Neighborhood Resources for Physical Activity and Healthy Foods and Their Association With Insulin Resistance

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Objective: Little is known about the influence of the built environment, and in particular neighborhood resources, on health. We hypothesized that neighborhood resources for physical activity and healthy foods are associated with insulin resistance.

Methods: Person-level data (n = 2026) came from 3 sites of The Multi-Ethnic Study of Atherosclerosis, a study of adults aged 45–84 years. Area-level data were derived from a population-based residential survey. The homeostasis model assessment index was used as an insulin resistance measure among persons not treated for diabetes. We used linear regression to estimate associations between area features and insulin resistance.

Results: Greater neighborhood physical activity resources consistently were associated with lower insulin resistance. Adjusted for age, sex, family history of diabetes, race/ethnicity, income and education, insulin resistance was reduced by 17% (95% confidence interval = −31% to −1%) for an increase from the 10th to 90th percentiles of resources. Greater healthy food resources were also inversely related to insulin resistance, although the association was not robust to adjustment for race/ethnicity. Analyses including diet, physical activity, and body mass index suggested that these variables partly mediated observed associations. Results were similar when impaired fasting glucose/diabetes was considered as the outcome variable.

Conclusion: Diabetes prevention efforts may need to consider features of residential environment.

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Prevalence of type 2 diabetes and metabolic abnormalities is rising. Little area-level research has been devoted to understanding environmental determinants of this epidemic. Residential environments may affect both diet and physical activity, 2 important risk factors for metabolic abnormalities. Two studies[1,2] have provided empirical evidence of an association between area socioeconomic disadvantage and a measure of metabolic abnormalities—insulin resistance—but no study has examined specific features of residential environments that may contribute to insulin resistance.

Resources for physical activity and availability of healthy foods are specific features of residential environments that may be related to the prevalence of diabetes and metabolic abnormalities among residents. The availability of high-quality fruits and vegetables and of low-fat foods may be an important determinant of a healthy diet. For example, supermarket prevalence has been positively associated with a healthy diet[3,4] and negatively associated with obesity.[5] Walking destinations and opportunities for physical activity, such as parks and recreational facilities, may increase the likelihood that residents will be physically active.[6] Density of facilities for physical activity in a neighborhood has been positively associated with physical activity[7,8] and negatively associated with obesity.[9] These environmental features have not been considered in relation to insulin resistance.

Hypotheses

We examined the cross-sectional association of availability of healthy foods and suitability of the residential environment for physical activity with insulin resistance in a population-based sample in 3 areas in the Eastern United States. We hypothesized that insulin resistance is inversely associated with these 2 area features. We also hypothesized that diet and physical activity mediate these associations, both directly and via obesity. Because residents are not restricted to their immediate residential neighborhoods, we also hypothesized that distance to areas with good availability of healthy foods and good resources for physical activity are positively associated with insulin resistance.

METHODS

Person-Level Data

Person-level data used in these analyses came from a cohort study of atherosclerosis, the Multi-Ethnic Study of Atherosclerosis. This study recruited persons age 45–84 years from 6 sites using a variety of population-based approaches, including

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commercial lists of area residents and random digit dialing, as previously reported.[10] Only persons free of clinical cardiovascular disease were eligible. For this analysis we used baseline data (collected 2000–2002) from the 3 sites for which neighborhood-level data were obtained: Baltimore City and County, Maryland; Forsyth County, North Carolina; and New York and Bronx counties, New York.

Our primary interest was to examine how environmental conditions may contribute to early metabolic abnormalities. We measured insulin resistance using a continuous index (the homeostasis model assessment index) among persons not treated for diabetes. This index is calculated as [fasting insulin (μU/mL) $\times$ fasting glucose (mmol/L)]/22.5, and is well correlated with measures from the gold-standard hyperinsulinemic clamp ($r = 0.88$[11])—the most widely used surrogate measure of insulin resistance in epidemiologic studies.[12] Values of this index were highly skewed and were therefore log transformed for multivariable analyses. Because persons treated for diabetes were excluded from these analyses, supplementary analyses used a binary variable that combined impaired fasting glucose and diabetes (as defined by the American Diabetes Association 2003 criteria[13]).

