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Operational Definitions of Walkable Neighborhood: Theoretical and Empirical Insights

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Background: The concept of walkable neighborhoods is increasingly important in physical activity research and intervention. However, limited theoretical understanding and measurable definitions remain a challenge. *Methods:* This paper reviews theories defining neighborhoods and offers an empirical approach to identify measurable attributes and thresholds of walkable neighborhoods. Bivariate and multivariate analyses are used for self-reported socio-demographic background, neighborhood walking behavior and perception, and objective measures of environments. *Results:* Environmental attributes positively associated with walking sufficiently to meet health recommendations included higher residential density and smaller street-blocks around home, and shorter distances to food and daily retail facilities from home. Threshold distances for eating/drinking establishments and grocery stores were 860 and 1445 feet. *Conclusions:* Results questioned theoretical constructs of neighborhoods centered on recreation and educational uses. They pointed to finer mixes of uses than those characterizing suburban neighborhoods, and small spatial units of analysis and intervention to capture and promote neighborhood walkability.

Key Words: walking, physical activity, neighborhood environment, measures, thresholds, GIS

The concept of walkable neighborhoods is receiving an increasing amount of attention because evidence suggests that neighborhood socio-physical structure may relate to physical activity for health and transportation purposes.[1-6]

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Definitions and measurements of neighborhood have eluded many disciplines for many years. Yet in the health fields, and specifically in relation to physical activity, characterizing neighborhood is important, first because in practice, neighborhoods are perceived by both residents and policy makers as meaningful congregations of people with common interests. As a result, they are key spatial units of intervention, planning, and organization for institution and capacity building. Second, in research, neighborhoods are important spatial units of sampling, measurement, and analysis. Diez Roux notes that "…investigating how places are related to health will require learning to characterize places as well as we have learned to characterize the biology and behavior of people."[7] At-risk populations experience the effects of the spatial dimension of neighborhood most strongly because financial constraints limit their mobility and access to daily activities and services.[8-10]

This paper has two objectives. First, it provides a brief overview of theoretical frameworks that define and measure neighborhoods. Second, it offers an empirical approach and evidence for a definition of *measurable* attributes and thresholds of walkable neighborhoods for research and intervention.

Theory

Walking and Neighborhood

The planning profession has, since its inception, devised models of neighborhoods based on walkability.[11, 12] In 1929, Clarence Perry proposed the "Neighborhood Unit," based on children and families being able to walk safely from their homes to elementary schools and community centers.[13] His theory derived from social reforms aimed at growing urban populations,[14] and from Ebenezer Howard's Garden City theory, which modeled "new" (turn of the 19th and 20th centuries) British cities on small agglomerations of 6000 to 30,000 people living within walkable distance to services and linked by rail transit.[15] Today, conspicuous supporters of the New Urbanism have continued to advocate walkable neighborhoods, characterized alternatively as Traditional Neighborhood Design (TND),[16] Transit Oriented Development (TOD),[17] Pedestrian Pockets,[18] Transit Villages, Urban Villages, etc.

Defining the walkable neighborhood extends beyond pedestrian concerns (double meaning intended), as the ability to walk in a neighborhood indicates not only a type of mobility and means of travel,[19-21] but also a type of sociability between neighbors, which, together, likely affect the physical, mental, and spiritual health of people in the community.[22-24]

Conceptualizations of Neighborhood

Various disciplines have formulated theories of neighborhood. Concepts evolved since the end of the 19th century[25] and some claim that neighborhood is an American invention.[26] Conceptualizing neighborhood corresponds historically to significant population growth and increases in the size of urban agglomerations, which precipitated the stratification of urban residents into relatively homogeneous groups at social and spatial levels. It is also related to the modern phenomenon of spatial division between residence and work, which leads to the social status-, rather than work-based, layering of urban societies—to the extent that, today, the term neighborhood is often used for areas whose sole function is residential.

Scholars in the social sciences now commonly consider a "*multiplicity*" of neighborhood definitions and numerous levels of influence on these definitions.[22, 27, 28] Quoting Suttles,[29] Galster identifies four scales of neighborhood.[30] First is the block face, or the area over which children can play without supervision. Second, the "defended neighborhood" is the smallest area possessing a corporate identity as defined by mutual opposition or contrast to another area. Third, the "community of limited liability," is a district represented by a local governmental body, in which individuals' social participation is selective and voluntary. And fourth, at the highest geographical scale, the "expanded community of limited liability," covers an entire sector of the city. These scales combine neighborhood geography and sociology, and thus help conceptualize different levels of interaction between neighborhood environment and behavior.

