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Original Contribution

Associations of the Local Food Environment with Diet Quality—A Comparison of Assessments based on Surveys and Geographic Information Systems

The Multi-Ethnic Study of Atherosclerosis

Latetia V. Moore[1], Ana V. Diez Roux[1], Jennifer A. Nettleton[2], and David R. Jacobs, Jr.[2]

[1] Department of Epidemiology, School of Public Health, University of Michigan, Ann Arbor, MI.
[2] Division of Epidemiology and Community Health, School of Public Health, University of Minnesota, Minneapolis, MN.

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There is growing interest in understanding how food environments affect diet, but characterizing the food environment is challenging. The authors investigated the relation between global diet measures (an empirically derived "fats and processed meats" (FPM) dietary pattern and the Alternate Healthy Eating Index (AHEI)) and three complementary measures of the local food environment: 1) supermarket density, 2) participant-reported assessments, and 3) aggregated survey responses of independent informants. Data were derived from the baseline examination (2000–2002) of the Multi-Ethnic Study of Atherosclerosis, a US study of adults aged 45–84 years. A healthy diet was defined as scoring in the top or bottom quintile of AHEI or FPM, respectively. The probability of having a healthy diet was modeled by each environment measure using binomial regression. Participants with no supermarkets near their homes were 25–46% less likely to have a healthy diet than those with the most stores, after adjustment for age, sex, race/ethnicity, and socioeconomic indicators: The relative probability of a healthy diet for the lowest store density category versus the highest was 0.75 (95% confidence interval: 0.59, 0.95) for the AHEI and 0.54 (95% confidence interval: 0.42, 0.70) for FPM. Similarly, participants living in areas with the worst-ranked food environments (by participants or informants) were 22–35% less likely to have a healthy diet than those in the best-ranked food environments. Efforts to improve diet may benefit from combining individual and environmental approaches.

diet; food; residence characteristics; social class

Abbreviations: AHEI, Alternate Healthy Eating Index; CI, confidence interval; FPM, fats and processed meats; MESA, Multi-Ethnic Study of Atherosclerosis.

Factors related to access to healthy foods have been receiving increasing attention (1–17) because of the growing obesity epidemic among Americans (18). Local food environments and residents' diets have been linked in observational studies (16, 19–24) and in natural experiments (25), although not all results have been consistent (26, 27). A causal relation between environmental features and diet would imply that efforts to prevent obesity may need to include strategies aimed at improving access to healthy foods in certain neighborhoods (28–34).

A major challenge in studying the effects of environment on diet is characterizing the local food environment. Many investigators have characterized food environments by counting the number of supermarkets in the areas in which study participants live (1, 9, 14, 15, 35). This approach relies on the assumption that only supermarkets offer healthy foods and that the availability and quality of foods offered by supermarkets do not vary across neighborhoods. Surveying residents of neighborhoods about the availability of

Correspondence to Dr. Ana V. Diez Roux, Department of Epidemiology, School of Public Health, University of Michigan, 1214 South University Avenue, 2nd floor, Ann Arbor, MI 48103 (e-mail: adiezrou@umich.edu).

healthy foods in their local food environment may provide information on foods actually available to residents that is not captured by data on the locations of supermarkets. A limitation of this approach is the possibility that reporting bias could generate spurious associations between reports of neighborhood conditions and self-reported behaviors. Alternatively, aggregating survey responses from a separate sample of ''neighborhood informants'' can be used to create a potentially more objective measure for an area (36–38).

Another limitation of prior work (16, 19–21) is that it has largely focused on individual dietary components (e.g., fruit and vegetable intake). Because foods are not consumed in isolation and because of the potential synergy between foods (39), measuring diet quality using indices may provide additional insight. Testing the robustness of results across alternate measures of the local food environment and different global measures of diet quality would strengthen inferences regarding the relation between the local food environment and diet.

Using data from three large and ethnically diverse geographic areas, we investigated the relation between two global measures of diet—an empirically derived ''fats and processed meats'' (FPM) dietary pattern (40) and the Alternate Healthy Eating Index (AHEI) (41, 42)—and three complementary measures of the local food environment: 1) the density of supermarkets, 2) participant-reported characteristics of the local food environment, and 3) a measure of the quality of the local food environment derived by aggregating survey responses from residents of the same neighborhoods as study participants.

