Transportation Research Part D 30 (2014) 10–20

Contents lists available at ScienceDirect

Transportation Research Part D

journal homepage: www.elsevier.com/locate/trd

Meso- or micro-scale? Environmental factors influencing pedestrian satisfaction

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ARTICLE INFO

Keywords:
Pedestrian satisfaction
Meso-scale environmental attributes
Micro-scale environmental attributes
Multilevel modeling

ABSTRACT

Despite interest in walking and its environmental, health, and social benefits, little research has investigated pedestrian satisfaction, and its potential influence on walking decisions. The present study examines the relationships between pedestrian satisfaction, and a variety of built environment factors, in order to gain insight into urban design strategies that can improve pedestrian satisfaction. We analyzed a pedestrian survey, carried out in Seoul, Korea, which includes questions about personal characteristics, micro-scale environmental attributes, and the level of pedestrian satisfaction, together with Seoul GIS data, which provided meso-scale environmental variables. The multilevel models estimated the effects of environmental factors on the level of satisfaction of utilitarian and recreational walkers. The analysis identified significant effects of both meso-scale (e.g. density, intersection density, hilliness, and the presence of bus stops), and micro-scale (e.g. sidewalk width, and the presence of bus dedicated lanes, crossings, lamps, and trees) variables on pedestrian satisfaction. The results calls on researchers to investigate a comprehensive set of psychological and environmental factors, in order to understand the various aspects of pedestrian satisfaction, and the diverse motivations behind it, as well as on planners, to adopt diverse design approaches that will produce more satisfactory pedestrian environments.

Introduction

Interest in walking, and its environmental, health, and social benefits, have grown in urban planning, transportation, and public health studies. Researchers have investigated walking, with regard to environmental and health issues, such as air pollution, traffic congestion, and obesity risk (Marshall et al., 2009; Hoehner et al., 2011). Studies in public health identified the health benefits of physical activities, including walking: moderate levels of physical activities tend to reduce health risks, such as high blood pressure, heart disease, colon cancer, and diabetes (Nelson et al., 2007). As the promotion of walking emerges as a policy agenda, a growing number of urban planning experts have become interested in enhancing walkability

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http://dx.doi.org/10.1016/j.trd.2014.05.005
1361-9209/

as a policy intervention tool. For example, Transit-oriented Developments (TOD), which pursues high-density, mixed-use compact urban form, aims to reduce private automobile-based travel, and to promote public transportation use and greater walking activities. In particular, since walking is essential to access public transportation, it is expected that creating pedestrian-friendly environments is important for the success of TOD (Park et al., 2014).

The promise of the planning and policy actions to improve walkability is that walking can be encouraged, by enhancing the quality of the built environment. Hence, most pedestrian-related studies have focused on the behavioral aspects associated with the built environment, such as walking distance, walking time, or walking mode choice. However, only a few studies investigated psychological aspects – such as personal motivation, residential preferences, travel-related attitudes, and pedestrian satisfaction – that may influence walking decisions at a specific site. Omission of these psychological factors in behavioral models can result in overestimation of the influence of the built environment on travel behavior (Cao et al., 2009). In particular, the level of satisfaction experienced by pedestrians is an under-explored topic in travel behavior research. Although it is not easy to operationalize the concept of pedestrian satisfaction, individual pedestrian satisfaction level of the built environment can help reveal potential environmental factors for improving pedestrian environments. How can we create a satisfactory walking environment to promote public transportation uses, and greater physical activities, like walking in cities? Satisfaction with the walking environment is important, not only because satisfaction is relevant to the policies for well-being, but also because satisfactory walking experienced by travelers is more likely to be chosen again next time, and sustained as a habitual behavior (Ettema et al., 2011). Therefore, the present study investigates the relationships between pedestrian satisfaction and a variety of built environment factors, in order to gain insight into urban design strategies that can improve both pedestrian satisfaction and activities.

Most walkability studies have paid attention to the meso-scale (or neighborhood-scale) built environment, investigating its impact on walking behavior. The meso-level built environment is measured by environmental factors, such as housing density, land use diversity, and street patterns within certain areas, since Cervero and Kockelman (1997) proposed the seminal concept of "3D" (density, diversity, and design). The 3Ds, originally developed for estimating the influence of the built environment on motorized travel behavior, are broadly used today for research on walking behavior, under the generic terminology termed "neighborhood walkability". Despite their popularity in walkability research, meso-scale measures in general have drawbacks as variables for capturing micro-scale (or street-level) built environment characteristics, such as the presence of trees, the width of sidewalks, and the quality of streets. However, developing objective and reliable measures of the micro-scale built environment is elusive and costly, leading to the heavy reliance of a large number of walking-behavior researches on meso-level variables. Consequently, the influence of micro-scale factors on walking behavior has rarely been thoroughly tested. Here, using a unique dataset collected in Seoul, Korea that includes both meso- and micro-scale environmental attributes, we attempt to investigate the effect and relative importance of the environmental factors at different scales, with regard to affecting pedestrian satisfaction.