Measurements of Neighborhood

Measuring neighborhood, on the other hand, lingers behind conceptualization, with few gauges proposed for tangible socioeconomic indicators, or for actual size or geographic spread of neighborhood. Ecologists note that humans evolved to interact within groups of only a few hundred acquaintances, suggesting that viable neighborhoods may be very small.[31] Yet population growth and cultural evolution have led to "global" living, with most people having many "pseudo-acquaintances." Evolutionary approaches pay little attention to individuals, highlighting intrinsic conflicts between neighborhood and larger, group-level interactions. Sociologists identify common attributes of social, economic, cultural, and physical aspects of neighborhood, bringing forth indicators of cohesiveness, homogeneity, and heterogeneity. However, they recognize that relevant sociologic measures vary by behavior, domain, and outcome of interest. The *temporal* dimension of neighborhood is acknowledged as involving not only the age of "neighbors," the time of day, week, year, etc., but also specific activities (e.g., shopping for food versus other goods, seeking medical services, conducting civic activities). Furthermore, neighborhood is characterized as highly *dynamic*.[32] Galster notes that "[h]ouseholds *consume* a neighborhood by choosing to occupy it, thereby *producing* an attribute of that location related to that household's demographic characteristics, status, civil behaviors, participation in local voluntary associations and social networks,...[emphasis added]."[30]

The question of whether *objective* or *subjective* measures of neighborhood are appropriate further complicates methods of neighborhood definition. Psychologists use mental mapping to measure individual neighborhoods.[33] In public health, health outcomes, which in the past were constructed solely on individual behavior, biology, and beliefs, are now often investigated in multilevel analyses that include group socioeconomic position (SEP), neighborhood crime, dilapidation of the built environment, housing type, and age of houses.[7] Studies show that people living in more disadvantaged census tracts are more likely to report health problems, and that perceptions of neighborhood are grounded in reality.[34] Yet, in general, few public health empirical studies have incorporated objective neighborhood environmental measures, so the ability to efficiently capture those measures that are hypothetically related to health can benefit future research and intervention.[35]

Overall, theoretical perspectives project neighborhood as a geographical construct of place, defined around home and everyday activities, centered on schools, community centers, parks, or retail services. Neighborhood evokes socio-physical homogeneity, a shared sense of place, connection, and access. It has multiple cognitive, economic, geographic, behavioral, cultural, and temporal dimensions. The concept is dynamic, individually defined, and changing over the short and long terms, including multiple levels of influence and geographic extents. While walkability has been an integral aspect of the neighborhood concept, the current body of knowledge lacks an operational definition of a walkable neighborhood.

Empirical Approach

An empirical approach serves to test the applicability of the traditional neighborhood theories as applied to contemporary settings, and to identify measurable attributes and thresholds of a walkable neighborhood for research and intervention.

Data and Measurements

Survey data included a telephone survey of 608 adults randomly sampled in King County, Washington. The study area was representative of medium density urban and suburban development.[36] The survey underwent human subjects review by the University of Washington, including institutional approval of the protocol and obtaining informed consent. The survey instrument and protocol are described elsewhere.[37] The response rate was estimated at 31.54% and the cooperation rate at 34.32%.[38] The survey provided socio-demographic, neighborhood perception, attitude toward environment, and walking behavior data.

Perceptual measures of neighborhood included the perceived presence or absence of grocery stores, schools, and parks, because of their theoretical significance as neighborhood centers and their selection as popular walking destinations in the survey responses.

Objective measures of physical environment included more than 200 variables and 900 measures, extracted from King County's parcel and network databases in geographic information systems (GIS). Objective measures of neighborhood attributes included count, area, distance and ratio measures of individual and groups of destinations. Constraints on the objective measurement of the geographic extent of neighborhood were cast as 1-km and 3-km "airline" (straight line) and "network" (street network-based) buffers around the respondent's home (Moudon AV, Lee C, Cheadle A, et al. unpublished data, 2005). However, distance measures between homes and individual or groups of destinations were taken continuously up to 3-km airline and network distances.

Land uses examined in this study included 24 destinations and 11 groups of destinations, called neighborhood centers (NCs), and established from theoretical constructs of neighborhood. We considered NCs that grouped daily shopping, open space/recreational, institutional, employment-based, and educational uses.

Analyses

Bivariate analyses examined the associations between walking and environmental variables, and between perceived and objective measures of environment. Perceived presence or absence of destinations was correlated with matching objective measures, using *t*-test and one-way ANOVA (Kruskal-Wallis test when the equal variance assumption did not hold).

Multivariate analyses included multinomial logit models to estimate walking, and logistic regression models to estimate neighborhood perception. Multinomial logit models estimated the odds of being a "moderate walker" or "sufficient walker," compared to not walking. The walking variable was constructed by adding weekly minutes of self-reported walking for commuting, recreation, and to and from retail/service facilities in the respondent's neighborhood: 0 min for non-walkers, 1-149 min for moderate walkers, and 150+ min for sufficient walkers. The threshold of 150 min corresponded to the 30 min per day, 5 days per week recommendation for health purposes.[39]

A base model was first estimated including only the survey variables (21 sociodemographic and perception variables). Two sets of final models were then estimated using airline and network objective environmental measures (Moudon AV, Lee C, Cheadle A, et al. unpublished data, 2005). Variables in the base and final models were prioritized into VIP and non-VIP, based on their theoretical importance. A total of 8 VIP environmental variables (with consistent and repeated support from previous research) were retained in the final models regardless of their statistical significance. A backward stepwise modeling process was used for the non-VIP variables, with 39 and 29 variables considered in the airline and network models, respectively. Only those statistically significant at the 0.1 level were included in the final models.

