Land Use, Residential Density, and Walking
The Multi-Ethnic Study of Atherosclerosis

Daniel A. Rodríguez, PhD, Kelly R. Evenson, PhD, Ana V. Diez Roux, MD, PhD, Shannon J. Brines, MS

Background: The neighborhood environment may play a role in encouraging sedentary patterns, especially for middle-aged and older adults.

Purpose: The aim of this study was to examine the associations between walking and neighborhood population density, retail availability, and land-use distribution using data from a cohort of adults aged 45 to 84 years.

Methods: Data from a multi-ethnic sample of 5529 adult residents of Baltimore MD, Chicago IL, Forsyth County NC, Los Angeles CA, New York NY, and St. Paul MN enrolled in the Multi-Ethnic Study of Atherosclerosis in 2000–2002 were linked to secondary land-use and population data. Participant reports of access to destinations and stores and objective measures of the percentage of land area in parcels devoted to retail land uses, the population divided by land area in parcels, and the mixture of uses for areas within 200 m of each participant's residence were examined. Multinomial logistic regression was used to investigate associations of self-reported and objective neighborhood characteristics with walking. All analyses were conducted in 2008 and 2009.

Results: After adjustment for individual-level characteristics and neighborhood connectivity, it was found that higher density, greater land area devoted to retail uses, and self-reported proximity of destinations and ease of walking to places were each related to walking. In models including all land-use measures, population density was positively associated with walking to places and with walking for exercise for more than 90 minutes/week, both relative to no walking. Availability of retail was associated with walking to places relative to not walking, and having a more proportional mix of land uses was associated with walking for exercise for more than 90 minutes/week, while self-reported ease of access to places was related to higher levels of exercise walking, both relative to not walking.

Conclusions: Residential density and the presence of retail uses are related to various walking behaviors. Efforts to increase walking may benefit from attention to the intensity and type of land development.
(Am J Prev Med 2009;37(5):397–404) © 2009 American Journal of Preventive Medicine

Introduction

By limiting opportunities for being physically active in everyday life, contemporary urban areas are believed to play a role in encouraging sedentary patterns and obesity. Relative to young adults, the role of the neighborhood environment as a barrier or support of active lifestyles may be more pronounced for middle-aged and older adults.[1] In addition to physical activity benefits, for older adults a supportive neighborhood environment may also encourage independent engagement in community life.[2] Despite the importance of the built environment, there is a paucity of studies examining its relationship to physical activity among older adults.[3–6]

Proximity to nonresidential land uses, specifically retail uses, has been linked to higher walking rates for utilitarian purposes in the general population.[7–12] For older adults, convenient access to nonresidential destinations has yielded inconsistent findings,[6] although recent studies using objective measures of the built environment have shown more consistent associations.[3,13] Only one study[3] has examined access to retail land uses for older women, and the analysis was limited to department, discount, and hardware stores. Positive associations were found between accessibility to retail and higher physical activity.

Beyond the presence of specific land uses, others have argued that the proportion of land devoted to different uses within a given distance from a home

From the Department of City and Regional Planning (Rodriguez), and Department of Epidemiology (Evenson), Gillings School of Global Public Health, University of North Carolina, Chapel Hill, North Carolina; Department of Epidemiology (Diex Roux), and School of Natural Resources and Environment (Brines), University of Michigan, Ann Arbor, Michigan

Address correspondence and reprint requests to: Daniel A. Rodríguez, PhD, Department of City and Regional Planning, CB 3140 New East, 319, Chapel Hill NC 27599-3140. E-mail: danrod@unc.edu.

doi:10.1016/j.amepre.2009.07.008

location may also affect levels of physical activity.[7,8,14] Areas with more proportional mixing of uses may be supportive of walking because of the availability and variety of destinations. Further, this diversity may be more important for populations with limited access to automobiles, such as children and older adults.[15] Thus, not only proximity to specific uses such as retail but also the relative intensity among uses within one's neighborhood may help explain physical activity levels. For example, a neighborhood with 95% of its parcel area devoted to residential uses and 5% to retail has a different, less proportionate distribution of area among uses than a neighborhood with 30% of its parcel area devoted to residential uses, 30% to retail, and 40% to institutional uses. Identifying associations of physical activity with specific uses of land, such as retail, and the intensity at which land is developed provides planners with guidance to improve communities and future decision making.

Relying on data from a large, multi-ethnic cohort of adults aged 45 to 84 years, associations between self-reported walking and neighborhood population density, retail access, and land-use distribution, while controlling for other environmental and individual characteristics, are examined. It is hypothesized that greater population density and improved access to retail land uses are related to higher levels of walking for various purposes. Responding to calls for including objectively measured and perceptual environmental data simultaneously,[16–18] the study combines self-reported and objectively measured land-use information. These analyses contribute to the understanding of the role that the mixing of particular land uses can play in supporting physical activity in middle-aged and older adults. Identifying the specific ways in which the mixing of land uses may affect physical activity has important implications for planning and public health policy.