MATERIALS AND METHODS

The Multi-Ethnic Study of Atherosclerosis (MESA) is a study of cardiovascular disease in adults aged 45–84 years (43). The MESA Neighborhood Study, an ancillary study to MESA, collected information on neighborhood characteristics for participants residing at three of the six study sites: Forsyth County, North Carolina; Baltimore City and County, Maryland; and New York, New York. At each site, MESA sampled approximately 1,000 White, Black, and Hispanic participants through population-based approaches. Whites and Blacks were recruited from all three sites, but all Hispanics were from New York. The baseline examination of the MESA cohort, on which these analyses are based, took place between July 2000 and September 2002. The study was approved by the institutional review board at each site, and all subjects gave written informed consent.

Dietary outcomes

Diet quality was assessed by means of a 120-item food frequency questionnaire using two dietary measures: the AHEI (41, 42) and the empirically derived FPM dietary pattern (40). The questionnaire was adapted from the Insulin Resistance Atherosclerosis Study instrument, which has comparable validity for multiethnic populations (40, 43).

The AHEI is a summary index of dietary patterns and eating behaviors that has been associated with a lower risk of chronic disease (41, 42). Higher scores indicate higher intakes of fruits and vegetables, nuts and soy protein, white meat (vs. red meat), cereal fiber, and polyunsaturated fat (vs. saturated fat). Higher scores also reflect moderate alcohol consumption, multivitamin use, and lower intake of *trans* fats. Previous work used data on fiber from all grain sources and long-term (5-year) multivitamin use (41, 42), which were not available in MESA; therefore, cereal fiber and use of any kind of vitamin at least once per month were substituted for these items. Participants whose AHEI scores ranked in the top fifth of the distribution for the sample were classified as having a high-quality diet, hereafter referred to as a healthy diet. In prior work, scoring in the top fifth of the population distribution (AHEI scores 47–86) was associated with a 28–39 percent reduced risk of cardiovascular disease in comparison with scoring in the bottom fifth (41, 42). In MESA, scores for the top quintile ranged from 53 to 81.

An empirically derived dietary pattern identified through principal-components analysis of MESA diet data (40), hereafter referred to as the FPM dietary pattern, was also investigated as a measure of overall diet quality. Higher scores indicate higher intakes of fats and oils, high-fat and processed meats, fried potatoes, salty snacks, and desserts. Participants scoring in the bottom quintile of the FPM were classified as having a higher-quality diet or a ''healthy'' diet. FPM scores were positively associated with biochemical markers of inflammation in this cohort (40).

Local food environment measures

The local food environment of MESA participants was characterized in three ways: 1) the density of supermarkets within 1 mile (1.6 km) of participants' homes; 2) participants' reports of the availability of healthy foods in their neighborhoods (henceforth referred to as MESA self-reports); and 3) a measure of the availability of healthy foods created by aggregating the perceptions of other residents (non-MESA participants) of participants' neighborhoods (henceforth referred to as informant reports).

Data on supermarkets were obtained from InfoUSA, Inc. (Papillion, Nebraska) in November 2003. Supermarkets were identified using supplemented Standard Industrial Classification codes (codes 541101 and 541104–541106) and were differentiated from other stores on the basis of chain name recognition and/or having an annual payroll of greater than 50 employees (1, 3, 14). Density of supermarkets per square mile within 1 mile of each MESA participant's residence was estimated by means of the kernel density method (44, 45), using the Spatial Analyst extension of ArcGIS, version 9.0 (ESRI, Inc., Redlands, California). The main area investigated was set at 1 mile to correspond with survey questions. Supermarket densities were weighted according to a Gaussian distribution so that resources more proximate to respondents' residences were weighted more heavily than those farther away (44, 45).