Logistic regression models estimated the odds of perceiving the presence (relative to their absence) of grocery stores, parks, and schools in the neighborhood. Independent variables included walking, and objectively measured total counts of each destination within the 1-km and 3-km buffers of the respondent's home and distances to the closest, using both airline and network buffers/distances in the respective models. The SPSS 12.0 statistical software package (SPSS, Inc., Chicago, IL) was used for all analyses.

Threshold values of neighborhood walkability were determined by use of the objectively measured environmental variables associated with people walking sufficiently to meet the recommendations for health. Only variables found to be significant in the final multinomial logit models were used. For reference purposes, threshold values of the variables that had been categorized were complemented with mean values of the original continuous variables.

Findings

Descriptive Statistics from Survey

Over half the respondents (60.5%) reported living in residential-only neighborhoods, and 38.5% were in neighborhoods with a mix of residential and commercial uses.

Almost 35% (34.6%) said they lived in neighborhoods where single-family homes predominated, and 49.5% in neighborhoods with a mix of single-family homes, apartments, and condominiums. Most (60.2%) owned their homes, and lived in households with one car per adult (64.1%). Almost 70% of the sample drove to work, and 14.5% used public transit. For those who drove, the mean one-way commute was 23.82 min, and the median 20 min.

More than 80% of the respondents reported a grocery store, a park, and a school in their neighborhood. Popular walking destinations, based on the proportion of respondents who reported walking to them on a weekly basis, included grocery stores (45.9%), non-fast food restaurants (23.0%), drug stores (19.2%), convenience stores (16.3%), banks (15.8%), cafés/coffee shops (15.0%), and post offices (12.8%). Among the 445 respondents (out of 608) who walked for recreation, common places used in the neighborhood were neighborhood streets (83.4%), parks and open space (62.9%), walking/jogging trail (42.5%), indoor gym or fitness center (18.0%), and shopping mall (9.2%). Almost 60% of the respondents reported walking outside of their neighborhood.

Perceived Measures of Walkable Neighborhood

Survey variables with consistently strong associations with walking in the multinomial logit models included age, income, education, health status, physical activity and overall walking levels, transit use, neighborhood social environment, and having a dog (Moudon AV, Lee C, Cheadle A, et al. unpublished data, 2005).

When controlled only for socio-demographic variables (base model, pseudo $R^2 = 0.35$), three of the four neighborhood perception variables showed statistical significance at the 0.05 level (Table 1). When controlled also for all objective environmental variables (final model, pseudo $R^2 = 0.47$), only one variable, perception of neighborhood social environment (a latent factor based on knowledge of neighbors and the presence of people who walked and biked in the neighborhood), was significant at the 0.05 level. In contrast, the perception of neighborhood street amenities was consistently insignificant. Furthermore, the remaining two perception variables became insignificant or less significant when controlled for the objective environmental variables, suggesting that they explained some of the variation in the perceived visual quality of and traffic in the neighborhood.

Objective Measures and Thresholds of Walkable Neighborhood

Twelve objectively measured attributes of walkable neighborhood were significant in the final multinomial logit airline model, after controlling for socio-demographic and perceived environmental variables (Table 2). Results of the network model and comparison with airline model are discussed elsewhere (Moudon AV, Lee C, Cheadle A, et al. unpublished data, 2005). These attributes pertained to the location characteristics of the respondents' homes, the distances between the respondents' homes and the destinations that attracted or deterred walking, and the characteristics of the buffer areas within a 1-km and 3-km airline of the respondents' homes. Table 2 presents threshold measures based on the mean values for sufficient walkers, and, for comparative purposes, associated mean, and lower and upper bound values of the non-walker and for the entire population.

Table 1 Neighborhood Perception Variables As They Relate to Walking in the Multinomial Logit Models

				Final model					
	Base model[1]			Airline[2]			Network[3]		
Variable definition	**-2 LL**	X^2	**P**	**-2 LL**	X^2	**P**	**-2 LL**	X^2	**P**
Neighborhood social environment for walking and biking in the neighborhood	1001.965	16.665	000	900.467	14.248	001	927.861	14.700	001
Street amenities	987.508	2.207	332	886.824	0.606	739	913.223	0.061	970
Visual quality	992.233	6.933	031	889.759	3.541	170	916.117	2.955	228
Problems related to automobiles in neighborhood	992.845	7.544	023	888.210	1.992	369	918.421	5.260	072

[1] *Note for base model:* –2 log Likelihood (-2 LL) of full model = 985.301; Pseudo R^2 of full model = 0.307 (Cox and Snell), 0.356 (Nagelkerke), 0.185 (McFadden); other variables included: age, education, health status, difficulty in walking, household income, dog in the household, self-selection for household location, vigorous physical activity, transit use, vehicle miles traveled, walking outside the neighborhood, attitude toward problems of traffic congestion and air pollution (latent factor), preference for walking and biking to solve congestion (latent factor), gender (insignificant), facilitators of walking (insignificant), number of cars in the household (insignificant), and knowledge of physical activity benefits (latent factor, insignificant).