The present research is carried out in Seoul, which is the capital city of the Republic of Korea. Although the city's public transportation system is well distributed across the city, the pedestrian environments in Seoul are not sufficiently convenient and safe. The present study estimates pedestrian satisfaction with explanatory variables, including built environment attributes, and pedestrian characteristics. The study uses the pedestrian survey that was carried out by the Seoul Metropolitan Government in 2009. The selection of survey locations was designed to include major activity centers, transportation nodes, and major land uses of Seoul. The survey instrument consisted of questions about personal characteristics, travel purpose and frequency, and the level of pedestrian satisfaction with their walking environment. At each survey location, surveyors not only collected responses from pedestrians, but also measured a variety of micro-scale built environment characteristics. The micro-scale attributes, measured within 50 m from the survey locations, are geographically distinguished from the meso-scale attributes, extracted from Seoul's geographic information systems (GIS) dataset within 400 m network distances. The survey data, combined with Seoul GIS data, provides an extraordinary opportunity to examine the influence of micro-scale environments on walkability, with a particular emphasis on pedestrian satisfaction, which can offer valuable policy and design insight into building desirable walking environments.

The rest of this paper is structured as follows. The next section reviews theoretical and empirical studies of travel behavior, the built environment, and residential and travel behavior. The settings and methods are then presented. The results of pedestrian satisfaction models follow. The final section discusses the implications, limitations, and future directions of the research.

Theoretical and empirical background

Satisfaction and the built environment

The level of satisfaction with environmental quality has been studied as an important factor that affects the quality of life of residents, and is known to trigger certain behavioral outcomes. Residential satisfaction is a "positive affective" psychological state that individuals experience toward the residential environment (Amerigo and Aragones, 1997). In the previous study, the level of satisfaction is determined by the interaction between objective and subjective environmental attributes, and residents' characteristics. Residents subjectively evaluate the objective attributes of the built environment, leading to a certain level of satisfaction. Hence, the individual's socio-demographic and personal characteristics affect the subjective environmental attributes (Amerigo and Aragones, 1997). Thus, most empirical studies focused on residential satisfaction, examining residents' characteristics and environmental characteristics (both physical and social) of living environments. The studies pertaining to residential satisfaction can be categorized into two groups. The first group of studies deals with residential satisfaction as a criterion of environmental quality evaluation. Thus, this group treats residential satisfaction as a dependent variable (e.g. Gifford, 1987; De Jong et al., 2012; Van Dyck et al., 2011). The second group of research regards residential satisfaction as a predictor of behavioral and psychological outcomes, and therefore, as an independent variable (e.g. Prieto-Flores et al., 2011; Speare, 1974).

In the field of transportation, utility theory that explains how travelers choose activity, destination, and travel mode deals with travelers' satisfaction derived from observed travelers' choice, assuming that travelers make rational decisions to maximize their utility, mostly by minimizing travel time and costs (disutility), under given time and budget constraints (McFadden, 2001). However, the weakness of the derived utility-based assessment of satisfaction is that anticipated and actual experiences may be significantly different, due to the underestimation of the intensity of experience (Ettema et al., 2010; Wilson and Gilbert, 2003). Hence, other studies have investigated "experienced" utility by travelers. Indeed, travelers' satisfaction is likely to be influenced by experienced events during travel. Studies show that single critical events and their frequencies influence public transportation users' satisfaction (Friman et al., 1998, 2001). Stradling et al. (2007) explored factors influencing satisfaction with bus service and walking trips, finding that non-instrumental factors, such as cleanliness, privacy, safety, convenience, and scenery, affect satisfaction with bus service. They also revealed that satisfaction with walking trips is influenced by micro-scale factors, including crowdedness, air quality, presence of trees and flowers, presence of beggars, and pavement condition. Investigating satisfaction with travel and subjective well-being (SWB), Ettema et al. (2011) showed that SWB is influenced by travel mode, travel time, and access to bus stops. The study of Manaugh and El-Geneidy (2013) investigated the relationship between walking distance and satisfaction with walking trips, and found that people who are most concerned with environmental issues are willing to walk longer distance, and tend to be more satisfied. Overall, travelers' satisfaction, including pedestrian satisfaction, is influenced not only by travel time and travel cost, but also by physical and nonphysical environments that affect the type of events experienced by travelers.

Meso-scale environmental factors and walking

Meso-scale environmental factors are area-based measures within certain boundaries. Cervero and Kockelman (1997) proposed the concept of the "3Ds" (density, diversity, and design), which became the most commonly used environmental variables in travel behavior research. The 3D attributes' popularity has been growing with the increasing availability of GIS and spatial data. Later, Cervero et al. (2009) proposed "5D" (3D plus "destination accessibility" and "distance to transit"), integrating meso-scale urban form and accessibility. The 5D attributes are also widely used to capture "neighborhood walkability". Walking behavior research consistently identified positive associations between utilitarian walking and meso-scale factors, such as higher residential and job density, mixed land use, better street connectivity, and proximity to destinations and public transit (e.g. Baran et al., 2008; Giles-Corti and Donovan, 2002; Huston et al., 2003; Lee and Moudon, 2006a; Lee et al., 2013; Moudon et al., 2005; Saelens et al., 2003a). While research focused on recreational walking yielded inconsistent results (Owen et al., 2004), some studies revealed the effect of accessible destinations (Giles-Corti et al., 2005), and hilliness (Lee and Moudon, 2006b), on recreational walking.