Three survey questions administered to MESA participants were used to measure the perceived availability of healthy foods in each person's neighborhood, defined as the area approximately 1 mile around his or her home (MESA self-report measure). Participants were asked the extent to which they agreed with the following statements: 1) ''lack of access to adequate food shopping is a problem,'' 2) ''a large selection of fruits and vegetables is available,'' and 3) ''a large selection of low-fat products is available.'' Responses to question 1 were coded on a four-point Likert scale (1 = very serious problem; 2 = somewhat serious problem; 3 = minor problem; 4 = not really a problem), and responses to items 2 and 3 were coded on a five-point Likert scale (0 = strongly agree; 1 = agree; 2 = neither agree nor disagree; 3 = disagree; 4 = strongly disagree). Responses were coded and summed into a summary score. Higher summary scores indicate better perceived accessibility of shopping and the availability of low-fat products and produce (Cronbach's $\alpha = 0.70$).

We also characterized the availability of healthy foods in each MESA participant's neighborhood by aggregating the perceptions of multiple non-MESA participants (neighbors of MESA participants) (the informant report measure). Neighborhoods were defined as census tracts in these analyses. Data with which to construct these measures were obtained from a random digit dialing phone survey of MESA neighborhoods conducted between January and August of 2004 (36). The final response rate was 46.5 percent, and the sample was approximately representative of the areas from which it was drawn (36). Telephone survey participants ranked their neighborhood (1 mile around their home) on the 1) quality and 2) availability of fresh fruits and vegetables and 3) the availability of low-fat products. All responses were coded on a five-point Likert scale (0 = strongly agree; 1 = agree; 2 = neither agree nor disagree; 3 = disagree; 4 = strongly disagree). A scale was constructed by calculating the mean value of the three responses. The scale had good internal consistency (Cronbach's $\alpha = 0.78$) and 2-week test-retest reliability (intraclass correlation coefficient = 0.69) (36). Responses for all informants within a census tract were aggregated to create a summary measure for each tract. To account for varying numbers of informants for the census tracts (median, 8; range, 1–64), we generated a conditional empirical Bayes estimate for each tract. Briefly, estimates for neighborhoods with few informants were adjusted towards the mean of neighborhoods with similar census characteristics shown to be predictive of food availability in these data (36, 38). The reliability of the aggregate measures for characterizing neighborhood-level constructs was high (neighborhood reliability = 0.64) (36). Higher scores indicate better availability of healthy foods.

In the absence of an a priori theory of relevant thresholds for the effects of the local food environment, local food environment measures were classified into four categories based approximately on quartiles of the observed distribution. The use of these distribution-based categories permitted investigation of thresholds while ensuring sufficient numbers of participants in each category to allow for meaningful estimation. Measures were positively, though not highly, correlated; Spearman's correlation coefficients were 0.49 for densities versus MESA self-reports, 0.15 for densities versus informant measures, and 0.24 for MESA self-reports versus informant measures.

Statistical analyses

Of the 3,265 participants at the three study sites, 302 were excluded because geocodes for their home addresses were unavailable. In addition, 403 persons were excluded because information on one or more dietary indicators was not available, and 176 persons were excluded because of missing food environment measures. This left 2,384 participants for analysis.

Binomial regression (46) was used to model the probability of having a healthy diet as a function of measures of the local food environment. The inclusion of a random intercept for each tract did not modify estimates or standard errors, so results from the simpler models are reported. Associations were adjusted for participant age (years), sex, race/ethnicity (Hispanic, Non-Hispanic White, and Non-Hispanic Black), and continuous annual per capita household income. Participants selected their household income from 13 family income categories and indicated the number of persons within the household. Per capita income was calculated by dividing the midpoint of each income category by the number of persons supported. In sensitivity analyses, we also investigated the robustness of results to additional adjustment for education, classified into nine categories.

RESULTS

New York participants were more likely to follow a healthy diet than respondents at the other two study sites (table 1). White participants were more likely to have a healthy diet than other groups by the AHEI measure, whereas Hispanics were more likely to have a healthy diet by the FPM measure. On the basis of AHEI scores, income was positively associated with the probability of having a healthy diet. In contrast, the probability of a healthy diet as assessed by the FPM measure was inversely associated with income, possibly because of the strong association of the FPM measure with Hispanic ethnicity.