[2] *Note for final airline model:* -2 Log Likelihood (-2 LL) of full model = 899.275; Pseudo R^2 = 0.339 (Cox and Snell), 0.465 (Nagelkerke), 0.256 (McFadden); all base model variables are included in the final model. Other significant objective environmental variables included ($P <= 0.1$ in at least one logit model) distance to the closest grocery store, eating and drinking place, and office+mixed use NC; size of the closest office NC; number of grocery stores, retail+restaurant+grocery NCs, educational uses, total sidewalk length (on major roads only) and mean net residential density within 1 km buffer; residential density of the household parcel; household block size; route directness to the closest school.

[3] *Note for final network model:* –2 log Likelihood (-2 LL) of full model = 913.368; Pseudo R^2 = 0.384 (Cox and Snell), 0.446 (Nagelkerke), 0.244 (McFadden); all base model variables are included in the final model. Other significant variables included ($P <= 0.1$ in at least one logit model) distance to the closest bank, office NC, and retail+restaurant+grocery NC; number of destinations within the closest school+church NC; residential density of the household parcel; destination compactness of the closest office NC; route directness to the closest grocery store and school.

Respondents living in parcels with a net density higher than 21.7 residential units per acre were more likely to walk than those whose home were in a parcel with lower density. However, net residential densities measured within the 1-km buffer of the respondents' homes were negatively associated with more walking when higher than 15.5 residential units per acre. Also, sufficient walkers lived on street-blocks of less than 4 to 5 acres (Table 3).

Significant neighborhood characteristics within 1 km of residents' homes consisted of both "attractor" and "deterrent" land uses, positively and negatively associated with walking. The former included grocery stores/markets/supermarkets and eating and drinking establishments. Thresholds for attractive walking environments included approximately two or more agglomerations of grocery stores, non-fast food restaurants and retail stores, but no more than four individual grocery

Table 2 Objective Measures and Thresholds of Neighborhood Attributes Significantly Related to the Probability of Walking Sufficiently to Meet Recommendations for Health

Class of measurement/ attribute	Measure–ment Unit	Sufficient Walker (*n* = 208)	Non–Walker (*n* = 85)		Total Population (*n* = 608)	
		Threshold	Mean	Bound (lower–upper)	Mean	Bound (lower–upper)
RESPONDENT HOME LOCATION [parcel]						
Density of household parcel	Residential Units/Acre	>21.7	12.5	4–83	18.1	0.8–680
Size of the household block[1] Categories: 11=0–2, 12=2.1–3, 13=3.1–4, 14=4.1–5, 15=5.1–10, 16=10.1–20, 17=20.1–50, 18=50.1–100, 19=100.1– 200, 20=200.1–500, 21=500.1+ acres	**Category (Acre)**	**<14 (5.9)**	**15.5 (15.2)**	**11–21 (1.8–9,198)**	**14.6 (8.3)**	**11–21 (0.7–11,558)**
AIRLINE DISTANCE TO CLOSEST [captured up to 3 km from home location]						
To grocery stores or markets	Feet	<1,445	2,191	211–9,843*	1,546	80–9,843[2]
To eating or drinking place	Feet	<861	1,411	59–9,843*	1,037	56–9,843[2]
To Neighborhood Center with office + mixed use Categories:11=0, 12=0.1–264,13=264.1–528, 14=528.1–1056, 15=1056.1–1584, 16=1584.1–2112, 17=2112.1–2640, 18=2640.1–5280, 19=5280.1–9240, 20=9240.0001+ feet	**Category (Feet)**	**>14.82 (1,786)**	**16.0 (3,016)**	**11–20 (0–9,843*)**	**15.2 (2,240)**	**11–20 (0–9,843)**[2]
Route directness between airline and network distance to the closest school	Percent	>74.5	69.0	22–100	73.9	20–100
1 KM NEIGHBORHOOD						
Total number of grocery stores or markets 11=0, 12=1, 13=2, 14=3–4, 15=5–7, 16=8+ stores	**Category (Count)**	**13.5 (3.7)**	**13.0 (2.6)**	**11–16 (0–12)**	**13.4 (3.3)**	**11–16 (0–18)**
Total number of education land uses	Count	<5.1	4.3	0–46	4.8	0–46
Total number of Neighborhood Centers with grocery + restaurant + retail	Count	>1.8	1.2	0–5	1.6	0–6
Average net residential density	Residential Units/Acre	<15.5	10.8	4.0–105	13.0	3.4–218
Total sidewalk length along major streets (collector, primary, and minor streets, excluding local streets and highways)	Feet	>56,261	48,045	1,584–99,187	52,316	1,500–122,716
3 KM NEIGHBORHOOD						
Size of the closest Neighborhood Center with 3 or more offices	Acre	<9.8	18.2	0.3–1,503	12.1	0.3–1,503

[1]Variables in **bold** are categorical variables. Variables in (brackets) are mean values from original continuous variables before categorizing, shown for reference purpose only)

[2]9,832 feet = 3 km (maximum search distance for all distance measures). See notes from Table 1 for information on the overall model fitness and the list of variables included

Table 3 Measures of Street-Block Sizes, by Non-Walker (*n* = 85), Moderate Walker (*n* = 295), and Sufficient Walker (*n* = 228)

