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Original Contribution

Neighborhood Environments and Incident Hypertension in the Multi-Ethnic Study of Atherosclerosis

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We examined relationships between neighborhood physical and social environments and incidence of hypertension in a cohort of 3,382 adults at 6 sites in the United States over 10 years of follow-up (2000–2011), using data from the Multi-Ethnic Study of Atherosclerosis. The sample was aged 45–84 years (mean = 59 years) and free of clinical cardiovascular disease and hypertension at baseline. Of the participants, 51% were female, 44% white, 23% Hispanic, 21% black, and 13% Chinese-American; 39% of participants developed hypertension during an average of 7.2 years of follow-up. Cox models were used to estimate associations of time-varying cumulative average neighborhood features (survey-based healthy food availability, walking environment, social cohesion, safety, and geographic information system–based density of favorable food stores and recreational resources) with incident hypertension. After adjustment for individual and neighborhood-level covariates, a 1-standard-deviation increase in healthy food availability was associated with a 12% lower rate of hypertension (hazard ratio = 0.88, 95% confidence interval: 0.82, 0.95). Other neighborhood features were not related to incidence of hypertension. The neighborhood food environment is related to the risk of hypertension.

hypertension; longitudinal studies; neighborhoods

Abbreviations: BMI, body mass index; CI, confidence interval; GIS, geographic information system; HR, hazard ratio; MESA, Multi-Ethnic Study of Atherosclerosis; SES, socioeconomic status.

Characteristics of residential environments have been associated with a variety of health outcomes, including cardiovascular disease incidence and mortality (1). However, existing research on the ways neighborhood environments affect blood pressure has been limited largely to cross-sectional analyses and use of generic measures of the neighborhood environment that shed little light on the specific processes involved (2, 3).

Studies using indicators of neighborhood socioeconomic status (SES) to characterize the neighborhood environment have generally, though not always (4, 5), found area-level affluence to be associated with lower prevalence (6–9) and incidence (10, 11) of hypertension. Studies investigating specific neighborhood environments typically use either survey data to aggregate resident perceptions of their environment or geographic information systems (GIS) data to summarize the presence of resources. Cross-sectional results using survey-based measures of neighborhood physical environments have been mixed, with some investigators reporting no association with prevalence of hypertension (12) and others finding a protective association (13). GIS-based local densities of grocery stores and fast-food restaurants were not associated with systolic blood pressure levels in the Women's Health Initiative Clinical Trials (14). In a small prospective study, Li et al. (15) found that high walkability was associated with beneficial changes in blood pressure. Neighborhood food and physical activity environments have also been associated with major risk factors for hypertension, including obesity, diet, and physical activity in cross-sectional (16–18) and longitudinal (19–22) analyses, although findings have not always been consistent (23, 24).

Less research has explored the ways neighborhood social environments affect blood pressure. Mujahid et al. (25) reported that chronic neighborhood-level stressors explain some or all of the disparity in hypertension prevalence between blacks and whites. In cross-sectional analyses of the Multi-Ethnic Study of Atherosclerosis (MESA), survey-based measures of greater neighborhood safety and greater social cohesion, as well as greater neighborhood availability of healthy foods and more favorable walking environments, were each associated with lower prevalence of hypertension, although associations were not robust to adjustment for race/ethnicity (13).

Investigating how specific measures of neighborhood physical and social environments are related to hypertension may improve our understanding of the mechanisms through which neighborhood environments influence health. We used longitudinal data from MESA to examine how survey- and GIS-based measures of specific neighborhood physical and social environments were related to incidence of hypertension in a diverse cohort with over 10 years of follow-up.

METHODS

Study population

MESA is a prospective study of men and women from 6 study sites (Los Angeles County, California; St. Paul, Minnesota; Chicago, Illinois; Forsyth County, North Carolina; Baltimore, Maryland; and New York, New York). Participants were aged 45–84 years at baseline (between August 2000 and July 2002), and they were free of clinical cardiovascular disease at baseline examination (e.g., no history of heart attack, stroke, heart failure, or atrial fibrillation). Participation among eligible persons was 60%. The study was approved by the institutional review board at each participating site, and participants provided informed consent (26). Participants attended 4 follow-up examinations in 2002–2004, 2004–2005, 2005–2007, and 2010–2011. Residential histories were collected at each visit and were used to geocode participants' home addresses for each month of follow-up.