Despite the popularity of the 5Ds, there has been controversy over the appropriate boundary of a neighborhood (Lin and Long, 2008). More broadly, meso-scale environmental factors have problems associated with the size and scale of areal measurement units. For example, the modifiable areal unit problem (MAUP) may occur, if a multivariate analysis is made based on spatially aggregated datasets, resulting in erroneous results, depending on the size and scale of the areal measurement unit (Fotheringham and Wong, 1991; Guo and Bhat, 2007; Kwan and Weber, 2008). In order to minimize the modifiable area unit problem, some walkability studies match behavioral outcomes of interest (walking) to an areal unit, utilizing network buffers to account for the actual distance a walker travels from origin (typically home), to nearby destinations, on the existing street network. Yet, the network distance utilized greatly differs, for example, 1 km (Frank et al., 2008), 0.5 mile (Coogan et al., 2009), and 0.25 mile (Wells and Yang, 2008; Zegras et al., 2012).

Micro-scale environmental factors and walking

The quality of the micro-scale walking environment has long been of interest to urban designers and planners. Urban designers presented a variety of theories related to the street-level walkability, for example, "eyes upon the street" (Jacobs, 1961), "path quality" (Lynch and Southworth, 1974), "street enclosure" (Alexander et al., 1977), "livable streets" (Appleyard, 1981), and "soft edges" (Gehl, 1987). While these concepts contributed to the definition of good walkability, few empirical studies developed objective and systematic measuring instruments.

As the health benefits of walking emerged as a crucial policy and design issue, studies focusing on walkability yielded walkability measurement tools, such as the Neighborhood Environmental Walkability Survey (Saelens et al., 2003b), Systematic Pedestrian and Cycling Environmental Scan (Pikora et al., 2003), and Measurement Instrument for Urban Design Qualities Related to Walkability (Ewing et al., 2006). These tools considerably contributed to defining and measuring micro-scale walkability in a comprehensive way. In particular, Ewing and Handy (2009) tried to objectively measure, and to quantify qualitative design attributes, measuring approximately one hundred physical and non-physical features of sampled streets, in order to test possible correlations with expert ratings on walkability.

Despite the progress in developing micro-scale measurement tools, few walkability studies included micro-scale environmental factors; instead, they primarily focused on meso-scale factors. This is because micro-scale factors require considerable effort and time to collect sufficient data. Also, some qualitative and subjective measures, such as pavement cleanliness, building design, and perception of safety, suffered from reliability issues. However, the urban design theories and empirical studies suggest that micro-scale environmental factors play an important role in walkability. Therefore, the omission of micro-scale factors in empirical studies can lead to inaccurate results. Overall, little research comprehensively investigated the effect of both meso- and micro-scale environmental factors, at the same time as placing a particular emphasis on pedestrian satisfaction. The present study attempts to fill this gap, testing and comparing the effects of meso- and micro-scale environmental factors on pedestrian satisfaction.

Setting and methods

Context

The present research is carried out in Seoul, which is the capital city of the Republic of Korea. Seoul is one of the largest and densest cities in the world. Seoul is inhabited by 10.4 million citizens, as of 2013, within its 605.25 km^2 boundary, yielding a population density of approximately 17,200 inhabitants per km^2. The districts of Seoul are categorized into commercial, green, semi-industrial, and residential areas (Fig. 1(a)). The main commercial area is located in the historic city center, and other commercial areas have emerged in other areas in Seoul. Green areas include parks and natural features, such as mountains and streams. Semi-industrial areas can be characterized as light industries mixed with retail and housing. Residential areas consist of diverse housing types, and neighborhood retail outlets.

The public transportation system of Seoul is relatively well developed (Fig. 1(b)). Currently, nine subway lines with 306 stations cover 64.4% of Seoul's total area, within one kilometer distance from each subway station (Jang, 2008). Seoul's bus system complements the public transportation system, connecting destinations not easily accessible by subway. In particular, dedicated bus lines in the center of the road, implemented in the major areas around Seoul, enhance the efficiency of the bus system.

As one of the oldest cities in Korea, Seoul exhibits diverse urban forms, with a variety of building types, street patterns, and land use patterns. However, from a global perspective, Seoul may not be one of the highly walkable cities. Major roads tend to be very wide, making it difficult for pedestrians to cross roads; and many neighborhood streets do not have appropriate sidewalks. Also, Korea shows the highest pedestrian death rate (11.3 in every 100,000 people in 2010), among all of the OECD countries.[3] The national and city governments recently strived to improve the pedestrian environment, implementing a sizable number of pedestrian-only streets and new sidewalks, as well as designating several "pedestrian-friendly" districts across the city. However, the quality of the pedestrian environment in Seoul still varies. Hence, the urban setting of Seoul offers a heterogeneous context in which to examine how the built environment influences pedestrian satisfaction.

Survey design and data

The Seoul Metropolitan Government carried out a comprehensive pedestrian study in 2009. The government hired and educated 2,000 auditors, in order to measure pedestrian volume, and audit the built environment characteristics at 10,000 locations in Seoul. The pedestrian survey was conducted at approximately 10% of the 10,000 locations (1170 locations, see Fig. 1(c)). The selection of the locations was designed to include major activity centers, transportation nodes, and major land uses of Seoul. The survey instrument consisted of questions about personal characteristics, travel purpose and frequency, and the level of pedestrian environment satisfaction. At each survey location, surveyors collected responses from 24 pedestrians on Tuesdays, Wednesdays, and Fridays, yielding 72 responses per location. Excluding missing values, the final dataset contains 83,291 responses. The auditors also collected micro-scale built environment characteristics, within 50 m from each location.