	Mean values			Examples
	Grid Size (street centerline, in acres)	Approx. Grid Dimension (street center-line, in feet)	Approx. Block Size (excl. 70-foot wide streets, in feet)	Actual Block Sizes of Selected Cities (excl. streets, in feet)
Non-Walker (1 km airline buffer)	12.25	725 x 725	650 x 650	Bellevue, WA, 600 x 600
Moderate Walker (1 km airline buffer)	8.49	600 x 600	530 x 530	Perth, Australia, 500 - 600 x 430-460
Sufficient Walker (1 km airline buffer)	6.52	520 x 520	450 x 450	Seattle, 250 - 350 x 350-450 Chicago, 400 x 460
Sufficient Walker (mean continuous variable; house-hold block)	5.90	510 x 510	440 x 440	San Francisco, 275 x 412
Sufficient Walker (lower bound cat-egorical variable household block)	4.00	420 x 420	350 x 350	

stores within 1 km of the respondents' homes. However, large office parcels and schools were "deterrent" land uses. Threshold parameters for environments not supportive of walking included office complexes larger than 9.8 acres (one and a half to two traditional blocks) within 3 km, and more than five schools within 1 km of respondents' homes.

Distances between sufficient walkers' homes and attractor land uses (restaurants, grocery stores and agglomerations of grocery stores, restaurants, and retail stores) were less than one-third mile. Office complexes located within one-third mile from the respondents' homes deterred walking, while more direct routes to schools supported walking.

The threshold of transportation infrastructure needed to support walking sufficiently for health was slightly more than 10 miles (52,800 feet) of sidewalks along major streets (excluding local streets) in the area within 1 km of home.

For comparative purposes, bivariate analyses of distances between the respondent's home and selected destinations (a sample of variables that correlated significantly with walking at the 0.1 level) found a range of objectively measured neighborhood geographic extents associated with the two extremes of walking behavior (walking sufficiently and not walking in the neighborhood) (Figure 1). The results seem robust, because all mean values of distance between homes and destinations were in the expected direction as related to amounts of walking.

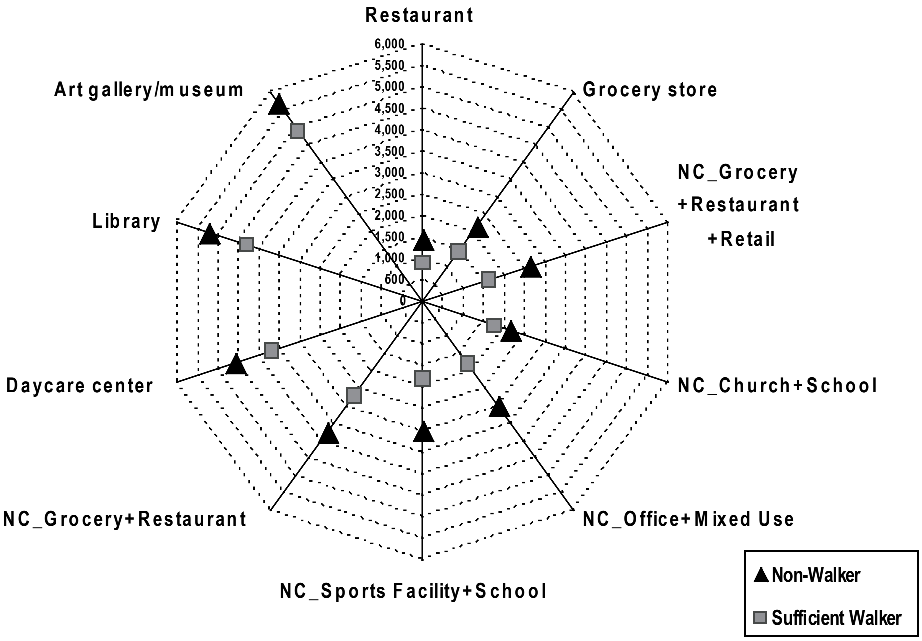

Figure 1—Mean airline distance from respondent's home to the closest destination and group of destinations (unit = feet)

Objective Environmental Correlates of Perception

Logistic regression results showed that the perceived presence of grocery stores, parks, and schools was significantly related to objective count and distance measures to these destinations (Table 4). However, count measures of these land uses were only significant within the 1-km buffer.[40]

Holding objective environmental measures constant, sufficient walkers were significantly more likely than non-walkers and moderate walkers to perceive the presence of grocery stores and parks in their neighborhood. Associations between the perception of schools in the neighborhood and amounts of walking were insignificant for all classes of walkers.

Regardless of the amount of walking they did, residents were more likely to report the presence, rather than the absence of particular land uses when those land uses were closer to and more abundant around their homes (Figure 2). However, the thresholds for walking behavior were inconsistent. Sufficient walkers who perceived the destinations to be within their neighborhood had more grocery stores and schools (but not parks), and were closer to them than moderate and non-walkers. In the case of parks, however, and for people who did *not* perceive any of these three destinations to be in their neighborhoods, mean thresholds of count and distance were not in the expected direction of association with amounts of walking.