Information on person-level covariates [age, sex, race/ethnicity, family history of diabetes, income, education, physical activity, dietary intake, and body mass index (BMI)] was obtained during the clinic examination. Family history of diabetes was positive if at least 1 blood-relative parent and at least 1 blood-relative sibling had diabetes.[14] Participants selected their total combined family income for the past 12 months from 13 income categories. Per capita income was calculated by dividing the interval midpoint of the selected family income category by the number of persons supported. Participants selected their education from 8 categories, and continuous years of education was assigned as the interval midpoint of the selected education category.

Because moderate and vigorous physical activity are known to be inversely associated with insulin resistance,[15,16] we estimated metabolic equivalent task-minutes for walking and moderate and vigorous intensity sports and conditioning activities from a physical activity questionnaire.[10,17] Physical activity measures were skewed and so were log transformed for multivariable analyses. We selected dietary measurements (compiled from a food frequency questionnaire[10]) that may protect against insulin resistance: daily total dietary fiber and servings per day of low-fat dairy. Diets higher in fiber[18–20] and dairy[18,21] have been associated with less insulin resistance for their intrinsic properties or because they are proxies for a "healthy" diet.[18,22]

Area-Level Data

Measures of area resources were obtained from an independent sample: the Community Survey,[23] a population-based random-digit-dialing telephone survey conducted as part of an ancillary study, the Multi-Ethnic Study of Atherosclerosis Neighborhood Study.[10] (We used a sample that was independent but colocated with the original study's sites/participants to avoid spurious associations that can result when neighborhood information and behaviors are self-reported.[24,25]) Community Survey data were collected in 2004 from 5988 persons residing in Baltimore, Forsyth, and New York. The survey collected information on a number of neighborhood-level domains potentially related to cardiovascular disease. Two scales were used in this analysis: suitability of the environment for physical activity and availability of healthy foods. (See Table 1 footnote for list of scale items.) Both scale internal consistency and test-retest reliability were acceptably high (Cronbach $\alpha \geq 0.73$, test-retest 2 weeks postsurvey ≥ 0.60), as previously reported.[23] To derive area characteristics (latitude/longitude) for each residence of participants in The Multi-Ethnic Study of Atherosclerosis, scales were modeled spatially across each study site using spatial error regression. These regression models used supplementary data (2000 US census block group socio-demographic data, InfoUSA Inc. food retailer data,[26,27] and recreational facility data[8]) to improve prediction. Methodologic details of this method are provided elsewhere.[2] The modeled data characterize a 1-mile area around the residence.

Because participants in The Multi-Ethnic Study of Atherosclerosis are not restricted to the 1-mile around their residence, Euclidean distances were computed between their residences and the closest neighborhood with above-median ("good") suitability for physical activity and above-median ("good") availability of healthy foods. Neighborhood resources for the distance measures were derived by applying the spatial error regression model (described above) to a grid of 300 m.[2]

Participants Included in Study

Of the 3265 participants at baseline residing in the 3 study sites, 2963 agreed to participate in the ancillary neighborhood study.[10] Of these persons, 92 were excluded because of address errors and 645 because of missing information on outcome, exposure, or key covariates. Data on the remaining 2226 participants were available for secondary analyses that examined the binary impaired fasting glucose/diabetes variable. In primary analyses that used the continuous homeostasis model assessment index as the outcome, an additional 200 individuals were excluded because they used oral hypoglycemic agents or insulin that would medically alter glucose or insulin levels. This left 2026 participants for analyses. Demographic characteristics of persons included in primary analyses (n = 2026) were similar to excluded persons (n = 1239) except that excluded participants were less likely to be white (32% vs. 45%) and more likely to be African-American (54% vs. 40%); had lower income ($24,000 vs. $28,000 per capita family income) and lower education (12.8 vs. 13.6 years education); and had somewhat higher BMI (29.5 vs. 28.9 kg/m^2). All participants provided written informed consent.