In order to gather meso-scale built environment characteristics, the survey data were combined with the city's spatial data, including building footprints and heights, roads, parcels, land use, and transportation systems that came from Seoul's GIS dataset. We generated 400 m network buffers for each location, to measure the physical characteristics around the locations. The 400 m network buffers were drawn according to walking paths along streets, rather than a buffer based on a straight line radius from the locations, based on the assumption that only physical characteristics within a certain walking distance of the location affect walking behavior. The street network used is based on the roads data, excluding highways, since our focus is on pedestrians. Within each buffer, the following meso-scale variables are measured:

Gross density: A floor area ratio (FAR) is measured, to represent the amount of built activity space:

$$FAR = \text{total floor area}/\text{total area of a buffer}$$

[3] IRTAD, Road Safety Annual Report 2011

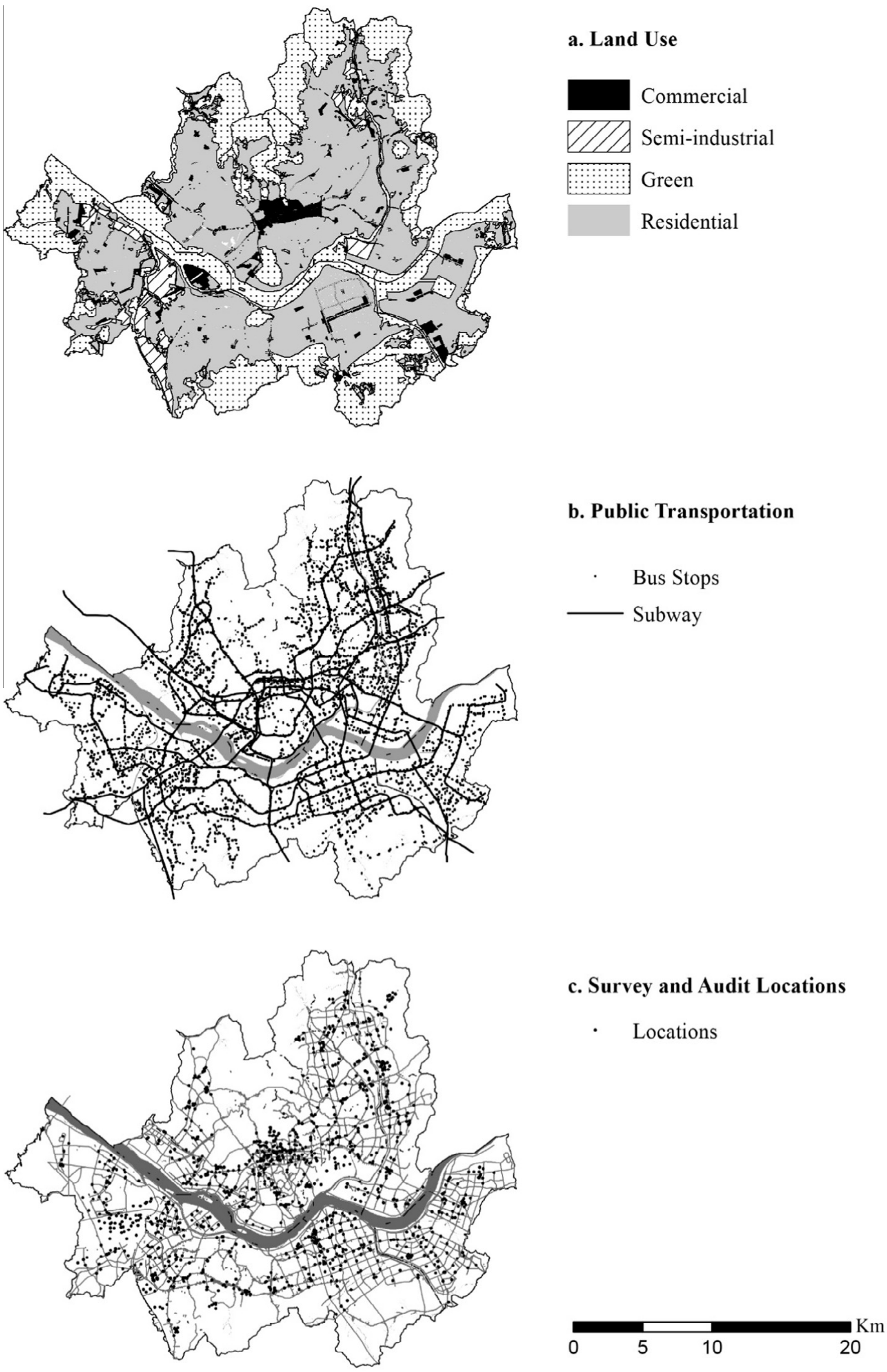

Fig. 1. Land use, public transportation, and survey locations of Seoul, Korea.