Table 4 Logistic Regression Results for Perceived Presence of Destination in 1 Km Airline and Network Buffers

Perceived presence of		Objective measure√		Walking level			
				Moderate Walker (vs. Non-Walker)		Sufficient Walker (vs. Non-Walker)	
		β	Odds ratio	β	Odds ratio	β	Odds ratio
Grocery stores	Model 1: Count-A	0.181[a]	1.20	0.655	1.92	0.781[b]	2.18
	Model 2: Count-N	0.282[a]	1.33	0.595	1.81	0.730[b]	2.08
	Model 3: Distance-A	-0.772[a]	0.46	0.488	1.63	0.635[b]	1.89
	Model 4: Distance-N	-0.920[a]	0.40	0.484	1.62	0.619[b]	1.86
Parks	Model 1: Count-A	0.755[a]	2.13	0.543	1.72	0.738[b]	2.09
	Model 2: Count-N	0.680[b]	1.97	0.518	1.68	0.857[b]	2.36
	Model 3: Distance-A	-0.594[a]	0.55	0.497	1.64	0.718[b]	2.05
	Model 4: Distance-N	-0.667[a]	0.51	0.492	1.64	0.633	1.88
Schools	Model 1: Count-A	0.522[a]	1.69	0.186	1.20	0.064	1.07
	Model 2: Count-N	0.349[b]	1.42	0.202	1.22	0.090	1.09
	Model 3: Distance-A	-1.283[a]	0.28	0.163	1.18	0.000	1.00
	Model 4: Distance-N	-1.040[a]	0.35	0.070	1.07	-0.081	0.92

Note. [a] significant at 0.01 level: [b] 0.05 level; √ Objective measure used in each model:

Model 1: Count 1 km airline buffer (e.g., total count of grocery stores within 1 km airline buffer/distance from home).

Model 2: Count 1 km network buffer (e.g., total count of grocery stores within 1km network buffer/distance from home).

Model 3: airline distance to the closest destination (e.g., airline distance to the closest grocery store from home, measured up to 3 km in log-feet).

Model 4: network distance to the closest destination (e.g., network distance to the closest grocery store from home, measured up to 3 km in log-feet).

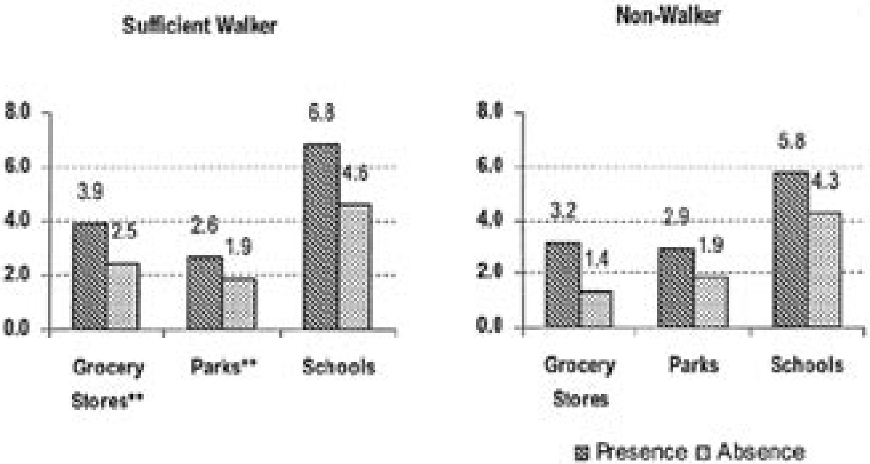

Figure 2—Perception of presence versus absence of destinations in the neighborhood, by non-walkers and sufficient walkers and by mean values of parcel counts in 1-km airline buffer; **significant at the 0.05 level.

Discussion

Implications for the Theory and Design of Walkable Neighborhoods

Comparing threshold values of the 12 variables significantly associated with sufficient walking to mean values for the non-walker and the total population showed that environments associated with more walking were denser, had activities closer together, and more sidewalks and smaller blocks. Differences between measures of environment for non-walkers and those for sufficient walkers were substantial. However, differences between the same measures for the entire population and those of sufficient walkers were small, indicating that overall, if further research confirms causal links between environmental features and walking, achieving more walkable environments is reasonably feasible for the future. This discussion and the conclusion are predicated on the assumption these causal links exist.

Residential Density. The threshold values of residential density found to be related to neighborhood walkability were within 15% of those in the total population of the study's sample frame. These thresholds were higher than the densities associated with many contemporary suburban single-family subdivisions, yet they could be met relatively easily if future developments comprised compact single-family, cottage and row housing, or low-rise garden apartments. These housing types can achieve a net single-parcel density of more than 20 units per acre. Also, net residential densities of 15.5 units per acre within a 1-km buffer are typical of extant 1920s neighborhoods, in which a few small apartment buildings were mixed with prevailing single-family detached housing, a model now being successfully replicated in many new towns. Hence the density threshold values do not preclude the prevalence of single-family housing. In design terms, the 500-acre walkable neighborhood would have approximately half its land in residential parcels with some 3900 residential units. Assuming the units averaged 2500 ft^2 each (including parking, and corresponding to the national average of contemporary house size), and were two stories high, less than 50% of the net residential land would be covered by buildings or structures. Such densities are compatible with existing lifestyles, as indicated by the current mean (13 residential units per net acre; range 3 to 220 of this total sample frame).