Methods

Study Sample

The Multi-Ethnic Study of Atherosclerosis (MESA) is a longitudinal study of cardiovascular disease among adults aged 45–84 years at six field sites in the U.S.: Baltimore MD, Chicago IL, Forsyth County NC, Los Angeles CA, New York NY, and St. Paul MN.[19] There was no clinically overt cardiovascular disease at cohort incept. The baseline visit for MESA, on which these analyses are based, took place between July 2000 and September 2002. The study was approved by the IRBs at each site and all participants gave written informed consent.

Walking Outcomes

A detailed interviewer-administered, semiquantitative questionnaire adapted from the Cross-Cultural Activity Participation Study[20,21] was used to collect data on all forms of physical activity, including leisure, household, work, and transportation activities at the baseline examination. The questionnaire was developed using extensive qualitative research[22] and has been shown to have acceptable test–retest reliability and validity among a sample of women.[23] For each type of activity queried, participants were asked (1) whether they did the activity during a typical week in the past month and (2) how many days per week and how many hours and minutes per day they did the activity.

For this study, the focus was on the types of physical activities related to walking, which are most likely to be associated with two key land characteristics: the type of land use and the intensity of residential development. The two walking behaviors examined were minutes per week in walking for transport (e.g., walking to get places such as to the bus, car, work, or store), defined as walking to places; and minutes per week walking for leisure (e.g., walking for exercise, pleasure, social reasons, during work breaks, walking the dog), defined as walking for exercise. Given unavoidable measurement error in reports of exact times of walking, the data were categorized rather than investigated as a continuous measure. Categories usually have better reliability than continuous measures and allow a parsimonious way to manage data skewness. As a result, outcome variables were created by classifying each type of walking into three levels: no walking, walking time that is less than the median of nonzero data, and walking time greater than or equal to the median for nonzero data.

Neighborhood Built Environment Characteristics

Neighborhood information was collected in part by the MESA Neighborhood Study, an ancillary study to MESA, which included the geocoding of each participant's home address. All objective measures were derived using ArcGIS 9.2. Neighborhoods were person specific, defined as the area covered by a circle of 200-m radius drawn around each person's home location.

Land-use data were collected from municipal and regional governments in the six study sites. The data were dated between 2001 and 2005 depending on the site. An investigator classified the land-use codes of each site into four mutually exclusive categories: retail (including commercial), residential, institutional, and office. For each parcel, whenever a retail use was present (regardless of other uses present in the building occupying the parcel), the parcel was coded as retail use. If the parcel had institutional uses (but no retail), it was coded as institutional use. If the parcel had industrial use (but no retail or institutional), the parcel was coded as industrial use. Land uses in Baltimore County were categorized into only commercial and residential uses, as their data lacked the institutional and office designations. A second investigator verified the classification and resolved disagreements. Appendixes A–F, available online at www.ajpm-online.net, detail the classification of land uses for each site.

Availability of retail in each neighborhood was calculated using the percentage of land area in parcels that contain retail uses. By focusing on the area in parcels, transportation features such as roads and railroads, water bodies, and utilities are excluded from the calculations. One drawback of using parcel area is that it penalizes vertical development, for example by treating a parcel with a four-story building in the same way as a parcel with a one-story building. Entropy was calculated using an established formula[24] to assess the similarity in the proportion of the area in parcels devoted to retail, residential, institutional, and office land uses.[7,9,14,24–26] Entropy values range between 0 and 1, with 1 representing equal proportion (25%) among the four uses in the neighborhood and 0 representing the presence of a single dominant land use.

Population density (hundreds of people/hectare) was measured using population data from the U.S. Census at the block level and dividing them by the land area in parcels. When a block was not fully contained within a neighborhood, its population was assigned in direct proportion to the area of the block contained within the neighborhood, which assumes a uniform population density within each block. Road connectivity was measured as the proportion of the neighborhood (the 200-m–radius circle area around each person's home) that is covered by a network buffer. The ratio varies between 0 and 1, with 0 meaning that none of the circle area can be reached through the road network and 1 meaning that the entire circle can be reached through the street network, denoting highest connectivity.

Subjective measures of the neighborhood physical environment were obtained from a questionnaire administered to MESA participants that included items on ease of walking to places and having stores within walking distance. Responses were reported on a 1 to 5 scale in which 1=*strongly agree* and 5=*strongly disagree* and are treated as continuous. These questions were part of an 11-item index shown to have high test–retest reliability (intraclass correlation coefficient [ICC]= 0.88, 95% CI=0.79, 0.93).[27] The questionnaire also included two questions on the availability of YMCAs/YWCAs and on the availability of free community centers and schools open to the public, both reported as a binary variable (yes or no). The two variables were merged into a single variable defined as the availability of institutional uses for physical activity and coded as a binary variable (yes if either is present, or no if neither is present). These two questions were part of an eight-item index with high test–retest reliability (ICC= 0.85, 95% CI=0.75, 0.92).[27] Item reliabilities were not reported. In responding to these neighborhoods' environment items, participants were asked to refer to the area that was approximately a 20-minute or 1-mile walk from their home.