Diversity: The diversity index (DI) measures the mix of land uses, ranging from 0 for a single use, to 1 for perfect mixing of uses. Four land uses are used in the calculation: commercial, green, semi-industrial, and residential. The DI is expressed as (Rajamani et al., 2003):

$$DI = 1 - \left\{ \frac{\left|\frac{r}{T} - \frac{1}{6}\right| + \left|\frac{c}{T} - \frac{1}{6}\right| + \left|\frac{i}{T} - \frac{1}{6}\right| + \left|\frac{g}{T} - \frac{1}{6}\right|}{\frac{3}{2}} \right\},$$

where, r = area in residential use (single and multifamily housing); c = area in commercial use; i = area in semi-industrial use; g = green area; and the total area, $T = r + c + i + g$.

Design: A variety of design elements, such as street connectivity, measured by intersection density (Dill, 2004) and hilliness, may influence pedestrian satisfaction:

Intersection density = the number of true intersections (three-way and more)/road length (km)

$$Hilliness = \text{the average slope}(\%\ \text{rise})$$

Transportation: The presence of transportation services is also expected to influence the level of pedestrian satisfaction:

$$Subway = \text{presence of subway stations}$$
$$Bus = \text{presence of bus stops}$$

Measures and descriptive statistics

Table 1 presents definitions and descriptive statistics of key variables. The majority of observations (91%) are utilitarian walking, and recreational walking accounts for only 9% of the total observations. The recreational pedestrians' average satisfaction level is higher than that of utilitarian pedestrians. The data structure is multi-level: individual pedestrian's responses (level-1) are clustered at 1,170 locations (level-2). Level-2 variables are meso- and micro-scale built environment characteristics, measured from each location. Meso-scale variables measure the 3Ds and transportation characteristics. Approximately 46% of survey locations have subway stations, and 96% have bus stops, within 400 m.

Micro-scale variables are street and sidewalk characteristics, and street furniture. Approximately, 11% of roads have dedicated bus lanes. About half of the locations are within 50 m from a pedestrian crossing. The average sidewalk width in the data set is 4.16 m. One-fifth of streets have fences, to separate pedestrians from vehicular circulations. Other noticeable street elements are street lamps, ramps, and trees. Only a few streets have pedestrian signal control devices and trashcans.

Level-1 variables are personal characteristics of pedestrians clustered at each location. Approximately one-fourth of pedestrians are accompanied, and most pedestrians are familiar with their locations, walking through at least 1 or 2 times a week. Among respondents, 45% are male pedestrians. Most pedestrians (79%) are adults aged between 20 and 59.

Table 1
Definitions and descriptive statistics of key variables.

Variables	Definition	Total	Utilitarian walking	Recreational walking
		Mean (S.D.)	Mean (S.D.)	Mean (S.D.)
Dependent variable				
Satisfaction	How satisfied are you with walking here? (1. Very dissatisfied; 2. Dissatisfied; 3. Neutral; 4. Satisfied; 5. Very satisfied)	3.27 (0.95)	3.25 (0.94)	3.41 (0.99)
n		82,211	74,644	7567
Level-2 variables				
Meso-scale				
FAR	Gross floor area ratio	1.32 (0.76)	–	–
Diversity index	Land use diversity index	0.15 (0.16)	–	–
Intersection density	Number of true intersections/road length (km)	12.11 (4.56)	–	–
Slope	% Rise	2.52 (2.31)	–	–
Subway	Presence of subway stations (0. no; 1. yes)	0.46	–	–
Bus	Presence of bus stops (0. no; 1. yes)	0.96	–	–
Micro-scale				
Bus lane	Presence of bus-dedicated lanes (0. no; 1. yes)	0.11	–	–
Crossing	Presence of crossings (0. no; 1. yes)	0.57	–	–
Sidewalk width	Sidewalk width (m)	4.16 (2.30)	–	–
Fence	Presence of sidewalk fences (0. no; 1. yes)	0.19	–	–
Signal	Presence of signal control device (0. no; 1. yes)	0.02	–	–
Lamp	Presence of street lamps (0. no; 1. yes)	0.15	–	–
Ramp	Presence of ramps (0. no; 1. yes)	0.25	–	–
Tree	Presence of trees (0. no; 1. yes)	0.28	–	–
Trashcan	Presence of trashcans (0. no; 1. yes)	0.01	–	–
N		1170	–	–
Level-1 variables				
Together	Walking with companions (0. no; 1. yes)	0.27	0.27	0.28
Familiar	Walk here at least 1 or 2 times/week (0. no; 1. yes)	0.86	0.85	0.93
Male	Male (0. no; 1. yes)	0.45	0.44	0.46
Teenager	Age 15 and 19 (0. no; 1. yes)	0.07	0.08	0.01
Adult	Age 20 and 59 (0. no; 1. yes), base category	0.79	0.81	0.59
Senior	Age 60 and over (0. no; 1. yes)	0.14	0.11	0.40
n		82,211	74,644	7567

Table 2
Correlations of meso- and micro-scale variables.