Block Size. The street-block size threshold of less than 5 acres (street center-line measure) for the household parcel corresponded to the medium-sized city blocks developed prior to World War II and found in contemporary single-family development. Bivariate analyses showed the mean values of block size within the 1-km buffer of the respondent to be slightly larger, at 6.8 acres for sufficient walkers. Taking into account standard residential street widths of 70 feet, this measure is consistent with blocks less than 500 by 500 feet (excluding streets) (Table 3). Today's single-family subdivisions have blocks smaller than this threshold, but typical suburban multifamily and commercial development take place in larger blocks—ranging from 12 to more than 100 acres—because their large parcels require few streets for access.[41] Large differences in block size measures between sufficient walkers and the total population indicated that reducing block size could enhance neighborhood walkability.[42]

Sidewalks. The threshold of 56,000 linear feet of sidewalks along major streets in the 1 km buffer is achievable within current development practices. The mean value for the total population was slightly more than 53,000 feet. On average, 71.2% (ranges from 28.6% to 89.4%) of the total street network consisted of local (non-major) streets for which sidewalk data were unavailable. Accordingly, the threshold value for full sidewalk coverage would be just under 200,000 feet.

Linear feet of sidewalks along all streets of traditional pre-war areas (with street-blocks averaging about 6 acres—center-line measure applied to the 1-km buffer) add to almost 300,000.[43] On the other hand, post-war suburban areas with poor pedestrian infrastructure (street-block averaging more than 30 acres) have only 60,000 feet of sidewalks. (The average for Seattle with full sidewalk data available, is 124,285 feet—ranging from 3169 feet to 197,121 feet.)

Attractor Destinations (Grocery, Restaurant, and Retail) as Centers of Walkable Neighborhoods. Multivariate analyses pointed to walkable neighborhoods being centered on basic daily retail and food-related activities. Models and survey reports showed proximate presence of grocery stores/markets/supermarkets, restaurants, and to a lesser extent, banks, as significant attractors of walking. Drug stores and coffee shops are potentially important, but were not included in the models due to a lack of objective data. Post offices had a moderate bivariate association with walking, but did not maintain their significance in multivariate analyses. Destinations that were expected to be less conducive of walking, such as big box stores, shopping centers and malls, hospitals, theaters, and museums, did not show any significant relationship with amount of walking. Covariance between these variables and other environmental variables was small, confirming their lack of association with walking.

The insignificance of parks and trails, which have been featured as neighborhood "centers" in many 20th century neighborhood design and planning theories, and which are still commonly believed to support walking, should be noted. In this study, parks were not a significant attribute of walkable neighborhoods and trails were only marginally so at the bivariate level, suggesting the need to examine the importance of open space in creating walkable neighborhoods, but also keeping in mind the possibility that open space may be associated with increased overall physical activity.

The findings generally did not support planning theories of the early part of the 20th century which placed schools, community centers, and open space at the heart of community, but concurred with contemporary theories claiming commercially focused "town centers" as a necessary element of community. However, this research identified land uses different from those found in today's town centers. The new centers typically house activities related to discretionary rather than necessary spending, and exclude grocery or drug stores, which are believed to be associated with car travel,[44] and located to serve not one, but several neighborhoods.

The strength of association between walking and the objective presence of proximate grocery stores and non-fast food restaurants likely reflected the rise of smaller families, changing life styles, time constraints that lead to frequent eating out or purchase of take-out meals, and diets that favor deli over frozen foods. Much remains to be understood about society's changing relationship to food and its impact on neighborhood life.

Deterrent Land Uses (Offices and Schools) in Walkable Neighborhoods. Why offices and schools appear to deter walking was discussed elsewhere (Moudon AV, Lee C, Cheadle A, et al. unpublished data, 2005). Importantly, the size of office complexes rather than the land use itself was associated with walking. Office complexes in the sample frame averaged 12 acres in size, about 20% higher than the threshold of walkability. Over time, however, office parcels have become larger—in suburban Puget Sound, they are more than 60% larger than those in Seattle. A promising alternative land use distribution in walkable neighborhoods will mix office and retail to attenuate the impact of office uses at the street level.

Schools and educational land uses were scattered throughout the sample frame, as they tend to be in all urbanized regions. Only the number of schools near the respondent's home was negatively associated with walking. The threshold of fewer than five such uses within the 1-km neighborhood seems achievable, given this study's total population mean of 4.8 educational uses.

Perceived Number of Central Activities in and Geographic Extent of Walkable Neighborhood. The lack of association between perceived and objectively measured neighborhood attributes in the 3-km buffer pointed to the small geographic extent of neighborhood perception. This finding is consistent with the short walking distances reported. While not surprising, it has important implications for both research and design of neighborhoods: the walkable neighborhood seems geographically contained within a 1-km circle, an area smaller than 500 acres (2 km^2). This spatial unit (approximately 1.4 by 1.4 km or 4700 by 4700 feet) is considerably smaller than that commonly used in either social science research or in planning practice.