Sociodemographic Measures

Person-level data on age, gender, race/ethnicity, family income, and education were self-reported during the baseline MESA examination. Age was classified into four categories (45–54, 55–64, 65–74, and 75–84 years). Race and ethnicity were classified as Hispanic, non-Hispanic white, non-Hispanic black, and Chinese. Family income was grouped into four categories (<$20,000, $20,000–$39,999, $40,000–$74,999, and ≥$75,000). Education was categorized as less than high school, high school/GED diploma, college, or graduate/professional school.

Statistical Analysis

Of the 6061 MESA participants at baseline that lived within geographic areas for which land-use data were available, 237 were excluded because their address information could not be connected to the road data set, likely the result of geocoding error, road data error, or the fact that participants lived on very small roads not represented given the scale of the road data. An additional 284 were excluded because they were missing physical activity information, and 11 participants were excluded because of missing self-reported neighborhood environment data, leaving 5529 participants for analysis.

Multinomial logistic models were used to analyze the three-level categoric outcomes for each of the two outcome variables (walking to places and walking for exercise) using Stata 9.2. In all cases, no walking was used as the reference category. Robust SEs with clustering were used to account for potential correlations among participants within sites.

None of the neighborhood objective and self-reported variables had particularly high colinearity (variance inflation factor <4), suggesting that they measure different constructs or they measure similar constructs differently. Therefore, the neighborhood environment variables (objective and self-reported) were first entered one at a time into models that adjusted for individual characteristics (age, gender, education, race/ethnicity, and family income). Models also adjusted for neighborhood road connectivity, because it may be associated with both land use and walking and could therefore confound the association of land use with walking. Next, all environment variables were entered simultaneously into a single model, adjusting for the same factors. Finally, Stata's lincom command was used to provide a graphic representation of the relationships of interest. All analyses were conducted in 2008 and 2009.

Results

Descriptive statistics for sociodemographic characteristics and walking activity of participants are shown in Table 1. Age of study participants ranged between 45 and 84 years. Just over half of the sample (51.7%) were women; 40.1% of participants were non-Hispanic Caucasian, 25.9% non-Hispanic blacks, 22.1% Hispanics, and 11.9% Chinese. The median time of walking to places was 150 minutes/week, and the median time for exercise walking was 90 minutes/week.

Table 2 shows descriptive statistics for the measures of objective and self-reported land use and residential development intensity. Neighborhoods had an average population density of 153.2 people per hectare. Forty-one percent of respondents had no retail land uses in their neighborhood, and only one quarter of the sample had ≥10.6% of the parcel area in the neighborhood devoted to retail uses. The entropy measure revealed substantial variability in the land-use mixes around the homes of participants. The percentage of participants agreeing or strongly agreeing with the statements *In my neighborhood it is easy to walk to places* and *There are stores within walking distance of my home* were 79.8% and 76.3%, respectively. On average, 62.1% of participants reported having schools or community centers with recreational facilities available for free to the public or YMCA/YWCAs available within a 20-minute walk from their home.

Table 1. Selected individual-level characteristics of participants included in the analyses, MESA, 2000–2002 (n=5529)

	n	%[a]	VIF[b]
Age (years)			
45–54	1654	29.9	NA
55–64	1588	28.7	2.6
65–74	1588	28.7	2.5
75–84	699	12.6	2.4
Gender			
Female	2856	51.7	1.0
Race/ethnicity			
Non-Hispanic Caucasian	2217	40.1	NA
Chinese	659	11.9	2.3
Non-Hispanic black	1432	25.9	1.6
Hispanic	1221	22.1	1.9
Education completed			
Less than high school	881	15.9	NA
High school graduate/GED	999	18.1	1.9
College	2595	46.9	2.8
Graduate/professional school	1054	19.1	2.6
Family income (thousands $)			
<20	1207	21.8	NA
20 to <40	1474	26.7	1.8
40 to <75	1520	27.5	2.1
≥75	1328	24.0	2.5
OUTCOMES			
Walking to places (min/wk)			
0	779	14.1	
<150	2253	40.8	
≥150	2497	45.2	
Walking for exercise (min/wk)			
0	1918	34.7	
<90	1800	32.6	
≥90	1811	32.8	

[a]Percentages do not add to 100 because of rounding.
[b]A measure of colinearity among variables.
MESA, Multi-Ethnic Study of Atherosclerosis; NA, not applicable; VIF, variance inflation factor

Walking to Places

Adjusted associations of the objective and self-reported land-use/intensity variables with walking to places are shown in Table 3. When models were estimated for each exposure separately, higher levels of population density and the highest quartile of the percentage of parcel area devoted to retail were each associated with higher levels of walking to places after adjustment for age, gender, race/ethnicity, education, income, and street connectivity. Being in the top quartile (≥10.6% of parcel area in retail) relative to the baseline category of having no retail was associated with 1.81 higher odds of some walking (>0 but <150 minutes/week) and 2.57 higher odds of walking to places ≥150 minute/week. None of the entropy measures was associated with walking to places.