	Satisfaction	FAR	Diversity index	Intersection density	Slope	Subway	Bus	Bus lane	Crossing	Sidewalk width	Fence	Signal	Lamp	Ramp	Tree	Trashcan
Satisfaction	1.00															
FAR	0.08	1.00														
Diversity index	0.06	0.12	1.00													
Intersection density	−0.14	−0.29	−0.24	1.00												
Slope	−0.09	−0.18	−0.12	0.20	1.00											
Subway	0.01	0.15	0.09	0.07	−0.11	1.00										
Bus	0.04	0.09	0.05	0.04	−0.07	0.12	1.00									
Bus lane	0.06	0.02	0.07	−0.04	−0.08	0.07	0.06	1.00								
Crossing	0.07	0.02	0.03	−0.11	−0.10	0.02	0.09	0.13	1.00							
Sidewalk width	0.04	0.11	0.12	−0.08	−0.07	0.13	0.01	0.06	−0.10	1.00						
Fence	0.06	0.06	0.10	−0.17	−0.05	0.01	0.05	0.16	0.22	−0.01	1.00					
Signal	0.00	−0.04	0.00	−0.02	0.01	0.02	0.03	0.01	0.04	−0.03	−0.02	1.00				
Lamp	0.00	−0.02	−0.01	0.05	−0.02	−0.02	−0.07	−0.02	−0.01	−0.03	−0.06	−0.06	1.00			
Ramp	−0.03	0.00	−0.01	0.08	0.23	−0.04	−0.05	−0.05	0.01	0.00	−0.07	0.05	−0.03	1.00		
Tree	0.09	0.03	0.03	−0.09	0.01	−0.06	0.00	0.06	0.23	−0.08	0.20	−0.09	−0.26	0.03	1.00	
Trashcan	0.02	0.07	0.06	−0.04	−0.01	−0.02	0.02	−0.03	−0.06	0.01	−0.04	−0.01	−0.04	−0.01	−0.06	1.00

A potential complication is that environmental attributes are often highly correlated, leading to the multicollinearity that can yield invalid results in statistical models (Lee and Moudon, 2006a). Table 2 shows the Pearson correlation matrix of meso- and micro-scale environmental measures. None of the correlation coefficients are greater than 0.3, implying that the multicollinearity problem may not arise in our analysis.

Modeling

The multilevel structure of the dataset raises an analytical challenge, in estimating the level of pedestrian satisfaction with the built environment factors and personal characteristics. Level-1 units (pedestrians) are clustered within level-2 units (survey locations). Pedestrians at the same location tend to be more similar to each other, than to pedestrians at other locations, due to common environments, and experiences at the same location. The potential similarity or mutual influences among pedestrians at the same location can lead to invalid statistical analysis results, by violating the ordinary regression models' assumption that individual observations (pedestrian satisfaction levels in this case) should not influence or influenced by other observations. Multilevel modeling deals with this spatial autocorrelation issue, by accounting for both the variability among survey locations (level-2 units) and the variability among pedestrians (level-1 units).

In other words, ordinary regression estimation with multilevel data results in incorrect standard errors. Multilevel modeling overcomes this challenge, by including explanatory variables at different levels, and by attributing unexplained variability (residuals) to the different levels (Rabe-Hesketh and Skrondal, 2012). We specify models for ordinal responses of the dependent variable, pedestrian satisfaction, by using a latent-response formulation. Multilevel modeling distinguishes within-cluster (location) effects from between-cluster effects, by including a location-specific random intercept ζ_j in the model

$$Y_{ij}^* = \beta_2 X_{ij} + \beta_3 X_j + \zeta_j + \epsilon_{ij}$$

$$Y_{ij} = \begin{cases} 1 & \text{if} \quad < y_{ij}^* \le k_1 \\ 2 & \text{if} \quad k_1 < y_{ij}^* \le k_2 \\ 3 & \text{if} \quad k_2 < y_{ij}^* \le k_3 \\ 4 & \text{if} \quad k_3 < y_{ij}^* \le k_4 \\ 5 & \text{if} \quad k_4 < y_{ij}^* \end{cases}$$

where, Y_{ij}^* is the latent response of pedestrian i in cluster (here location) j. K_s are category specific parameters or thresholds. X_{ij} are level-1 variables, and X_j are level-2 variables. ε_{ij} are residuals that are uncorrelated with both locations and pedestrians. The location-specific random intercept $\zeta_j \sim N(0, \psi)$ is assumed to be independently distributed over locations, and to be independent from explanatory variables X_{ij}.

The within-location dependency is modeled by calculating the intraclass (intra-location) correlation (ρ), as defined below. The models are estimated by using the command *gllamm* in the statistical software, Stata 11. Ordinal logit is fitted in *gllamm* with the *link(ologit)* option.

$$\hat{\rho} = \frac{\hat{\psi}}{\hat{\psi} + \pi^2/3}$$

Lastly, we use a likelihood ratio test for nested models, to evaluate the relative importance of grouped explanatory variables, according to the second hypotheses (Lichstein et al., 2002; Tognelli and Kelt, 2004). The three reduced models – without meso-scale, micro-scale, and personal variables, respectively – are contained within the full model (model containing all variables):

$$LR = -2(LL_{reduced} - LL_{full})$$

where, LR is the likelihood ratio test statistic. $LL_{reduced}$ and LL_{full} are the log-likelihood of the reduced and full models, respectively. For example, a reduced model is a model lacking meso-scale variables; whereas, the full model is the model containing all variables. In this case, larger LR values indicate a greater contribution of meso-scale variables as a group to the model.