TABLE 1. Person-Level Characteristics and Area-Level Characteristics* for the Full Sample and Stratified by Physical Activity and Healthy Foods Environments† and Distance to a Neighborhood With Good Resources†, Multi-Ethnic Study of Atherosclerosis 2000-2002

	Total Sample	Physical Activity Environment			Healthy Food Environment			Distance to a Neighborhood With Good Resources		
	(n = 2026)	Worst (n = 664)	Intermediate (n = 673)	Best (n = 689)	Worst (n = 670)	Intermediate (n = 662)	Best (n = 694)	Worst (n = 664)	Intermediate (n = 626)	Best (n = 736)
Person-Level Characteristics										
Demographic data										
Age (yrs)	62.2 ± 10	61.7 ± 9.8	62.3 ± 9.7	62.4 ± 10.4	62.2 ± 9.9	61.3 ± 9.8	62.9 ± 10.2	61.9 ± 10	61.6 ± 9.5	62.8 ± 10.3
Female; %	54	55.9	53.3	52.8	54.3	56.1	51.6	57.3	50.7	53.7
Race/ethnicity‡; %										
White	47	32.2	47.2	61.2	34.3	40.1	66.2	33.5	41.2	64.3
African American	37.5	54.9	36.7	21.4	54.6	38.4	19.9	57.6	36.3	20.2
Hispanic	15.5	12.9	16.1	17.3	11.2	21.5	13.9	8.9	22.5	15.5
Family history of diabetes; %	7.5	9.6	6.7	6.1	7.3	9.1	6.1	9.3	7.5	5.7
Socioeconomic status										
Family income ($)	29,000 ± 20,000	25,000 ± 17,000	27,000 ± 7,000	34,000 ± 23,000	26,000 ± 18,000	26,000 ± 17,000	34,000 ± 22,000	25,000 ± 17,000	27,000 ± 18,000	34,000 ± 22,000
Education (yrs)	13.7 ± 3.5	13.2 ± 3.4	13.4 ± 3.5	14.5 ± 3.4	13.2 ± 3.5	13.4 ± 3.6	14.5 ± 3.1	13.4 ± 3.3	13.1 ± 3.8	14.5 ± 3.2
Mediators										
Dietary low-fat milk (servings per day)§	0.7 ± 1.1	0.7 ± 1	0.7 ± 1.1	0.8 ± 1.2	0.6 ± 0.9	0.7 ± 1.0	0.8 ± 1.3	0.6 ± 1.0	0.7 ± 1.0	0.8 ± 1.3
Dietary fiber, per 100 g per day¶	0.2 ± 0.1	0.2 ± 0.1	0.2 ± 0.1	0.2 ± 0.1	0.2 ± 0.1	0.2 ± 0.1	0.2 ± 0.1	0.2 ± 0.1	0.2 ± 0.1	0.2 ± 0.1
Physical activity; %										
Low	24.4	28.4	25.0	20.0	26.3	27.0	20.1	27.3	28.5	18.0
Medium	49.9	49.2	47.9	52.5	52.4	48.2	49.1	50.4	47.0	52.4
High	25.7	22.4	27.1	27.5	21.3	24.8	30.8	22.3	24.5	29.6
Body mass index (kg/m^2)	28.6 ± 5.3	29.4 ± 5.5	28.5 ± 5.2	27.9 ± 4.9	29 ± 5.4	28.9 ± 5.3	28 ± 5	29.3 ± 5.4	28.4 ± 5.1	28.2 ± 5.1
Outcome										
Insulin resistance (Homeostatic Model Assessment index)	1.6 ± 1.4	1.7 ± 1.3	1.6 ± 1.3	1.6 ± 1.5	1.6 ± 1.2	1.7 ± 1.4	1.6 ± 1.5	1.7 ± 1.4	1.6 ± 1.3	1.5 ± 1.4
Median (25–75th percentile)	1.26 (0.79–1.98)									
Impaired fasting glucose or diabetes; %‖	41.4	47.0	40.4	36.8	43.8	42.2	38.2	45.4	40.9	38.0

(*Continued*)

TABLE 1. (*Continued*)