Hypertension

Blood pressure was measured at each of the 5 examinations, following a standardized protocol: After 5 minutes of seated rest, 3 measurements were taken at 2-minute intervals with an automated oscillometric sphygmomanometer (27). The average of the second and third measurements was used for analysis. Hypertension was defined as systolic blood pressure at least 140 mm Hg, diastolic blood pressure at least 90 mm Hg, or reported use of antihypertensive medication (28). The date of incident hypertension was assigned to the midpoint between the last nonhypertensive examination and the first hypertensive examination; participants who did not develop hypertension were censored at the date of their last examination.

Neighborhood environment

Measures of neighborhood environment came from 3 data sources: surveys of MESA participants, surveys of individuals living at MESA sites (community surveys), and GIS-based densities of resources. Community surveys were cross-sectional phone surveys that collected information from non-MESA participants at least 18 years of age who lived in the MESA communities. The first community survey was completed in 2004 by 5,988 individuals at the Maryland, New York, and North Carolina sites, and the 2011 community survey included 4,122 respondents in a subsample of tracts at all 6 sites. Respondents were sampled using random-digit dialing and list-based sampling.

Two survey scales related to the physical environment (healthy food availability and walking environment) and 2 survey scales related to the social environment (social cohesion and safety) were selected for investigation because of these variables' potential relevance to hypertension (18, 25, 29, 30) and because these environments were assessed consistently across MESA and community survey questionnaires at multiple time points. Each community survey included all 4 survey scales of interest; MESA participants responded to each scale twice (social cohesion in 2000–2002; safety, healthy food, and walking environment in 2003–2005; and all 4 scales in 2010–2011).

The healthy food availability scale measured the availability of fresh fruits and vegetables and low-fat foods in the neighborhood. The walking environment scale asked about the pleasantness of walking in the neighborhood, ease of walking to destinations, and frequency of seeing others walking or exercising in the neighborhood. The social cohesion scale included questions relating to trust in neighbors, shared values with neighbors, willingness to help neighbors, and extent to which neighbors got along. The safety scale asked about neighborhood violence and ability to walk in the neighborhood without fear. All survey scales used a 5-point Likert scale with response options from "strongly agree" to "strongly disagree," and participants were asked to refer to the area approximately 1 mile (0.6 km) around their homes. Scales were based on previous work and have acceptable internal consistency, ecometric properties, and reliability (31).

Scores from the survey scales were summarized as the average of all responses from participants who lived within 1 mile of each MESA participant's home address. These 1-mile crude means were calculated for 2 time periods: 2000–2005, using data collected from MESA participants in that time frame and the 2004 community survey, and 2006–2011, combining data from MESA participants with data from the 2011 community survey.

GIS-based densities of resources were derived from commercially available business listings through the National Establishment Time-Series database (Walls and Associates, Oakland, California). Standard Industrial Classification codes (Occupational Safety and Health Administration, Washington, DC) related to indoor conditioning, dance, bowling, golf, biking, hiking, team and racquet sports, swimming, physical activity instruction, and water activities were defined as physical activity resources (32, 33). Favorable food stores included chain and nonchain supermarkets and food and vegetable markets. Data were obtained for each year from 2000 to 2011. Annual data were attributed to all months in the year. The simple densities of favorable food stores and physical activity resources per square mile were calculated for a 1-mile buffer around each participant's home address using ArcGIS software (ESRI, Redlands, California).