Results

Utilitarian walking model result

Table 3 presents the utilitarian walking models that estimate the level of pedestrian satisfaction. The rho value indicates that 27.4% of the variation in reported pedestrian satisfaction is attributable to locational differences. Therefore, ordinary ordered logit produces incorrect standard errors. The pseudo *R*-squared value indicates that between-location residual variance declines, as independent variables are added from the null model without independent variables. The results partially confirm our first hypothesis, that the built environment characteristics are correlated with pedestrian satisfaction. Among meso-scale environmental variables, the effects of intensity of activities (represented as FAR) and availability of bus stops are positive, and significant. The effect of intersection density is significant and negative, indicating that when they need to cross more intersections, pedestrians tend to be less satisfied. Pedestrians tend to be less satisfied when they walk through hillier routes. Also, several micro-scale environmental variables are significantly associated with pedestrian satisfaction. The presence of dedicated bus lanes and available pedestrian crossings are positively correlated with the pedestrian satisfaction level. When pedestrians walk on wider sidewalks, the level of satisfaction tends to be higher. Among micro-elements, the presence of trees is also positively associated with the satisfaction level. Level-1 personal characteristics are also statistically significant. Pedestrians tend to be less satisfied being accompanied, than walking alone. Walking familiar streets tends to be more satisfactory, than walking unfamiliar streets. Senior pedestrians' satisfaction level is significantly higher, than that of adult pedestrians.

Table 3
Utilitarian and recreational walking model results estimating pedestrian satisfaction.

		Utilitarian walking multilevel model			Recreational walking multilevel model		
		Coef.	(S.E.)	*p*-Value	Coef.	(S.E.)	*p*-Value
Level-2 variables							
Meso-scale	FAR	0.151[c]	(0.036)	0.000	0.118	(0.079)	0.135
	Diversity index	0.208	(0.202)	0.305	−0.109	(0.323)	0.735
	Intersection density	−0.046[c]	(0.007)	0.000	−0.057[c]	(0.012)	0.000
	Slope	−0.053[c]	(0.015)	0.000	−0.056[b]	(0.022)	0.011
	Subway	0.019	(0.065)	0.765	−0.140	(0.105)	0.180
	Bus	0.435[c]	(0.128)	0.001	0.273	(0.227)	0.229
Micro-Scale	Bus lane	0.215[b]	(0.100)	0.032	0.376[c]	(0.174)	0.030
	Crossing	0.152[b]	(0.068)	0.027	0.080	(0.107)	0.453
	Sidewalk width	0.038[c]	(0.013)	0.005	0.020	(0.023)	0.373
	Fence	0.037	(0.083)	0.653	0.139	(0.135)	0.305
	Signal	0.167	(0.248)	0.501	0.663	(0.370)	0.073
	Lamp	0.175[a]	(0.090)	0.053	0.345[b]	(0.147)	0.019
	Ramp	−0.015	(0.077)	0.846	0.018	(0.118)	0.881
	Tree	0.401[c]	(0.077)	0.000	0.502[c]	(0.120)	0.000
	Trashcan	0.146	(0.200)	0.465	0.506	(0.694)	0.466
	N	1170			1057		
Level-1 variables							
Personal	Together	−0.090[c]	(0.017)	0.000	0.027	(0.057)	0.639
	Familiar	0.158[c]	(0.021)	0.000	0.189[a]	(0.102)	0.064
	Male	−0.018	(0.014)	0.224	0.002	(0.049)	0.967
	Children	0.001	(0.027)	0.971	−0.129	(0.229)	0.573
	Senior	0.142[c]	(0.023)	0.000	0.046	(0.052)	0.372
	n	74,644			7567		
	$Variance_u$	1.244	(0.054)		1.742	(0.121)	
	Rho	0.274			0.346		
	Pseudo R_u^2	0.127			0.133		

[a] $p < .10$,
[b] $p < .05$,
[c] $p < .01$.

Table 4
Relative importances (likelihood ratio) of meso-scale, micro-scale, and personal variables.

	Meso-scale variables	Micro-scale variables	Personal variables
LR utilitarian	85.17	58.02	148.03
LR recreational	46.51	42.10	11.28

Recreational walking model result

Recreational walking model results are presented in Table 3. The intraclass correlation of recreational pedestrian satisfaction is 0.346, justifying the multilevel model over an ordinary ordered logit model. The random-intercept ordered logit model includes independent variables. The pseudo *R*-squared value indicates that the multilevel model with independent variables is improved from the null model. Two meso-scale variables, the effects of intersection density and hilliness, are negatively associated with the level of pedestrian satisfaction. Among micro-level variables, the presence of bus lanes is positively associated with satisfaction levels. The presence of pedestrian amenities, such as lamps and trees, positively affects recreational walkers' satisfaction levels. Personal variables are not statistically significant.

Likelihood ratio test result

Table 4 presents the relative importance of meso-scale, micro-scale, and personal variables, as groups. In the utilitarian walking model, the explanatory variables that have the highest relative importance are personal variables. Meso-scale environmental variables rank the second in importance. The micro-scale environmental variables' contribution to the model is the smallest. In the recreational walking model, variables that rank among the most important are meso-scale variables. The contribution of micro-scale variables is a little smaller, ranking second. The importance of personal variables is the lowest in the recreational model.