	Total Sample (n = 2026)	Physical Activity Environment: Worst (n = 664)	Physical Activity Environment: Intermediate (n = 673)	Physical Activity Environment: Best (n = 689)	Healthy Food Environment: Worst (n = 670)	Healthy Food Environment: Intermediate (n = 662)	Healthy Food Environment: Best (n = 694)	Distance to a Neighborhood With Good Resources: Worst (n = 664)	Distance to a Neighborhood With Good Resources: Intermediate (n = 626)	Distance to a Neighborhood With Good Resources: Best (n = 736)
Area-Level Variables										
Neighborhood score**										
Neighborhood physical activity resources	3.6 ± 0.3	3.3 ± 0.2	3.6 ± 0.1	4.0 ± 0.2	3.4 ± 0.2	3.6 ± 0.2	3.9 ± 0.3	3.4 ± 0.2	3.6 ± 0.2	3.9 ± 0.3
Neighborhood healthy foods resources	3.3 ± 0.4	3.0 ± 0.3	3.2 ± 0.3	3.6 ± 0.4	2.9 ± 0.2	3.3 ± 0.1	3.8 ± 0.3	2.9 ± 0.3	3.2 ± 0.2	3.7 ± 0.3
Surrounding area (km)††										
Distance to neighborhood with good physical activity resources	0.8 ± 1.1	2 ± 1.2	0.5 ± 0.6	0 ± 0.1	1.6 ± 1.3	0.8 ± 1	0.2 ± 0.4	2 ± 1.3	0.6 ± 0.4	0 ± 0.1
Distance to neighborhood with good healthy foods resources	1.0 ± 1.3	1.9 ± 1.5	0.9 ± 1.1	0.2 ± 0.5	2.3 ± 1.3	0.8 ± 0.9	0 ± 0.1	2.4 ± 1.4	0.7 ± 0.5	0 ± 0.1

*Mean ± SD, unless otherwise indicated.

†Categories were derived from tertiles of the area-level variables. Tertile cutpoints were 3.48 and 3.71 for physical activity environment, at 3.09 and 3.44 for healthy food environment, and 0.42 km and 1.70 km for distance to a neighborhood with good resources. Distance to a neighborhood with good resources was derived from the Euclidean distance to a neighborhood that had above-median environment for both physical activity and healthy foods.

‡The study enrolled Chinese, Caucasian, African-American, and Hispanic participants at 6 field sites. These analyses were restricted to 3 study sites (New York, Baltimore, and Forsyth County) that did not enroll Chinese persons.

§Combined servings per day of skim or low-fat milk, plain or flavored yogurt, and cottage cheese.

¶Total dietary fiber (per 100 g) per day.

‖Unlike the other rows in this table, this variable includes persons treated for diabetes (n = 200), and thus, is based on 2226 participants. Impaired fasting glucose (glucose 100–125 mg/dL) or diabetes (glucose ≥126 mg/dL or being treated for diabetes).

**Neighborhood measures were derived from predicted values of neighborhood scales collected in the Community Survey (see text for more details on the prediction model). The scale for suitability of the environment for physical activity was the mean for 6 items: "My neighborhood offers many opportunities to be physically active"; "Local sports clubs and other facilities in my neighborhood offer many opportunities to get exercise"; "It is pleasant to walk in my neighborhood"; "In my neighborhood it is easy to walk places"; "I often see other people walking in my neighborhood"; and "I often see other people exercise (for example jog, bicycle, play sports) in my neighborhood." The scale for availability of healthy foods was the mean for 3 items: "A large selection of fresh fruits and vegetables is available in my neighborhood"; "The fresh fruits and vegetables in my neighborhood are of high quality"; and "A large selection of low-fat foods is available in my neighborhood." Scales were age- and sex-adjusted, weighted to account for the differential probabilities of selection into the sample, and had a possible range of 1–5. Higher scale values indicate better resources.

††Distances are total Euclidean distances (km) to nearest neighborhood that had good (above-median) levels of neighborhood resources. Median distance (25–75th percentile) for neighborhood resources was 0.3 km (0–1.2) for physical activity and 0.6 km (0–1.5) for healthy foods.