Ninety-five percent of participants stated that they used supermarkets for most of their household food shopping, and 47 percent of participants reported that they did most of their food shopping within 1 mile of their home (not shown in table). Overall, 31 percent of participants did not have a supermarket located within 1 mile of their home. New York MESA participants were significantly more likely to live in areas with the highest densities of supermarkets (due to the considerably higher population density of this area), and they also reported better food environments (table 1). Hispanic participants lived in areas with higher densities of supermarkets (reflecting their location in New York) and ranked their neighborhoods better than did Blacks or Whites. Whites lived in neighborhoods that had the best food environments based on informant reports. Supermarket densities were highest in the lowest income category, possibly reflecting the predominant location of this income group in New York (49 percent of low-income participants resided in New York). However, informant reports showed a positive association of better food environments with higher income levels.

Table 2 shows participant characteristics across categories of the local food environment. Overall there was substantial overlap in individual characteristics across categories, with the exception of New York and Hispanic

TABLE 1. Proportions of participants with healthy diets and mean measures of the local food environment, by study site and selected personal characteristics, Multi-Ethnic Study of Atherosclerosis, United States, 2000–2002

	No. of participants	% with a healthy diet*		Local food environment measure†		
		Alternate Healthy Eating Index	"Fats and processed meats" dietary pattern	No. of supermarkets per square mile (per 1.6 km^2)	Perceived access to healthy foods: self-reports	Perceived access to healthy foods: informant reports
Total	2,384	20.0	20.0	1.4 (1.9)‡	7.3 (2.5)	3.2 (0.4)
Range				0–12	0–11	2.4–4.3
Study site						
Maryland	785	20.9	14.5	0.5 (0.6)	7.1 (2.5)	3.2 (0.3)
North Carolina	839	17.5	12.2	0.2 (0.4)	6.1 (2.5)	3.1 (0.3)
New York	760	21.7	33.9	3.4 (2.0)	8.7 (1.7)	3.3 (0.4)
p value§		0.066	<0.001	<0.001	<0.001	<0.001
Sex						
Male	1,092	18.3	15.3	1.4 (1.9)	7.3 (2.6)	3.2 (0.4)
Female	1,292	20.9	24.0	1.3 (1.9)	7.3 (2.5)	3.2 (0.4)
p value§		0.2189	<0.001	0.0914	0.6331	0.1268
Race/ethnicity						
Non-Hispanic Black	995	19.6	16.1	1.0 (1.5)	7.0 (2.5)	3.1 (0.3)
Hispanic	351	15.2	43.5	3.2 (1.6)	8.7 (1.5)	3.2 (0.4)
Non-Hispanic White	1,038	22.0	15.8	1.0 (2.0)	7.0 (2.6)	3.3 (0.4)
p value§		0.016	<0.001	<0.001	<0.001	<0.001
Per capita annual income						
$0–14,999	587	14.1	25.6	1.9 (1.8)	7.7 (2.2)	3.1 (0.3)
$15,000–24,999	678	19.8	19.0	1.3 (1.8)	7.1 (2.6)	3.2 (0.3)
$25,000–34,999	517	21.6	17.5	1.1 (1.7)	7.2 (2.6)	3.2 (0.3)
≥$35,000	494	26.8	17.9	1.3 (2.3)	7.4 (2.7)	3.3 (0.4)
p for trend¶		<0.001	0.001	<0.001	0.08	<0.001

* A healthy diet was defined as scoring within the top quintile of the Alternate Healthy Eating Index and within the bottom quintile of the "fats and processed meats" dietary pattern.

† Higher scores indicate greater availability of supermarkets/healthy foods.

‡ Numbers in parentheses, standard deviation.

§ Two-sided *p* value for differences among categories using chi-squared tests for proportions and analysis of variance for mean values.

¶ Two-sided *p* value for trend.

participants, who were overrepresented in the higher supermarket-density categories.