Table 1. Distribution of Sociodemographic Characteristics and Environmental Summary Scores Among Participants Without Hypertension at Baseline, Multi-Ethnic Study of Atherosclerosis, 2000–2011

Characteristic	No. of Participants	%	Neighborhood Domain and Mean (SD) Summary Score		
			Healthy Food Environment	Physical Activity Environment	Social Environment
Overall	3,382	100	−0.10 (1.58)	−0.08 (1.65)	−0.04 (1.62)
Age, years					
<60	1,886	55.8	−0.11 (1.57)	−0.14 (1.58)	−0.09 (1.61)
≥60	1,496	44.2	−0.09 (1.59)	−0.01 (1.72)	0.03 (1.63)
P value[a]			0.735	0.022	0.039
Sex					
Female	1,737	51.4	−0.05 (1.60)	−0.02 (1.67)	−0.05 (1.62)
Male	1,645	48.6	−0.15 (1.55)	−0.14 (1.62)	−0.03 (1.62)
P value[a]			0.060	0.032	0.835
Race/ethnicity					
White	1,473	43.6	−0.18 (1.75)	0.46 (2.02)	0.56 (1.44)
Chinese-American	453	13.4	−0.09 (0.69)	−0.62 (0.89)	0.12 (1.20)
Black	695	20.5	−0.30 (1.59)	−0.48 (1.16)	−0.55 (1.78)
Hispanic	761	22.5	0.25 (1.54)	−0.43 (1.22)	−0.82 (1.53)
P value[a]			<0.001	<0.001	<0.001
Education					
High school or less	1,046	30.9	−0.18 (1.44)	−0.63 (1.10)	−0.56 (1.56)
Some college or associate's degree	945	27.9	−0.25 (1.47)	−0.27 (1.43)	−0.04 (1.59)
Bachelor's degree or more	1,391	41.1	0.07 (1.73)	0.47 (1.93)	0.36 (1.57)
P for trend[a]			<0.001	<0.001	<0.001
Annual income, dollars					
<20,000	671	19.8	−0.21 (1.27)	−0.63 (1.06)	−0.69 (1.47)
20,000–39,999	831	24.6	−0.06 (1.56)	−0.39 (1.31)	−0.37 (1.55)
40,000–64,999	946	28.0	−0.23 (1.62)	−0.16 (1.53)	0.01 (1.61)
≥65,000	934	27.6	0.09 (1.73)	0.67 (2.06)	0.67 (1.51)
P for trend[a]			0.003	<0.001	<0.001

Table continues

In order to maximize the information available about neighborhood environments, we created environmental summary measures that combined survey and GIS measures (or multiple survey measures) related to the same domain, by standardizing and summing together scores from the component measures. Survey-based healthy food availability and GIS-based density of favorable food stores were combined to capture the food environment; survey-based walking environment and GIS-based density of recreational resources were combined to capture the physical activity environment; and survey-based safety and social cohesion were combined to capture the social environment. Cronbach's α was 0.44 for the food environment (suggesting poor internal consistency) and 0.75 for both the physical activity environment and the social environment (suggesting adequate internal consistency) (34, 35). Due to the variable reliability of the environmental summary measures and the potential for the summing of survey and GIS scores to mask important differences between these 2 data sources, we analyzed the environmental summary measures as well as their component measures in relation to incident hypertension.

In order to better reflect the long-term accumulation of neighborhood exposures, we calculated the time-varying average of each neighborhood measure (survey-based, GIS-based, and environmental summary measures) from baseline through each month of follow-up (henceforth referred to as the cumulative average). The median duration of residence in the neighborhood at baseline was 14 years, and 70% of participants stayed at the same address throughout the study; although most participants were geographically stable, using the cumulative average of neighborhood scores captured information on neighborhood environmental characteristics before and after moving for participants who moved during follow-up, with contributions relative to the amount of time spent in each place. The cumulative average approach also emphasizes long-term trends in neighborhood environments rather than short-term changes, which