For self-reported measures, people reporting that it was easier to walk to places had higher odds of walking to places, and those reporting more stores within walking distance had higher odds of walking to places ≥150 minute/week, after adjustment. Other land-use characteristics (availability of institutional uses) were not related to walking to places. When all the exposures were included in a single model, density remained positively associated with walking to places for both walking levels relative to no walking, and the third and top quartiles of retail area were positively associated with more walking. Those with more stores within walking distance had higher odds of walking to places ≥150 minute/week, after adjustment. Entropy was not associated with walking.

Walking for Exercise

Table 4 shows adjusted associations for the exercise walking outcome. When models were estimated for each exposure separately, density and all self-reported measures were related to exercise walking for >90 minutes/week, and ease of walking to places was the only variable related to some walking (>0 and <90 minutes/week), relative to no walking. For the measures of land-use mixtures, the third and top quartiles of retail area and the top quartile of entropy were positively associated with walking >90 minutes/week. When all the exposures were included in a single model, density, the top quartile of entropy, and ease of walking to places remained positively related to exercise walking for >90 minutes/week. Ease of walking to places remained significantly associated with some walking (>0 and <90 minutes/week).

Figure 1 portrays how density and retail uses were jointly related to the probability of walking to places based on the parameters estimated, while holding constant all continuous variables at their means and all categoric variables at their modes. The values of density vary from the 5th to the 95th percentile in the data. The values for retail represent the indicator variables in quartiles used in the models. The probability of walking to places for <150 minutes/week relative to no walking increased from 75.7% to 98.2% when density and retail increased jointly from the 5th to the 95th percentile. For similar changes in density and retail, the probability of walking for exercise for >150 minutes/week relative to no walking increased from 66.4% to 95.2%.

Discussion

In a diverse population sample of middle-aged and older adults, objective and self-reported measures of land use and residential density were consistently associated with higher odds of walking. In adjusted models examining each measure separately, higher population density and a higher percentage of parcel area devoted to retail land uses were each associated with higher odds of walking to places and walking for exercise. Weaker evidence was found for self-reported measures

Table 2. Objective and self-reported land-use/intensity characteristics around the home of participants included in analyses, MESA, 2000–2002 (n=5529)

	n	%	Median	M	SD	Min	Max
OBJECTIVE/DERIVED MEASURES (200-m buffer unless noted)							
Density (hundreds of people/hectare)	5529	—	0.41	1.53	2.55	0.00	15.20
% parcel area devoted to retail use							
First quartile (=0)	2269	41.04					
Second quartile (>0 and <1.43)	494	8.93					
Third quartile (≥1.43 and <10.61)	1384	25.04					
Fourth quartile (≥10.61)	1382	25.00					
Entropy[a]							
First quartile (<0.022)	1383	25.01					
Second quartile (≥0.022 and <0.26)	1382	25.00					
Third quartile (≥0.26 and <0.54)	1382	25.00					
Fourth quartile (≥0.54)	1382	25.00					
Proportion of 400-m buffer from home accessible via roads (0–1)	5529	—	0.51	0.47	0.15	0.00	0.73
SELF-REPORTED MEASURES							
Easy to walk to places[b]							
1=*Strongly disagree*	119	2.15					
2=*Disagree*	683	12.35					
3=*Neutral (neither agree nor disagree)*	317	5.73					
4=*Agree*	3342	60.44					
5=*Strongly agree*	1068	19.32					
Stores within walking distance (20 min)[b]							
1=*Strongly disagree*	274	4.96					
2=*Disagree*	902	16.31					
3=*Neutral (neither agree nor disagree)*	132	2.39					
4=*Agree*	3186	57.62					
5=*Strongly agree*	1035	18.72					
Availability of institutional uses (schools, YMCA/YWCAs) within walking distance (20 min)							
0=*No*	2093	37.85					
1=*Yes*	3436	62.15					

[a]Entropy was calculated among residential, institutional, retail, and office uses using the formula presented by Cervero and Kockelman.[24] For parcels with mixed uses, if they contained any retail uses they were considered retail use. Those having any office uses (but no retail) were considered office uses. Any institutional uses (but no retail or office uses) were considered institutional uses. Higher values represent a more even proportion of area devoted to each land use.
[b]Measured with a Likert-type scale ranging between 1 and 5, with 1=*strongly agree* and 5=*strongly disagree*. Scale shown in table and used in analyses is reversed so that higher values mean more support for walking, consistent with the objective measures.
MESA, Multi-Ethnic Study of Atherosclerosis

of ease of walking, presence of stores, and availability of institutional uses.