Within the 1-km buffer, the "actual" presence of grocery stores, parks, and schools performed well in predicting their "perceived" presence. Yet only grocery stores were strongly associated with sufficient walking, using both objective and subjective measures. Parks and schools had insignificant or inconsistent associations with the activity. Overall, perceptual measures appeared to relate more strongly to general characteristics of neighborhood than to those specific to the walkable neighborhood.

Surprisingly, sufficient walkers who reported having no grocery store in their neighborhood still had an average of 2.46 such uses within 1-km airline of their home. The figure dropped to a mean of 1.26 grocery stores in the 1-km network buffer, suggesting that network measures and/or shorter buffer distances need to be considered to define neighborhood. Counts of parks and schools were even higher than counts of groceries for those reporting an *absence* of such uses in their neighborhood (Figure 2). The apparent lack of awareness of the presence of theoretically important neighborhood land uses on the part of some respondents may confirm that perception is related to the need for or the practice of an activity (e.g., childless people may not notice the schools in their neighborhood; or people may ignore a grocery store that does not cater to their taste or budget). The findings suggest that carefully matching neighborhood services with population habits and needs may strengthen interventions to increase walking in neighborhoods. They also suggest that future research should continue to compare both objective and subjective data to define neighborhood.

Implications for General Theory of Neighborhood

Sociologic measures of neighborhood considered in the study included behavior (walking), domains (personal, physical environment), and outcome of interest (more walking). Even within these narrow parameters, the study confirmed that multiple neighborhoods exist, defined as those of sufficient walkers, non-walkers, and the general population. Had the study addressed the temporal and dynamic dimensions of walkable neighborhood, additional definitions would have emerged—e.g., weekend versus weekday, morning versus evening, summer versus winter neighborhoods.

The study addressed two levels of neighborhood: the individual and the physical environmental levels, the latter being contained within the first two scales identified by Galster—the block face and the defended neighborhood. Both perceptual and objective measures brought the geographic extent of a walkable neighborhood to 1 km of the residents' homes, an area smaller than commonly used in urban planning.

Implications for Research

The few objective measures found to define walkable neighborhoods may help simplify future research. However, the need for fine-grained measurement suggested by the threshold values suggests significant changes in research methods. Census-based spatial units seem too coarse to capture walkable neighborhoods, except perhaps in dense urban areas. At 1000 persons per census block group, the average side of a hypothetically square block group will vary between 1600 and

2100 feet (0.49 and 0.64 km), assuming medium gross residential densities between 16 and 10 people per acre. The same dimension for a 4000-person census tract will vary between 3300 and 4200 feet (1 to 1.3 km). These dimensions are considerably longer than the 860 and 1445 threshold distances for sufficient walkers to the closest restaurant and grocery store, respectively. Furthermore, census geography is based on streets and typically "cuts through" main street intersections where neighborhood retail is found. This means that neighborhood areas under study likely spread across four census units, thus doubling the dimensions noted above, and grossly oversizing the units of data and analyses.

The study indicated that both airline and network buffers were useful to understand and interpret perception of neighborhood. Also, subjective and objective measures seemed needed because respondents may perceive as present in their neighborhood only those land uses that they employed.

Limitations

As noted, causal links between the dependent variables (walking) and independent variables cannot be assumed from this cross-sectional study. Measures of walking are self-reported, although great care was provided in insuring the validity and reliability of survey questions. In addition, the study's generalizability is limited to areas with characteristics similar to those of the spatial sample frame—medium-density residential areas in proximity to neighborhood retail, but excluding rural and low-density suburban areas, and small towns.

This study focuses on general walking, combining walking for recreation and transport,[45] and considering adult populations of all ages. Environmental correlates of walking likely differ by walking purpose and by population.[37]

Conclusions

This study examined measures of walkable neighborhoods based on individual-level, self-reported, and objective data. Residential density, block size, presence of proximate grocery stores, restaurants, and retail facilities were strongly associated with walking sufficiently to meet recommendations for health. The presence of large office complexes and too many educational facilities in a neighborhood were negatively related to walking. The presence of parks was not associated with walking in the neighborhood. The dominant role of food environments in defining walkable neighborhood found in this study suggests that reappraisal of common theoretical constructs of neighborhood may be needed.

In general, objectively derived threshold measures of walkable neighborhood attributes were fairly close to the typical conditions found in the study area, indicating that the creation of supportive environments for walking could be achieved within current development practices in the urbanized areas of the country—though not in fringe or sprawling suburban areas. The greatest challenge is locating food and daily retail uses within very short distances of residences (1500 feet or less).

Perception measures also pointed to a small (less than 1 km) neighborhood geographic extent. While the general population perceived the presence of land uses in their neighborhood if there were more such uses and they were closer, only sufficient walkers seemed significantly more likely than non-walkers to perceive the presence of land uses in relation to their actual number and their distances. The study therefore indicated that only relatively high levels of walking corresponded to enhanced perceptions of neighborhood, with the implication that walking may help people "know" their neighborhood or that people who know their neighborhood walk more.

From a physical activity perspective, this study finds that routine activities carried out in small geographic areas could be associated with health-supportive levels of walking. Research and practice will need to readjust significantly downward the size of spatial units of analysis and intervention to capture neighborhood walkability. They also will need to include an individual-level definition of neighborhood to capture the multiplicity of neighborhood geographic boundaries.

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