Table 1. Continued

Characteristic	No. of Participants	%	Neighborhood Domain and Mean (SD) Summary Score		
			Healthy Food Environment	Physical Activity Environment	Social Environment
BMI category[b]					
<25	1,183	35.0	0.09 (1.60)	0.18 (1.88)	0.14 (1.55)
25–29.9	1,315	38.9	−0.12 (1.58)	−0.14 (1.58)	−0.07 (1.61)
≥30	884	26.1	−0.31 (1.53)	−0.34 (1.31)	−0.25 (1.69)
P for trend[a]			<0.001	<0.001	<0.001
Census tract SES					
Low	1,133	33.5	−0.44 (1.48)	−0.96 (0.78)	−0.94 (1.45)
Medium	1,123	33.2	−0.51 (1.11)	−0.58 (0.66)	0.00 (1.43)
High	1,126	33.3	0.66 (1.79)	1.31 (2.03)	0.83 (1.47)
P for trend[a]			<0.001	<0.001	<0.001
Study site					
Winston-Salem, North Carolina	438	13.0	−1.72 (0.96)	−0.94 (0.87)	1.72 (1.38)
New York, New York	538	15.9	2.23 (1.37)	1.04 (2.20)	−1.53 (1.43)
Baltimore, Maryland	458	13.5	−0.99 (0.68)	−0.80 (0.56)	−0.02 (1.80)
St Paul, Minnesota	618	18.3	−1.18 (0.64)	−0.55 (0.57)	−0.08 (1.13)
Chicago, Illinois	666	19.7	0.71 (0.99)	1.45 (1.77)	0.17 (1.21)
Los Angeles, California	664	19.6	−0.10 (0.69)	−1.00 (0.66)	−0.18 (1.30)
P value[a]			<0.001	<0.001	<0.001

Abbreviations: BMI, body mass index; SD, standard deviation; SES, socioeconomic status.
[a] *P* values correspond to analysis-of-variance tests or linear tests of trend.
[b] BMI was calculated as weight (kg)/height (m)^2.

we felt was appropriate because hypertension is a progressive disease that develops gradually.

Additional covariates

Individual-level covariates included age, race/ethnicity, and education. Race/ethnicity was self-reported as white, African-American, Hispanic, or Chinese-American, based on questions adapted from the 2000 US Census. Educational level was measured as years of education based on the midpoint of 9 categories (reduced educational categories were used for descriptive statistics) (36).

Neighborhood SES may be a confounder of the relationship between specific features of the neighborhood environment and hypertension if it is associated with neighborhood physical and social environments and has an independent effect on hypertension (through pathways that do not involve the neighborhood physical and social environments being measured) (37–40). However, if neighborhood SES captures the same underlying constructs as the specific measures of neighborhood features, adjusting for neighborhood SES would constitute overadjustment. For transparency, we present results derived from models with and without adjustment for neighborhood SES.

Neighborhood SES was characterized on the basis of principal factor analysis of all US census tracts with orthogonal rotation of 16 tract-level variables. The first factor explained 49.2% of total variance and represents education (percentage of adult residents with a bachelor's degree), occupation (percentage of residents with management/professional occupations), income (median household income and percentage of households with interest, dividends, or rental income), and median housing value; this factor score was used to summarize tract-level SES, such that a higher score represented greater socioeconomic advantage. Data were retrieved from the 2000 US Census (41) (linked to 2000–2004) and the American Community Survey in 2005–2009 and 2007–2011 (linked to 2005–2007 and 2008–2011, respectively) (42, 43). Neighborhood SES was moderately correlated with the specific neighborhood features in this analysis (ranging from $r = 0.13$, with the density of favorable food stores, to $r = 0.76$, with the survey-based walking environment scale).

Potential mediators included body mass index (BMI), physical activity (for the physical activity environment), and diet (for the healthy food environment). BMI (weight (kg)/height (m)^2) was measured using height and weight measurements obtained at each MESA examination and was modeled continuously. Physical activity was measured as total metabolic-equivalent hours per week of intentional exercise and was categorized into none, low, medium, and high (defined by tertiles of nonzero values). Diet was measured at the baseline examination with a food frequency questionnaire and summarized according to the Healthy Eating Index (2005 guidelines) (44).

Statistical analysis

Descriptive analyses examined the distribution of the environmental summary measures according to relevant participant characteristics. Incidence rates were calculated by tertile of environmental summary score using Poisson models adjusting for mean age at baseline and the sex distribution of the sample. We also tested for linear trends in rates of hypertension by tertiles of environmental summary scores.