Table 3 shows the relative probability of having a healthy diet according to each measure of the local food environment, after adjustment for personal characteristics. Additional adjustment for education (in nine categories) had virtually no impact on the results (not shown). Participants with no supermarkets within 1 mile of their home (the lowest category) were 25 percent less likely to have a healthy diet, as measured by the AHEI, than participants who had the most stores near their home (relative probability = 0.75, 95 percent confidence interval (CI): 0.59, 0.95). They were also 46 percent less likely to have a healthy diet on the basis of the FPM measure (relative probability = 0.54, 95 percent CI: 0.42, 0.70). Similar results were obtained when the food environment was assessed using survey measures: Participants living in the areas ranked worst in food availability (by themselves or by informants) were 22–35 percent less likely to have a healthy diet than those in the best-ranked areas.

For the AHEI, there was no consistent evidence of a trend across categories: The probability of having a healthy diet was similarly reduced in the three bottom categories of local food environment measures in comparison with the top category. However, there was a suggestion of a dose-response trend for the FPM measure: The probability of a healthy diet was lower in the bottom category than in the two middle categories for all three measures.

Because of regional variation in population densities, the New York site was overrepresented in the top categories of supermarket density. In analyses using site-specific quartiles of densities, rather than quartiles based on the distribution of densities pooled across sites, living in areas with fewer supermarkets was still associated with worse diets, but associations were attenuated; for the AHEI, the relative probabilities were 0.84 (95 percent CI: 0.68, 1.04), 0.99 (95 percent CI: 0.78, 1.27), and 0.72 (95 percent CI: 0.56, 0.93) for the first, second, and third quartiles, respectively.

TABLE 2. Distribution of selected participant characteristics (%) according to various measures of the local food environment, Multi-Ethnic Study of Atherosclerosis, United States, 2000–2002†

	No. of participants	Category of local food environment measure (based on approximate quartiles*)											
		No. of supermarkets per square mile (per 1.6 km^2)				Perceived access to healthy foods: self-reports				Perceived access to healthy foods: informant reports			
		First (low)	Second	Third	Fourth (high)	First (low)	Second	Third	Fourth (high)	First (low)	Second	Third	Fourth (high)
		778	441	585	580	831	414	821	318	579	589	596	617
Study site													
Maryland	785	33.8	49.7	50.4	1.4	32.5	37.9	34.6	23.3	23.7	30.6	40.1	37.1
North Carolina	839	66.2	47.6	18.8	0.7	61.5	24.6	20.1	19.2	42.8	35.3	37.2	26.1
New York	760	0.0	2.7	30.8	97.9	6.0	37.4	45.3	57.5	33.5	34.1	22.7	36.8
Sex													
Male	1,092	48.5	45.6	43.9	44.3	45.2	47.6	47.7	39.9	44.6	44.3	48.0	46.4
Female	1,292	51.5	54.4	56.1	55.7	54.8	52.4	52.3	60.1	55.4	55.7	52.0	53.6
Race/ethnicity													
Non-Hispanic Black	995	46.5	46.3	41.4	32.2	44.2	48.1	38.2	36.2	61.8	49.9	36.1	20.3
Hispanic	351	0.1	0.9	13.8	45.7	2.3	18.1	23.6	19.8	18.0	17.1	12.6	11.5
Non-Hispanic White	1,038	53.3	52.8	44.8	22.1	53.5	33.8	38.1	44.0	20.2	32.9	51.3	68.2
Per capita annual income													
$0–14,999	587	15.4	19.9	28.9	40.1	18.2	29.3	34.3	18.0	36.6	30.5	22.1	15.5
$15,000–24,999	678	30.4	29.4	31.0	28.1	33.6	29.3	27.9	25.7	34.9	28.0	32.8	24.0
$25,000–34,999	517	28.5	26.2	19.7	15.9	25.1	22.1	20.3	23.8	15.5	24.2	24.9	25.5
≥$35,000	494	25.7	24.5	20.4	15.9	23.0	19.3	17.5	32.5	13.0	17.3	20.2	34.9

* Categories for supermarket density were based on cutoffs of 0, 0.5, and 2.2 supermarkets per square mile (range, 0–12); categories for participant self-reports were based on cutoffs of 5, 8, and 9 (range, 0–11); and categories for informant reports were based on cutoffs of 2.9, 3.1, and 3.4 (range, 2.4–4.3). Higher categories indicate better availability of supermarkets/healthy foods.

† Columns add up to 100%.

