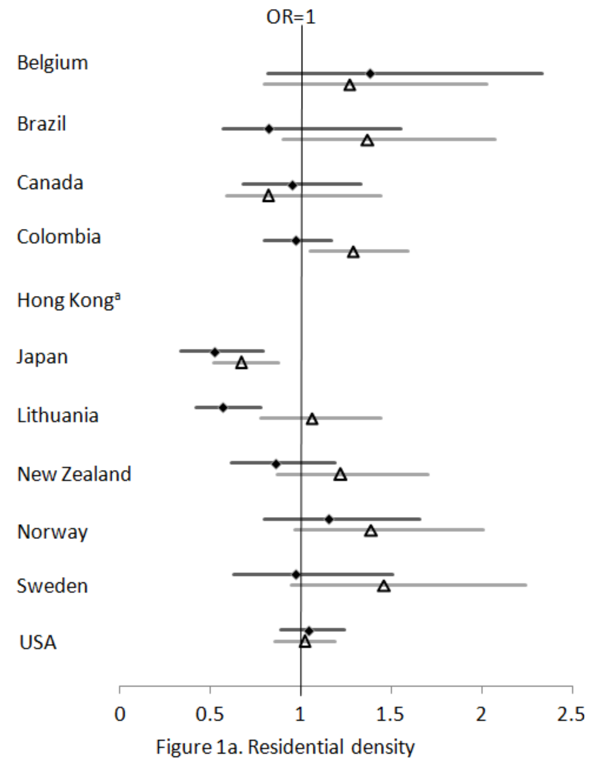
PA=meeting recommendations for overall physical activity; W=meeting recommendations for walking

"+": the association was significant and in the expected direction; "-": the association was significant and in the unexpected direction; "0": the association was non-significant

[a] The sum of significant neighborhood attributes in each country

[b] The sum of countries where the associations between neighborhood attributes and physical activity were significant

[c] Could not be calculated due to the lack of variance in residential density



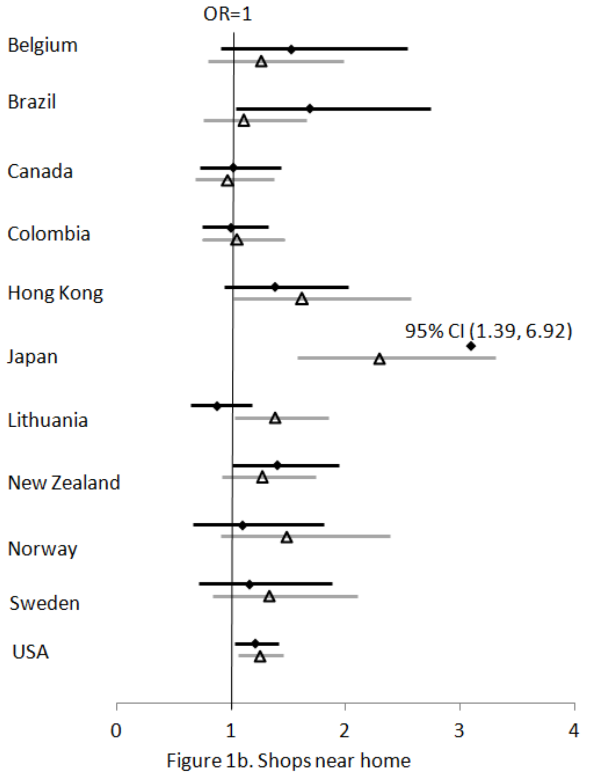


Figure Caption

Figure 4.1. (1a-1g) Odds ratios (ORs) and 95% Confidence Intervals (CIs) for the associations between neighborhood attributes and physical activity in 11 countries