Cox models were used to estimate associations of time-varying cumulative average neighborhood measures with incident hypertension, before and after adjustment for individual- and neighborhood-level covariates. Neighborhood measures were modeled continuously, because exploratory analyses found no evidence of nonlinearity in relationships with hypertension. All models adjusted for baseline age, sex, educational level, income, and a term for interaction between age and (log)time, because Schoenfeld residuals (45) indicated that baseline age violated the proportional hazards assumption. Initial models adjusted for each neighborhood measure separately, with additional covariates added in stages to illustrate potential confounding. Mutual adjustment for all 6 neighborhood measures, and subsequent adjustment for neighborhood SES, was used to identify the independent association of each neighborhood measure with hypertension.

Robust standard errors were used to account for dependencies among individuals within the same census tract. Effect modification was investigated by adding interaction terms for interactions between neighborhood measures and sex, baseline age, and time-varying working status. Mediation was explored by adding relevant covariates to regression models.

RESULTS

Of the 6,191 MESA neighborhood participants, 2,718 (43.9%) were excluded due to prevalent hypertension at baseline and 91 (2.6%) could not be geocoded to a census tract or were missing key covariates, leaving a final analytical sample of 3,382 individuals. The median person-time contributed was 7.2 years (interquartile range, 4.3–10.1); 17% of the sample was lost to follow-up or died before the final examination.

Descriptive information about the neighborhood measures is available in Appendix Table 1. Correlations between the neighborhood measures at baseline were moderate, ranging from 0.07 (healthy food availability and safety scales) to 0.65 (healthy food availability and walking environment scales).

Sociodemographic and neighborhood characteristics of the 3,382 participants in the study sample at baseline are presented in Table 1. The average age was 59.1 years at baseline; 43.6% were white, 22.5% were Hispanic, 20.6% were black, and 13.4% were Chinese-American. Older participants and white participants tended to have higher-scoring physical activity and social environments at baseline than did other groups, and Hispanic participants lived in healthier food environments than did participants of other racial/ethnic groups. Participants with more education and those living in higher-SES neighborhoods reported higher scores for food, physical activity, and social environments compared with participants with less education and those who lived in lower-SES neighborhoods (in tests for linear trend, $P < 0.0001$). Neighborhood environment scores varied by site; New York had the highest food environment scores and the lowest social environment scores, while Winston-Salem had opposite. Physical activity environment scores were slightly more equally distributed.

During 21,340 person-years of observation, 1,335 incident cases of hypertension were identified. Table 2 shows differences between persons who developed hypertension and those who did not. Older participants, black participants, participants with less education, and those living in low-SES census tracts were overrepresented in the incident hypertension group. Those who developed hypertension lived in areas with significantly lower healthy food, physical activity, and social environment summary scores at baseline than did those who remained free of hypertension.

Age- and sex-adjusted incidence rates of hypertension (Table 3) showed that better food, physical activity, and social environment summary scores were each associated with lower hypertension incidence rates (all tests for trend: $P < 0.01$). These patterns persisted in Cox models that adjusted for age, sex, educational level, income, and neighborhood environment summary scores as continuous measures (Table 4, model 1, per standard-deviation increment in score, HR = 0.94 (95% confidence interval (CI): 0.89, 0.99) for healthy food environment, HR = 0.92 (95% CI: 0.86, 0.98) for physical activity environment, and HR = 0.93 (95% CI: 0.88, 0.99) for social environment). Additional adjustment for race/ethnicity attenuated most associations. Summary scores for the healthy food environment remained significantly protective (Table 4, model 2; HR = 0.95, 95% CI: 0.89, 1.00), although associations with the summary physical activity and social environment scores did not (HR = 0.95 (95% CI: 0.89, 1.01) and HR = 0.98 (95% CI: 0.93, 1.04), respectively).

GIS-based densities related to the food environment and physical activity environment were not associated with incident hypertension, whereas the survey-based healthy food, walking environment, and safety scores were all inversely associated with hypertension in models that adjusted for age, sex, educational level, and income (Table 4, model 1). The associations with the survey-based healthy food and walking environment scales persisted after additional adjustment for race/ethnicity (HR = 0.91 (95% CI: 0.86, 0.96) and HR = 0.94 (95% CI: 0.88, 1.00), respectively), but associations with safety did not (HR = 0.98, 95% CI: 0.92, 1.04).