In stratified analyses, there was no consistent evidence that the association of food environment measures with diet differed qualitatively by age (<65 years vs. ≥65 years), sex, race/ethnicity, per capita income (dichotomized at the median), or time spent in the neighborhood (dichotomized at the median) (results not shown).

DISCUSSION

Participants who had no supermarkets near their homes were 25–46 percent less likely than participants in the highest category of supermarket density to have a healthy diet. Similarly, participants living in neighborhoods with the worst-ranked healthy food availability (by their own reports or by their neighbors' reports) were 22–35 percent less likely to have a healthy diet than those living in the best-ranked neighborhoods. Several prior studies of the food environment and diet have used the presence of supermarkets as the key measure of local food environment. Greater proximity to supermarkets has been linked to better diets among pregnant women (20), as well as to lower fat intakes (16) and greater consumption of fresh produce (10, 16, 21) in samples of adults. In a natural experiment, people who consumed fewer than two servings of fruits and vegetables per day were found to increase consumption by 34 percent after the opening of a large food superstore (25). Several studies have also found positive associations between the availability of healthy foods, as assessed by shelf space in stores, and the reported consumption of healthy foods by residents (22–24). Our study confirms previous work showing a relation between supermarket availability and dietary patterns, and it demonstrates the robustness of these results to alternate measures of healthy food availability.

There was no consistent evidence of a dose-response relation between the local food environment and diet quality. However, a suggestion of a dose-response relation was observed for the FPM dietary outcome, with the probability of a healthy diet being lower in the bottom category than in the two middle categories for all three food environment measures. Evidence of a graded relation between food environment and diet has been mixed. Morland et al. (16) and Rose and Richards (21) reported greater produce consumption for each additional supermarket in neighborhoods, and Laraia et al. (20) reported that fruit and vegetable intake was lower only among persons who lived farthest from a supermarket. Therefore, additional work is needed to determine the minimum necessary level of food availability to ensure a healthy diet.

A major innovation of our study was the use of three different measures to characterize the local food environment. The three environment measures were positively but

TABLE 3. Adjusted relative probability of having a healthy diet* according to two different diet measures and three measures of the local food environment, Multi-Ethnic Study of Atherosclerosis, United States, 2000–2002†

Diet measure and category of local food environment measure (based on approximate quartiles‡)	Local food environment measure											
	No. of supermarkets per square mile (per 1.6 km^2)				Perceived access to healthy foods: self-reports				Perceived access to healthy foods: informant reports			
	No.§	%¶	RP#	95% CI#	No.	%	RP	95% CI	No.	%	RP	95% CI
Alternate Healthy Eating Index												
First (low)	778	18.3	0.75	0.59, 0.95	831	17.6	0.68	0.54, 0.87	579	17.3	0.78	0.61, 1.01
Second	441	20.2	0.78	0.60, 1.02	414	20.3	0.81	0.62, 1.06	589	17.0	0.76	0.60, 0.96
Third	585	18.3	0.74	0.58, 0.94	821	18.2	0.73	0.57, 0.92	596	17.8	0.78	0.62, 0.98
Fourth (high)	580	21.6	Referent		318	26.4	Referent		617	25.3	Referent	
"Fats and processed meats" dietary pattern												
First (low)	778	12.9	0.54	0.42, 0.70	831	14.0	0.65	0.50, 0.84	579	17.8	0.78	0.62, 0.98
Second	441	16.1	0.67	0.50, 0.88	414	18.8	0.78	0.61, 1.00	589	21.2	0.99	0.81, 1.22
Third	585	18.0	0.67	0.53, 0.84	821	24.1	0.94	0.77, 1.14	596	17.6	0.85	0.69, 1.06
Fourth (high)	580	34.8	Referent		318	27.0	Referent		617	23.5	Referent	

* A healthy diet was defined as scoring within the top quintile of the Alternate Healthy Eating Index and within the bottom quintile of the "fats and processed meats" dietary pattern.

† Results were adjusted for age, race/ethnicity, sex, and continuous per capita annual income.