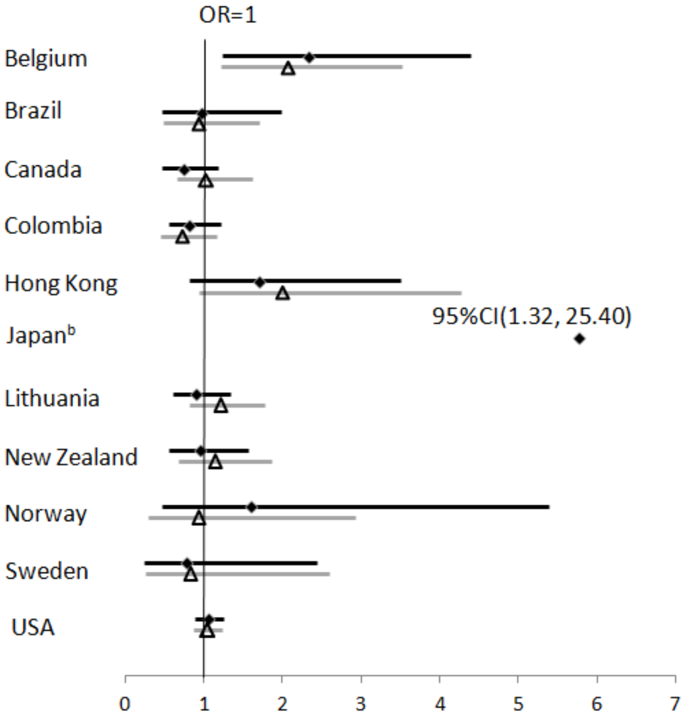


Figure 1c. Transit stop near home

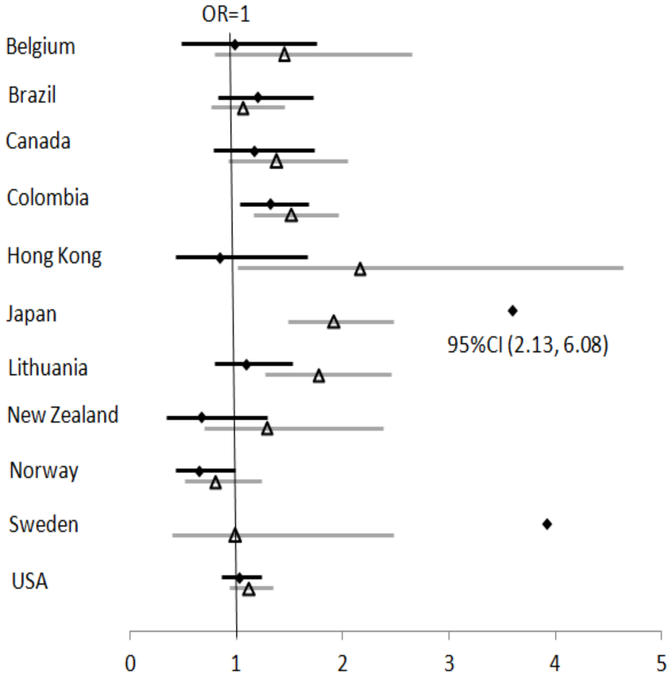


Figure 1d. Sidewalks present

Figure 4.1 continued

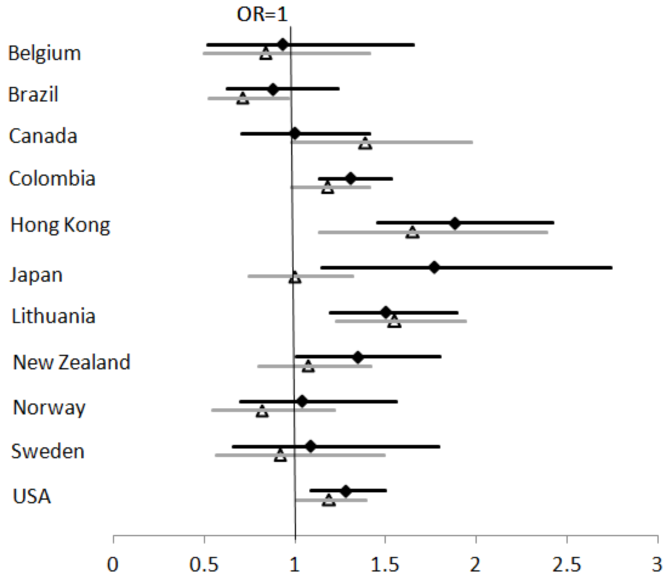


Figure 1e. Facilities to bicycle

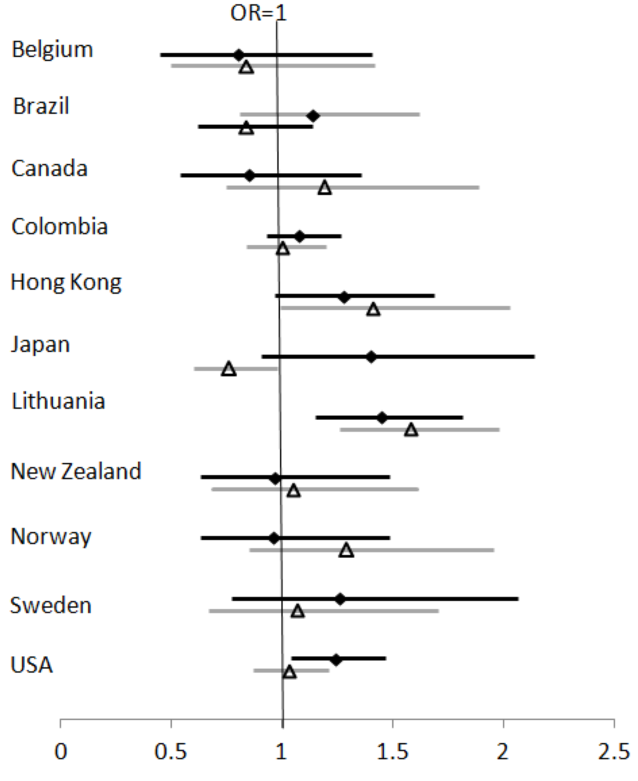


Figure 1f. Low-cost rec facilities

Figure 4.1 continued

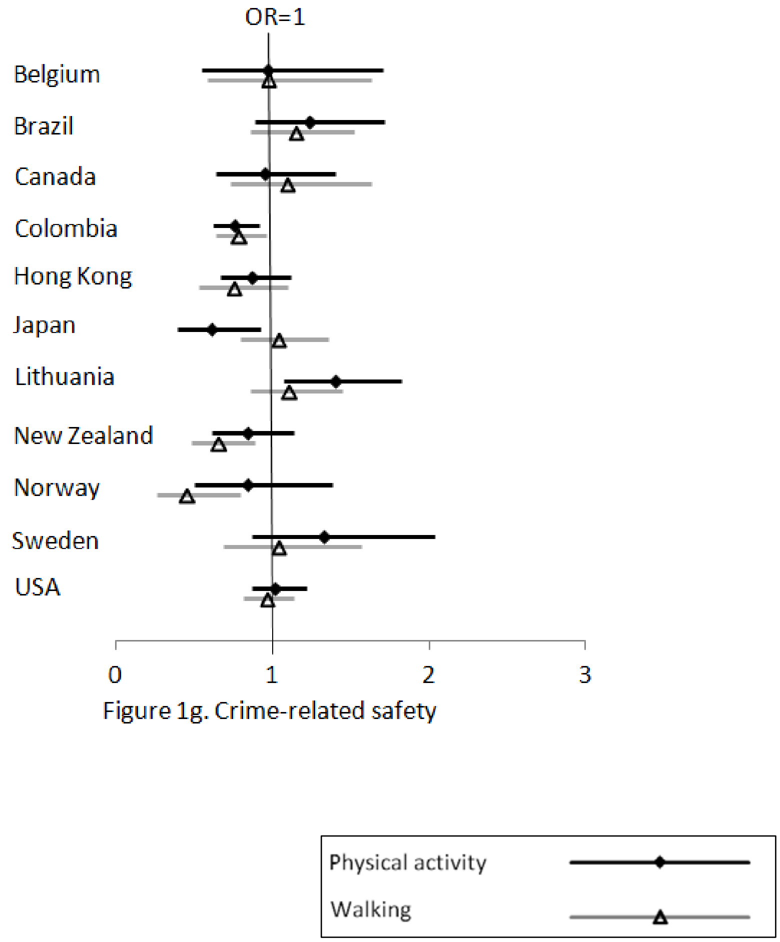


Figure 1g. Crime-related safety

Figure 4.1 continued

[a] ORs and 95% CIs could not be determined due to lack of variance in residential density in Hong Kong
[b] OR (95%CI) with the walking outcome in Japan: 20.71 (6.33, 67.71)

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CHAPTER 5

Discussion

The conceptualization of this dissertation was based on knowledge gaps identified by theoretical and empirical literature.[1, 2] It was also driven by the practical importance of understanding moderators of the associations between built environments and physical activity—to identify combinations of intervention strategies or population subgroups that environmental interventions are likely to be effective and efficient in promoting behavior change. The three papers included in the dissertation used different datasets, tested different research hypotheses, yet addressed the unifying theme of cross-level interactions in ecological models in the context of built environments and physical activity. These papers expanded the knowledge of the moderators, but also raised more questions about the conceptualization and methodology of current research.