When all 6 neighborhood measures were simultaneously included in the model (Table 4, model 3), the survey-based healthy food scores remained significantly associated with a lower rate of hypertension (HR = 0.89, 95% CI: 0.82, 0.96), but the association with the survey-based walking environment scores was attenuated and no longer statistically significant (HR = 1.03, 95% CI: 0.93, 1.12). Adjusting for neighborhood SES (Table 4, model 4) did not substantially affect these associations.

Terms for interaction between the healthy food survey scale and sex, baseline age, and time-varying working status were all nonsignificant ($P > 0.10$). Adjusting for BMI

Table 2. Participant Characteristics at Baseline by Incident Hypertension Status Through 2011, Multi-Ethnic Study of Atherosclerosis, 2000–2011

Characteristic	No Hypertension (*n* = 2,047)		Incident Hypertension (*n* = 1,335)		*P* Value[a]
	Mean	%	Mean	%	
Neighborhood domain summary score					
Healthy food environment	−0.05		−0.17		0.037
Physical activity environment	−0.00		−0.19		0.001
Social environment	0.02		−0.13		0.006
Age, years	57.6		61.0		<0.001
Male sex		49.0		48.1	0.605
Race/ethnicity					
White		46.5		39.0	<0.001
Chinese-American		14.2		12.1	
Black		16.9		26.1	
Hispanic		22.4		22.7	
Education					
High school or less		28.1		35.2	<0.001
Some college or associate's degree		27.6		28.5	
Bachelor's degree or more		44.3		36.3	
BMI category[b]					
<25		39.2		28.5	<0.001
25–29.9		39.3		38.3	
≥30		21.5		33.3	
Census tract SES					
Low		30.5		38.0	<0.001
Medium		33.2		33.3	
High		36.3		28.7	
Study site					
Winston-Salem, North Carolina		11.9		14.5	0.057
New York, New York		15.4		16.6	
Baltimore, Maryland		13.1		14.2	
St Paul, Minnesota		18.4		18.1	
Chicago, Illinois		21.0		17.7	
Los Angeles, California		20.1		19.0	

Abbreviations: BMI, body mass index; SES, socioeconomic status.
[a] *P* values correspond to tests for differences between hypertension outcome groups (analysis of variance for continuous variables; χ^2 tests for categorical variables).
[b] BMI was calculated as weight (kg)/height (m)^2.

Table 3. Age- and Sex-Adjusted Incidence Rates of Hypertension per 1,000 Person-Years by Tertiles of Environmental Summary Scores (*n* = 3,382), Multi-Ethnic Study of Atherosclerosis, 2000–2011

Neighborhood Domain	Tertile of Environmental Summary Score						*P* for Trend[a]
	Lowest		Middle		Highest		
	IR	95% CI	IR	95% CI	IR	95% CI	
Healthy food environment	69.1	63.1, 75.7	58.3	52.8, 64.4	58.3	52.9, 64.2	0.009
Physical activity environment	70.0	63.9, 76.7	63.1	57.4, 69.4	52.7	47.6, 58.4	<0.001
Social environment	72.7	66.4, 79.5	59.8	54.3, 65.8	53.7	48.6, 59.4	<0.001

Abbreviations: CI, confidence interval; IR, incidence rate.
[a] *P* values for neighborhood summary scores entered as ordinal variables into a Poisson model.