In models that included both objective and self-reported measures, higher population density and higher percentage of parcel area devoted to retail uses remained significantly associated with higher odds of walking to places. The estimates for the percentage of parcel area in retail uses suggest a dose–response relationship between exposure to retail uses and walking to places. In addition, higher density, being in the top quartile denoting the most proportional distribution of land among various uses, and self-reported ease of walking to places remained associated with walking for exercise after adjustment for other objective and self-reported land-use measures.

By focusing on land use and residential density in six diverse urbanized areas in the U.S., this study extends prior evidence[9,14,28,29] regarding the importance of land use and residential density for walking in middle- to older-age adults. Although measures of neighborhood perceptions were limited, the results suggest that objective features of neighborhoods may influence residents' behaviors independently of their perceptions. Interestingly, perceived presence of stores within walking distance remained significant for the highest level of walking to places even when objective measures were controlled.

Density was the measure most consistently related to walking. Few studies have included as much variation in density as the present study, and fewer have focused on middle-aged and older adults. The strength of density in predicting walking activity has been previously noted,[9,28,30–32] but studies of older adults remain rare. The results suggest that the importance of density for physical activity promotion goes beyond the connectivity and access to destinations that density brings.

Figure 1, showing the joint contribution of density and retail to explaining the probability of walking to

Table 3. Adjusted OR (95% CI) of walking to places (in three levels) associated with neighborhood land-use and density variables, MESA, 2000–2002 (n=5529)

	Models for each exposure separately[a,b]		Full model with all exposures included[a,b]	
	Level 2 vs Level 1 OR (95% CI)	Level 3 vs Level 1 OR (95% CI)	Level 2 vs Level 1 OR (95% CI)	Level 3 vs Level 1 OR (95% CI)
OBJECTIVE/DERIVED MEASURES				
Density (hundreds of people/hectare)	**1.31 (1.14, 1.51)**	**1.41 (1.21, 1.65)**	**1.28 (1.12, 1.46)**	**1.34 (1.16, 1.55)**
% parcel area devoted to retail use				
First quartile	ref	ref	ref	ref
Second quartile	1.15 (0.81, 1.64)	1.09 (0.67, 1.78)	1.05 (0.80, 1.37)	0.93 (0.69, 1.25)
Third quartile	1.44 (0.94, 2.20)	1.68 (0.92, 3.06)	**1.19 (1.02, 1.38)**	**1.22 (1.02, 1.46)**
Fourth quartile	**1.81 (1.12, 2.93)**	**2.57 (1.28, 5.15)**	**1.44 (1.19, 1.76)**	**1.73 (1.26, 2.38)**
Entropy				
First quartile	ref	ref	ref	ref
Second quartile	0.84 (0.42, 1.66)	0.62 (0.30, 1.27)	1.27 (0.86, 1.87)	1.13 (0.78, 1.62)
Third quartile	0.76 (0.40, 1.43)	0.53 (0.25, 1.12)	1.05 (0.80, 1.37)	0.82 (0.60, 1.13)
Fourth quartile	1.26 (0.71, 2.24)	1.36 (0.63, 2.96)	0.96 (0.67, 1.37)	0.90 (0.58, 1.39)
SELF-REPORTED/PERCEIVED MEASURES				
Easy to walk to places	**1.13 (1.03, 1.24)**	**1.26 (1.06, 1.50)**	1.05 (0.97, 1.13)	1.07 (0.97, 1.19)
Stores within walking distance	1.13 (0.98, 1.30)	**1.29 (1.07, 1.55)**	1.03 (0.93, 1.14)	**1.09 (1.01, 1.18)**
Availability of institutional uses	1.06 (0.83, 1.35)	1.18 (0.87, 1.60)	1.01 (0.80, 1.28)	1.08 (0.82, 1.42)

[a]Walking to places measure categorized into level 1 (none); level 2 (>0 and <150 min/wk); and level 3 (≥150 min/wk)
[b]Adjustment factors are age, gender, education, race/ethnicity, family income, and proportion of 400-m buffer from home accessible via roads. Robust SEs with clustering on each site are shown. All objective measures are calculated for a 200-m radius around each participant's home. Bolded coefficients are significant at a 95% level of confidence.
MESA, Multi-Ethnic Study of Atherosclerosis

places, has two salient characteristics: nonlinearity and high uncertainty. First, the figure graphically depicts that the benefits of walking, owing to increased density and the inclusion of retail land uses, can materialize even when density and retail use are already at considerable levels, as they move toward the higher percentiles of their respective distributions. Second, the CIs suggest that even though the probability of walking to

Table 4. Adjusted OR (95% CI) of walking for exercise (in three levels) associated with neighborhood land-use and density variables, MESA, 2000–2002 (n=5529)