‡ Categories for supermarket density were based on cutoffs of 0, 0.5, and 2.2 supermarkets per square mile (range, 0–12); categories for participant self-reports were based on cutoffs of 5, 8, and 9 (range, 0–11); and categories for informant reports were based on cutoffs of 2.9, 3.1, and 3.4 (range, 2.4–4.3). Higher categories indicate better availability of supermarkets/healthy foods.

§ Number of participants.

¶ Unadjusted percentage of participants with a healthy diet within each quartile of the local food environment measure.

RP, relative probability; CI, confidence interval.

not highly correlated, suggesting that they may tap into different (though related) constructs and/or may have varying levels of measurement error. MESA participants' reports were more strongly correlated with supermarket density measures than were informant reports, because of the higher geographic comparability of these two measures. The density of supermarkets within a 1-mile radius around a participant's home is a relatively simple measure to calculate from existing data, but it does not directly quantify the actual availability of healthy foods. Survey measures may offer insight into the types of foods that are actually available. These measures, however, may be affected by same-source bias, which could arise if persons who follow a healthier diet are more likely to be aware of resources within their neighborhoods. The use of independent informants (neighbors of participants in this study) may provide a more objective measure by producing multiple impressions of the resources available in given areas. However, these measures may be more costly to obtain, and they rely on having sufficient sample sizes within and across neighborhoods.

Contrasting three different measures is useful, because all three may be subject to different types of measurement error. In addition, estimates based on each measure may be subject to varying levels of confounding, as well as confounding by different types of covariates. For example, in our analyses, supermarket density was strongly associated with study site (because of differences in population density), but other measures were not. The presence of robust results across these different measures strengthens our confidence that the associations we observed may reflect an effect of the food environment on diet.

A second important innovation of our study was the investigation of dietary patterns as opposed to investigation of individual foods or nutrients. Dietary patterns may be more relevant to health outcomes than individual dietary components and could be more sensitive to the food environment. The AHEI is based on dietary behaviors that have been shown to be associated with a lower risk of chronic disease (41, 42), and it encompasses many recommendations suggested in the US government's dietary guidelines for Americans (47). Thus, the AHEI represents dietary practices that are recommended for chronic disease prevention. The FPM measure, on the other hand, represents a constellation of actual dietary practices observed in this population. Each provides a unique perspective on eating behaviors, and each was differentially associated with other individual-level characteristics such as race/ethnicity and income in our data. The general consistency of the patterns observed for both measures also highlights the robustness of our results to varying levels of confounding.

Because of large differences in supermarket densities across study sites, New York respondents were overrepresented in the highest quartile of supermarket density. Having better spatial availability of supermarkets was still positively (although less strongly) associated with diet quality when site-specific quartiles of density were used. The use of site-specific categories (based on within-site distributions) accounts for site differences but also reduces the range in the density measure that is examined (because the top and bottom categories are more similar in density when site-specific categories are used). It is plausible that the relation between the local food environment and diet varies depending on regional factors such automobile use, transportation, and other features of urban design. Unfortunately, the limited sample size and sometimes limited range of food environment exposures within sites limited our ability to examine heterogeneity of effects by site. Another limitation of our study is that we had no direct measure of the cost or quality of healthy foods, which may be as important as (or more important than) availability for promoting healthier diet choices.

Overall, the robustness of our results to different measures of the local food environment and different dietary outcomes strengthens our confidence that the patterns we observed may reflect causal effects of the food environment on diet. The observational nature of our study does not allow us to categorically rule out confounding by poorly measured or omitted individual-level variables. In addition, the cross-sectional design does not preclude a reverse-causal explanation for our results (people's food preferences influencing the availability of certain foods in their neighborhoods). The impact of changes in the local food environment on changes in diet warrants further investigation in longitudinal and experimental designs. If confirmed, a causal relation between the local food environment and diet would imply that efforts to improve diet (and potentially reduce obesity) will need to combine culturally appropriate interventions targeted at individuals with changes in local food environments that support behavior change.

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Author contributions: L. M. conceptualized the research question, conducted the analyses, and wrote the manuscript. A. D. R. assisted in the conceptualization of the research, wrote sections of the manuscript, and supervised the work. J. N. and D. J. provided critical feedback on successive drafts of the manuscript.

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