Table 4. Adjusted Hazard Ratios for Hypertension Incidence Corresponding to a 1-Standard-Deviation Increment in Cumulative Average Neighborhood Environmental Measures, Multi-Ethnic Study of Atherosclerosis, 2000–2011

Neighborhood Domain	Model							
	1[a]		2[b]		3[c]		4[d]	
	HR	95% CI	HR	95% CI	HR	95% CI	HR	95% CI
Food environment								
Healthy food environment summary score	0.94	0.89, 0.99	0.95	0.89, 1.00				
Survey measure of healthy food availability	0.88	0.84, 0.93	0.91	0.86, 0.96	0.89	0.82, 0.96	0.90	0.83, 0.97
GIS density of favorable food stores	1.02	0.97, 1.08	1.00	0.95, 1.06	1.03	0.94, 1.13	1.03	0.94, 1.13
Physical activity environment								
Physical activity environment summary score	0.92	0.86, 0.98	0.95	0.89, 1.01				
Survey measure of walking environment	0.91	0.86, 0.97	0.94	0.88, 1.00	1.03	0.93, 1.12	1.07	0.96, 1.18
GIS density of commercial physical activity resources	0.95	0.89, 1.01	0.97	0.91, 1.03	1.00	0.89, 1.11	1.02	0.92, 1.14
Social environment								
Social environment summary score	0.93	0.88, 0.99	0.98	0.93, 1.04				
Survey measure of safety	0.91	0.86, 0.97	0.98	0.92, 1.04	0.97	0.89, 1.05	0.97	0.89, 1.05
Survey measure of social cohesion	0.97	0.92, 1.03	0.99	0.94, 1.05	1.01	0.93, 1.09	1.01	0.93, 1.10

Abbreviations: CI, confidence interval; GIS, geographic information systems; HR, hazard ratio.
[a] Results were adjusted for age, age-time interaction, sex, education, income, and neighborhood measure.
[b] Model 1 with the addition of race/ethnicity.
[c] Model 2 with the addition of mutual adjustment for all neighborhood measures.
[d] Model 3 with the addition of neighborhood socioeconomic status.

(time-varying) and diet (at baseline) as potential mediators of the relationship between healthy food availability and hypertension in a subsample ($n = 2{,}979$) with complete data did not change the association (HR = 0.90, 95% CI: 0.83, 0.98).

Sensitivity analyses explored the robustness of results to using baseline or time-varying neighborhood measures, kernel-based resource densities, density buffer sizes of 0.5 miles (0.3 km) and 3 miles (1.9 km), tract-level conditional empirical Bayes estimates of survey measures, restricting analyses to only those participants with at least 5 survey respondents within a 1-mile buffer, and adjusting for site. Estimated associations between neighborhood environments and hypertension did not change substantially.

DISCUSSION

In this sample of middle-aged and older adults at 6 sites in the United States, residents of neighborhoods with better healthy food, physical activity, and social environments had lower rates of incident hypertension than did residents of neighborhoods with lower scores in those areas. After adjustment for age, sex, educational level, income, and race/ethnicity, the survey-based healthy food availability and walking environment scores remained significant predictors of hypertension risk. After simultaneously accounting for all neighborhood variables, each standard-deviation increment in cumulative average of survey-based healthy food score was associated with a 12% lower rate of hypertension. Neither GIS-based densities of favorable food stores and physical activity resources nor the survey measure of social cohesion were associated with hypertension incidence. Associations with neighborhood safety were attenuated after adjustment for race/ethnicity.

These results concur with previous findings in MESA that higher-scoring neighborhood physical environments are associated with lower prevalence of hypertension (13). The finding that the healthy food environment was more strongly associated with incident hypertension than the walking environment in fully adjusted models is consistent with previous work in MESA that found similar patterns with incident obesity (19) and incident diabetes (29).

Associations between neighborhood environments and hypertension incidence were generally attenuated after adjustment for race/ethnicity, suggesting that race/ethnicity may be acting as a confounder (especially in the case of social environment factors, which were strongly patterned by race/ethnicity) or that neighborhood environments may partly mediate racial/ethnic disparities in hypertension. Previous research has found that neighborhood sociodemographic characteristics and chronic stressors can partially or fully explain disparities in hypertension prevalence (7, 25). Future work should continue to explore whether reducing the disparities in neighborhood environments may contribute to reducing disparities in hypertension.