Implications and conclusions

Implications

The present study investigates the effect of meso- and micro-scale environmental factors on pedestrian satisfaction, analyzing a unique large-scale pedestrian survey in Seoul. The relative importance of the two scale environmental variables are also compared as groups. The utilitarian pedestrian model shows that both meso- and micro-scale factors play a significant role in influencing pedestrian satisfaction. Utilitarian pedestrians are likely to be more satisfied with higher density that provides greater chances of multiple activities and events. The significant effect of the availability of the bus system indicates that better public transportation services may increase the satisfaction level of utilitarian pedestrians, implying that utilitarian pedestrians are potential bus users. However, the negative effect of intersection density is somewhat unexpected, because previous studies identified a positive correlation between better street connectivity and walking levels (e.g. Baran et al., 2008). A possible explanation may be that pedestrians tend to dislike frequently having to stop to cross roads, which may decrease their satisfaction levels. Lastly, hilly streets may make walking physical difficult, decreasing pedestrian satisfaction levels.

Several micro-scale variables also seem to significantly influence pedestrian satisfaction. The significant effect of dedicated bus lanes implies that, again, a convenient bus system can increase the satisfaction levels of pedestrians, who are mostly potential bus users. The availability of crossings contributes to a higher level of pedestrian satisfaction, by making it easier for walkers to cross roads. Pedestrians feel more satisfied with wider streets that provide more space for easier walking. The positive effect of green elements, such as trees, on satisfaction is consistent with previous findings (e.g. De Jong et al., 2012; Stradling et al., 2007). Comparing the importance of meso- and micro-scale variables, meso-scale variables are more important than micro-scale variables as groups. However, the importance of micro-scale variables is not negligible.

The recreational model identifies the negative influence of higher intersection density and greater hilliness. The availability of bus-dedicated lanes also influences recreational walkers' satisfaction. The model also shows that street amenities, such as lamps and trees, can influence recreational pedestrians. The relative importance of meso- and micro-scale variables are similar, while the meso-scale variables' importance is a little greater. In addition, personal characteristics tend to influence utilitarian walkers, rather than recreational walkers. A possible explanation may be that utilitarian walking can be non-voluntary, while recreational walking may be generally voluntary. Hence, the satisfaction levels of utilitarian walkers who need to walk may vary, depending on the individuals' condition; whereas, the satisfaction levels of recreational walkers who are willing to walk may be relatively stable over individuals.

The present findings have several design and policy implications. In metropolitan cities like Seoul, with high parking fees, creating a satisfactory pedestrian environment is essential for successful Transit-oriented Developments, because walking is generally necessary to use public transportation. Urban design and planning approaches (e.g. Smart Growth and New Urbanism) suggested meso-scale approaches, such as achieving higher density, mixed land-use, and better street connectivity.

However, these types of approaches are not easy to achieve in practice, generally requiring massive change of urban structure. In contrast, micro-scale approaches, which improve street-level environments, are relatively easy and feasible to realize. While implying that both scales of environmental factors are important for pedestrian satisfaction, micro-scale intervention can be an effective approach to improving environmental quality.

Academically, most previous walkability studies have focused on either meso- or micro-scale environmental variables, either of which is highly likely to produce incorrect results of the environmental effect, because as the present study shows, both scales of variables are considerably important in influencing pedestrian satisfaction, and possibly further walking behavior. Also, the significant correlation between pedestrian satisfaction and environmental factors implies the importance of considering psychological factors for walkability studies. In travel behavior research, a considerable amount of studies has focused on residential preference and traveler's attitude, in pursuit of controlling for self-selection (e.g. Ewing and Handy, 2009; Mokhtarian and Cao, 2008). Other studies examined perceptions of distance, safety, convenience, monetary cost, and travel time related to walking (Vojnovoc, 2006). However, only little research focused on the role of satisfaction in interactions between behavior and the built environment. While pedestrian satisfaction is expected to encourage walking (Ettema et al., 2011), few empirical studies examined the effect of satisfactory walking environments on the level of walking activities. Also, little is known about the influence of various aspects of pedestrian satisfaction – for example, satisfaction with safety, security, convenience, comfort, easiness for crossing, and visual experience – on walking. Therefore, the present analysis suggests that further investigation of pedestrian satisfaction can contribute to a better understanding of walkability.

Overall, this study calls on researchers to investigate a comprehensive set of psychological and environmental factors, in order to understand the various aspects of pedestrian satisfaction, and the diverse motivations behind them, as well as on planners, to adopt diverse design approaches that will produce more satisfactory pedestrian environments.

Limitations and future research

Despite the findings, an important limitation of the present research is the pedestrian survey that includes only one question addressing overall pedestrian satisfaction. In order to sufficiently examine pedestrian satisfaction, various aspects of satisfaction, for example comfort, safety, ease, and aesthetics of walking should be determined. However, few large-scale travel behavior surveys include these types of questions. Surveys that investigated these aspects of satisfaction would contribute to better understanding of walking behavior, and related policy outcomes. Hence, future research will examine pedestrian satisfaction in sufficient detail. Also, focusing on pedestrians in Seoul, the findings of the present study may be applied to large cities in Asia that are similar to Seoul. Parallel studies in other cities should enhance the generalizability of the study. Lastly, while our study investigated the effect of the built environment on pedestrian satisfaction, the influence of pedestrian satisfaction level on the actual level of walking activity is not sufficiently investigated in walkability research. Future studies that reveal the role of pedestrian satisfaction in promoting walking participation, may contribute to better design and health policies for healthy environments.

Acknowledgments

This work is supported by a National Research Foundation of Korea Grant, funded by the Korea government (MSIP) (NRF-2010-0029452). This work is also supported by the 2013 Hongik University Research Fund.

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