	Models for each exposure separately[a,b]		Single model with all exposures included[a,b]	
	Level 2 vs Level 1 OR (95% CI)	Level 3 vs Level 1 OR (95% CI)	Level 2 vs Level 1 OR (95% CI)	Level 3 vs Level 1 OR (95% CI)
OBJECTIVE/DERIVED MEASURES				
Density (hundreds of people/hectare)	1.00 (0.98, 1.01)	**1.09 (1.08, 1.11)**	1.00 (0.97, 1.02)	**1.06 (1.04, 1.09)**
% parcel area devoted to retail use				
First quartile	ref	ref	ref	ref
Second quartile	0.96 (0.83, 1.12)	1.16 (0.90, 1.50)	0.95 (0.81, 1.11)	1.05 (0.83, 1.33)
Third quartile	1.05 (0.90, 1.22)	**1.34 (1.07, 1.69)**	1.04 (0.88, 1.24)	1.08 (0.90, 1.30)
Fourth quartile	0.98 (0.87, 1.10)	**1.49 (1.06, 2.10)**	0.97 (0.83, 1.12)	1.07 (0.86, 1.33)
Entropy				
First quartile	ref	ref	ref	ref
Second quartile	1.10 (0.89, 1.37)	0.79 (0.62, 1.01)	1.15 (0.96, 1.38)	1.00 (0.90, 1.11)
Third quartile	1.03 (0.74, 1.43)	0.82 (0.62, 1.07)	1.06 (0.76, 1.47)	0.98 (0.82, 1.16)
Fourth quartile	1.05 (0.87, 1.27)	**1.29 (1.08, 1.54)**	1.06 (0.82, 1.37)	**1.19 (1.05, 1.34)**
SELF-REPORTED/PERCEIVED MEASURES				
Easy to walk to places	**1.12 (1.07, 1.18)**	**1.30 (1.20, 1.41)**	**1.14 (1.08, 1.20)**	**1.23 (1.14, 1.32)**
Stores within walking distance	1.04 (0.95, 1.13)	**1.18 (1.07, 1.29)**	0.99 (0.90, 1.09)	1.02 (0.96, 1.08)
Availability of institutional uses	1.08 (0.98, 1.18)	**1.18 (1.05, 1.32)**	1.06 (0.97, 1.15)	1.08 (0.95, 1.23)

[a]Walking for exercise or leisure measure categorized into level 1 (none); level 2 (>0 and <90 min/wk); and level 3 (≥90 min/wk)
[b]Adjustment factors are age, gender, education, race/ethnicity, family income, and proportion of 400-m buffer from home accessible via roads. Robust SEs with clustering on each site are shown. All objective measures are calculated for a 200-m radius around each participant's home. Bolded coefficients are significant at a 95% level of confidence.
MESA, Multi-Ethnic Study of Atherosclerosis

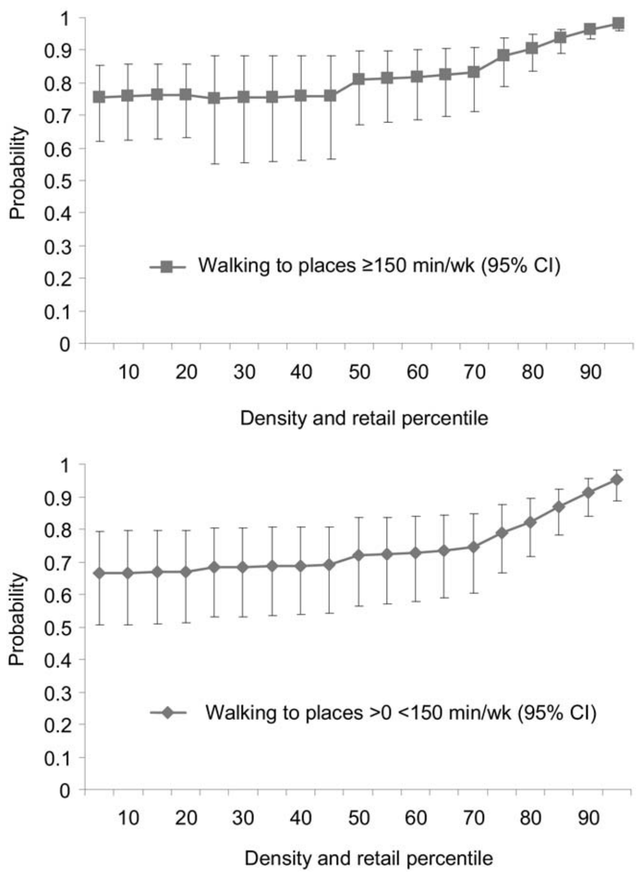

Figure 1. Adjusted predicted probability and 95% CI of walking to places relative to no walking by percentile of neighborhood density and percentage land area devoted to retail uses, Multi-Ethnic Study of Atherosclerosis (MESA), 2000–2002 (n=5529)
Note: Walking to places measure categorized into Level 1 (none); Level 2 (>0 and <150 min/wk); and Level 3 (≥150 min/wk). Level 1 is the reference category. Adjustment factors are age, gender, education, race/ethnicity, family income, and proportion of 400-m buffer from home accessible via roads. Robust SEs with clustering on each site are shown.

places increases when density and retail increase jointly from their 10th percentile to their 80th percentile, the uncertainty around the estimates is such that the predicted change in walking to places is no different from zero at a 95% level of confidence.