To our knowledge, this was the first study to investigate both survey-based and GIS-based measures of neighborhood physical environments in relation to incident hypertension. Survey-based measures of the food environment and physical activity environment were more strongly associated with hypertension than were GIS-based measures related to the same domains. GIS-based measures capture only the presence of resources; survey-based measures can capture additional considerations, such as quality and ease of access, which may be important in how neighborhood environments shape various health outcomes. Only 1 prior study has investigated GIS-based measures in relation to longitudinal blood pressure changes: Li et al. (15) found that residents of more walkable neighborhoods (defined by land use mix, street connectivity, public transportation, and green space) had smaller 1-year increases in systolic blood pressure. We assessed the presence of commercial businesses, but it is likely that more nuanced constructs, such as walkability or accessibility, may be more relevant to blood pressure outcomes. This may also explain why the survey measure of the physical environment (which included some walkability items) was related to hypertension incidence (although results were not robust to adjustment for other neighborhood variables), and it is consistent with recent work in MESA showing that changes in walkability (based on distances to various amenities) are related to changes in BMI (46).

It is likely that neighborhoods influence hypertension through intermediaries, including diet, physical activity, stress, and BMI (8, 47). We adjusted for diet and BMI, but these variables did little to affect the observed association between neighborhood healthy food environment and hypertension. However, our measure of diet was assessed only at baseline; recall-based food frequency questionnaires are prone to measurement error; and estimating direct and indirect effects from regression analyses is inherently challenging (48, 49). The observed association between neighborhood healthy food environments and hypertension is plausible in the context of data showing that healthy food environments are associated with better diets (50, 51) and that better diets can reduce hypertension risk (52, 53).

Differential measurement validity and reliability levels should be considered in interpreting the relative strength of associations between different neighborhood factors. The survey scales used to capture the quality of neighborhood physical and social environments may not have fully captured the dimensions most relevant for hypertension. Neighborhood social environments in particular are difficult to quantify, which may have limited our ability to detect associations. Additionally, the healthy food environment and walking environment scores were correlated ($r = 0.65$) at baseline, which limited our ability to statistically disentangle their associations.

Other limitations include the possibility of confounding by individual-level characteristics that may be patterned by neighborhood environments and affect hypertension risk, such as occupational factors. In MESA, participants who were lost to follow-up were more likely to be hypertensive and to live in lower-scoring neighborhood environments, suggesting that any bias in our results would likely be towards the null. Additionally, multiple hypotheses were examined in this analysis. Finally, we probably did not capture the total relevant exposure period for a chronic and multifactorial disease like hypertension, although we used the cumulative average of neighborhood measures and MESA participants had largely stable residential histories.

Strengths of this analysis include the unique availability of longitudinal data for specific domains of the neighborhood environment and the large, multiethnic cohort. This analysis contributes to our knowledge of the relationship between neighborhood environments and hypertension based on cross-sectional studies, and it highlights the importance of collecting survey-based measurements of neighborhood environments. Neighborhood food environment may be a useful target for public health interventions designed to reduce the population-level burden of hypertension.

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Appendix Table 1. Characteristics of the Neighborhood Environment Summary Measures and Their Components, Multi-Ethnic Study of Atherosclerosis, 2000–2011

Measure	Scale	Baseline Value	95% CI
Food environment summary score	Sum of standardized component measures	−0.10	−0.15, −0.04
Survey measure of healthy food availability	Likert scale, 1–5 (5 is best)	3.52	3.50, 3.54
Density of favorable food stores	No. of stores per square mile (per 0.6 km^2)	2.33	2.21, 2.45
Physical activity environment summary score	Sum of standardized component measures	−0.08	−0.13, −0.02
Survey measure of walking environment	Likert scale, 1–5 (5 is best)	3.93	3.92, 3.95
Density of commercial physical activity resources	No. of businesses per square mile (per 0.6 km^2)	4.48	4.24, 4.72
Social environment summary score	Sum of standardized component measures	−0.04	−0.09, 0.02
Survey measure of social cohesion	Likert scale, 1–5 (5 is best)	3.54	3.53, 3.55
Survey measure of safety	Likert scale, 1–5 (5 is best)	3.68	3.66, 3.69

Abbreviation: CI, confidence interval.