Findings from Paper 1 are the most interpretable. Consistent patterns of associations with leisure walking outcome suggested that neighborhood built environments were likely to play a stronger role among those with less favorable psychosocial predisposition towards physical activity. One important implication of these findings is that improving activity friendliness of the built environments can be a potential approach to reducing disparities of physical activity among populations.

Findings from Paper 2 are counter-intuitive. We hypothesized that built environments would be more critical to physical activity among non-driving seniors because they were more dependent on the environments due to lack of transportation. The findings, however, did not support this hypothesis. We found few significant interactions with accelerometer-based outcomes and transport walking. We found several significant neighborhood environment attribute × driving ability interactions with leisure walking. Consistently, these interactions suggested that neighborhood environments had strong associations with leisure walking among driving-able seniors, and almost no association among non-driving-able seniors. These findings suggest that certain attributes of the neighborhood are important to seniors' physical activity regardless of driving status, but it remains unknown why these attributes were unrelated to leisure walking among non-driving-able seniors.

Findings from Paper 3 are complex. Overall, findings supported the hypothesis that the associations of neighborhood environments with physical activity differed by country. Some neighborhood attributes, such as land-use mix tended to have more consistent associations with physical activity and walking across countries, suggesting generalizability of associations across countries. Other attributes, such as residential density and safety tended to have mixed and unexpected findings. Although cross-country comparison was facilitated by standardized methodologies, the comparability of effects and bias across countries was difficult to determine.

As the three papers revealed, cross-level interactions in the context of built environments and physical activity are complex. Finding the optimal conceptual and analytical approaches for this inquiry is challenging.

The first challenge lies in the conceptualization of research questions. Tests of interactions should only be based on existing hypotheses that are usually derived from theories or empirical literature.[3] Theoretically, ecological models emphasize general principles and lack specific testable hypotheses, making it difficult to pinpoint specific moderators and directional associations. Empirically, there has been very little intended effort to examine conditions under which built environments exert influence on physical activity. Both theoretical and empirical limitations have contributed to the difficulty of conceptualizing the potential moderators and the patterns of interactions.

The second challenge is the measurement of related constructs. Physical activity measures are complex because the same type of activity can be of different functional purposes (e.g., leisure, transport),[4] and these different domains of physical activity might be related to different attributes of neighborhood environments. Furthermore, physical activity always takes place in a setting and the characteristics of that specific environment should be the most relevant to behavior. Unfortunately, rarely did studies include measures of setting-specific physical activity (e.g., walking in the neighborhood) and none of the three dissertation papers included such measures. Modes of measurement are also important. Although objective measures, such as accelerometers, provide less biased measures than reports, they usually cannot provide domain-specific or location-specific measures. Such overall measures of physical activity provide less focused tests of associations with environmental attributes. In fact, a recent review quantified associations by measurement modes and found that neighborhood environments were more likely to be associated with reported physical activity outcomes than objectively measured total physical activity.[5] The emerging efforts to combine accelerometers with GIS or GPS have the potential of offer “the best of both worlds’ by creating objective location-specific physical activity measures.

Third, most research in this area is guided by the ecological models which emphasize more on the topography rather than mechanisms of environmental influence on behavior.[6, 7] Understanding complex cross-level interactions of influence requires more detailed knowledge and deliberate application of fundamental behavioral principles. Latest technologies that provide real-time assessment of the environments and behavior may help improve understanding of the mechanisms through which built environments influence behavior, and thus help conceptualize theoretical moderators of these associations.

Future directions

The current efforts to understand moderators of the associations between built environments and physical activity should continue. In the situation of limited resources for public health initiatives, it is particularly important to identify and prioritize population subgroups to whom environmental interventions are the most effective. Less-traveled roads should be taken in the process of conceptualizing research questions and developing research instruments, such as applying qualitative- quantitative mixed methods, involving policy makers in research, and using technologies and innovative theories to address both topography and mechanisms of human behavior.[6]

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