Results for the entropy variable were not entirely consistent. The highest quartile of entropy was associated with walking for exercise in models adjusted for individual-level characteristics. However, entropy was not associated with walking to places. This contrasts with other studies[9,29] and may be the result of measurement differences. Although mean entropy in this study is almost identical to values in other studies,[9,24] the figures cannot be compared directly. Further, the theoretic reasons to expect similarity in the proportion of land devoted to different uses to be related to walking are unclear. An instance in which a residential household is surrounded by walkable nonresidential destinations yields a disproportionate distribution of land uses in an environment supportive of walking to places. The evidence provided here, in addition to theoretic limitations, and the difficulty in correctly interpreting and communicating its meaning, suggests that caution should be used in applying entropy as a neighborhood environmental measure in future studies.

Compared to other studies, the neighborhood-area definition of a 200-m circle is small. Measures drawn from circles of 400-m and 800-m radii were tested by examining model fit using the Bayesian information criterion (BIC). It has been suggested[33] that evidence favoring one model over another is weak, positive, strong, or very strong if the absolute difference in BIC for two models is 0–2, 2–6, 6–10, or >10, respectively. With the exception of the single model with all exposures explaining exercise walking that exhibited weak evidence favoring the 400-m buffer, all models with exposures measured for the 200-m circle were strongly or very strongly favored over larger circles. In contrast, another study[13] found no pattern in model fit at various buffer sizes.

One explanation for the results favoring the smallest circle is that for an older population, proximal land uses may be more relevant than uses that are more distant. Another explanation is that the retail and entropy measures are neighborhood-scale dependent, a phenomenon known as the modifiable areal unit problem.[34] As the neighborhood area definition increases, neighborhood heterogeneity increases, thereby decreasing variation in the entropy and retail measures.

Limitations of this study include the use of self-reported walking, the reliance on land-use information collected from diverse sources, and potential residual confounding. Bias caused by the cross-sectional design is also a possibility, because people who enjoy walking are more likely to move to areas that support walking. Mis-specification of the relevant geographic area could also have affected the results.

Conclusion

Taken together, the results of this study provide support for the relationship of retail, land-use mix, and residential density with walking behaviors. The findings support calls for policies that guide new development and changes in already-developed areas to intensify density and mixed land uses. Further, these policies may be more effective in areas with established levels of development density and retail land uses, rather than in areas with very low density and residential-only land uses. Prospective studies and evaluation of natural experiments can further inform this discussion. The relationships of neighborhood characteristics with walking underscore calls for collaborative efforts among traffic engineers, city planners, and health professionals to understand how urban areas can be improved to address the welfare of residents.

This study was funded by a grant from the Robert Wood Johnson Foundation Active Living Research Program. Partial funding was also provided by R01 HL071759 from NIH NHLBI (National Heart, Lung, and Blood Institute). The MESA Study was supported by contracts N01-HC-95159 through N01-HC-95165 and N01-HC-95169 from the NIH NHLBI. The content is solely the responsibility of the authors and does not necessarily represent the official views of the NIH. The authors thank the other investigators, staff, and participants of the MESA Study for their valuable contributions. A full list of participating MESA investigators and institutions can be found at www.mesa-nhlbi.org. Lastly, we appreciate the spatial assistance of Melissa Smiley and data management from Fang Wen.

No financial disclosures were reported by the authors of this paper.

References

1. Chodzko-Zajko W, Sheppard L, Senior J, Park CH, Mockenhaupt R, Bazzarre T. The national blueprint for promoting physical activity in the mid-life and older adult population. Quest 2005;57(1):2–11.
2. Kochera A, Straight A. Beyond 50.05. Washington DC: American Association of Retired Persons, 2005.
3. King WC, Belle SH, Brach JS, Simkin-Silverman LR, Soska T, Kriska AM. Objective measures of neighborhood environment and physical activity in older women. Am J Prev Med 2005;28(5):461–9.
4. King A, Castro C, Wilcox S, Eyler A, Sallis J, Brownson R. Personal and environmental factors associated with physical inactivity among different racial/ethnic groups of US middle- and older-aged women. Health Psychol 2000;19(4):354–64.
5. Wilcox S, Castro C, King AC, Houseman RA, Brownson R. Determinants of leisure time physical activity in rural compared with urban older and ethnically diverse women in the United States. J Epidemiol Commun Health 2000;54:667–72.
6. Cunningham GO, Michael YL. Concepts guiding the study of the impact of the built environment on physical activity for older adults: a review of the literature. Am J Health Promot 2004;18(6):435–43.
7. Cerin E, Leslie E, du Toit L, Owen N, Frank LD. Destinations that matter: associations with walking for transport. Health Place 2007;13(3):713–24.
8. Frank LD, Sallis JF, Conway TL, Chapman JE, Saelens BE, Bachman W. Many pathways from land use to health—associations between neighborhood walkability and active transportation, body mass index, and air quality. J Am Plann Assoc 2006;72(1):75–87.
9. Frank LD, Schmid TL, Sallis JF, Chapman J, Saelens BE. Linking objectively measured physical activity with objectively measured urban form: findings from SMARTRAQ. Am J Prev Med 2005;28(2 S2):117–25.
10. Giles-Corti B, Broomhall MH, Knuiman M, et al. Increasing walking—how important is distance to, attractiveness, and size of public open space? Am J Prev Med 2005;28(2):169–76.
11. McCormack GR, Giles-Corti B, Bulsara M. The relationship between destination proximity, destination mix and physical activity behaviors. Prev Med 2008;46(1):33–40.
12. Saelens B, Handy S. Built environment correlates of walking: a review. Med Sci Sports Exerc 2008;40:S550–66.
13. Berke EM, Koepsell TD, Moudon AV, Hoskins RE, Larson EB. Association of the built environment with physical activity and obesity in older persons. Am J Public Health 2007;97(3):486–92.
14. Frank LD, Andresen MA, Schmid TL. Obesity relationships with community design, physical activity, and time spent in cars. Am J Prev Med 2004;27(2):87–96.
15. Li F, Harmer PA, Cardinal BJ, et al. Built environment, adiposity, and physical activity in adults aged 50–75. Am J Prev Med 2008;35(1):38–46.
16. Duncan MJ, Spence JC, Mummery WK. Perceived environment and physical activity: a meta-analysis of selected environmental characteristics. Int J Behav Nutr Phys Act 2005;2:9.
17. McCormack G, Giles-Corti B, Lange A, Smith T, Martin K, Pikora T. An update of recent evidence of the relationship between objective and self-report measures of the physical environment and physical activity behaviours. J Sci Med Sport 2004;7(1S):81–92.
18. McGinn AP, Evenson KR, Herring AH, Huston SL, Rodriguez DA. Exploring associations between physical activity and perceived and objective measures of the built environment. J Urban Health 2007;84(2):162–84.
19. Bild DE, Bluemke DA, Burke GL, et al. Multi-ethnic study of atherosclerosis: objectives and design. Am J Epidemiol 2002;156(9):871–81.
20. Ainsworth BE, Irwin ML, Addy CL, Whitt MC, Stolarczyk LM. Moderate physical activity patterns of minority women: the Cross-Cultural Activity Participation Study. J Womens Health Gend Based Med 1999;8(6):805–13.
21. LaMonte MJ, Durstine JL, Addy CL, Irwin ML, Ainsworth BE. Physical activity, physical fitness, and Framingham 10-year risk score: the cross-cultural activity participation study. J Cardiopulm Rehabil 2001;21(2): 63–70.
22. Henderson KA, Ainsworth BE. A synthesis of perceptions about physical activity among older African American and American Indian women. Am J Public Health 2003;93(2):313–7.
23. Ainsworth BE, LaMonte M, Drowatzky K. Evaluation of the CAPS typical week physical activity survey (TWPAS) among minority women. In: Community Prevention Research in Women's Health Conference. Bethesda MD: NIH, 2000.
24. Cervero R, Kockelman K. Travel demand and the 3Ds: density, diversity and design. Transport Res Pt D 1997;2(3):199–219.
25. Cervero R. America's suburban centers: the land use-transportation link. Boston MA: Unwin Hyman, 1989.
26. Frank LD, Pivo G. Relationships between land use and travel behavior in the Puget Sound region. Seattle WA: Washington State Transportation Center, 1994.
27. Echeverria SE, Diez-Roux AV, Link BG. Reliability of self-reported neighborhood characteristics. J Urban Health 2004;81(4):682–701.
28. Moudon AV, Lee C, Cheadle AD, et al. Attributes of environments supporting walking. Am J Health Promot 2007;21(5):448–59.
29. Rundle A, Roux AV, Free LM, Miller D, Neckerman KM, Weiss CC. The urban built environment and obesity in New York City: a multilevel analysis. Am J Health Promot 2007;21(4S):326–34.
30. de Vries SI, Bakker I, van Mechelen W, Hopman-Rock M. Determinants of activity-friendly neighborhoods for children: results from the SPACE study. Am J Health Promot 2007;21(4):312–6.
31. Lee C, Moudon AV. The 3Ds + R: quantifying land use and urban form correlates of walking. Transport Res Pt D 2006;11(3):204–15.
32. Rodriguez DA, Brown AR, Torped PJ. Portable global positioning units to complement accelerometry-based physical activity monitors. Med Sci Sports Exerc 2005;37(11):S572–81.
33. Raftery AE. Bayesian model selection in social research. In: Marsden PV, ed. Sociological methodology. Oxford UK: Blackwell Publishers, 1995:xxvii.
34. Cressie N. Change of support and the modifiable areal unit problem. Geogr Syst 1996;3:159–80.

Appendix

Supplementary Data

Supplementary data associated with this article can be found, in the online version, at 10.1016/j.amepre.2009.07.008.