Statistical Analyses

We first examined unadjusted correlations between variables as well as the distribution of individual-level variables by tertiles of neighborhood resources for[1] physical activity,[2] healthy foods, and[3] distance to a neighborhood with both above-median physical activity and healthy foods. Ordinary least squares regression was used to separately estimate adjusted associations of the following variables with insulin resistance: neighborhood resources for physical activity; neighborhood resources for healthy foods; distance to a neighborhood with good resources for physical activity; and distance to a neighborhood with good resources for healthy foods. Analyses controlled for age, sex, family history of diabetes, income, and education. Because it has often been difficult to separate area effects from race/ethnicity effects due to strong spatial patterning by race/ethnic composition,[28] models were examined before and after adjustment for race/ethnicity.

We investigated whether associations differed by household automobile ownership, study site, years of residence in the neighborhood, and shopping for food and exercising within 1 mile of the participant's residence. These variables were thought to potentially modify associations between area features and insulin resistance for the following reasons: persons who have access to transportation (via automobile) may be less confined to their neighborhoods and thus their area effects may be attenuated[29–31]; characteristics of prior neighborhoods may differ from the current neighborhood, which may lead to weaker cross-sectional relationships for residents who had moved into the neighborhood; associations may be weaker for persons who routinely access resources outside the neighborhood reported on by Community Survey participants; study site may signify differences in transportation infrastructure, public investment and commerce, all of which may modify area effects. Heterogeneity of effects were examined using stratified analyses and by including appropriate interaction terms in regression models.

Two approaches were used to examine our secondary hypothesis that individual-level diet, physical activity, and BMI are intermediaries in the pathway between area characteristics and insulin resistance. First, results from the primary analyses were examined before and after adjustment for physical activity, diet, and BMI. We expected that the magnitude of associations between insulin resistance and area features would be attenuated after including these variables. Second, because of the difficulty in estimating direct and indirect effects by controlling for potential mediators,[32] the suspected mediating variables (physical activity, diet, and BMI) also were examined as outcome variables regressed onto area features. When used as outcome variables, physical activity (total hours per day) and diet (mean of servings per day of whole grain/cereal fiber and low-fat diary) were log transformed.

For ease of interpretation, regression results are reported as percent differences for outcomes that were log-transformed [$100 \times$ (exponentiated mean difference -1)] or binary [$100 \times$ (exponentiated prevalence difference -1)]. To compare associations for area level variables that have different units, estimates shown correspond to differences between the 90th and 10th percentiles of the area-level variable [translating to a difference of 1.92 in the physical activity scale, 2.62 in the healthy foods scale, 2.70 km (1.68 miles) in the distance to good physical activity resources, and 2.97 km (1.85 miles) in the distance to good healthy foods resources]. We also computed 95% confidence intervals (CIs) for all multivariable analyses.

Generalized additive models[33] were used to explore nonlinear relations between the independent variables and the outcome variable while adjusting for covariates. There was no evidence of strong threshold effects among the area-level variables and therefore these were fit as continuous variables. Distance measures were square-root-transformed to better model the functional form of their adjusted relation with insulin resistance.

We examined the sensitivity of results to excluding persons treated for diabetes by conducting separate analyses using log binomial regression[34] with the presence of impaired fasting glucose/diabetes as the outcome. We also examined the sensitivity of results to alternate neighborhood measures by aggregating survey responses to census tracts using empirical Bayes estimation[35] and the crude mean. Additional sensitivity analyses used spatial error regression to model residual spatial dependence in models where the homeostasis model assessment index was the outcome.[36]

RESULTS

Descriptive Results

Table 1 shows characteristics of the study sample. Mean neighborhood score was higher for physical activity than for healthy foods (3.6 and 3.3, respectively). Only 22% of study participants resided in a neighborhood that was an above-median environment for physical activity and healthy foods. Participants were relatively close to environments with above-median resources [median distance 0.3 km (0.2 miles) for physical activity and 0.6 km (0.4 miles) for healthy foods] although median distance between residences and neighborhoods that had above-median resources for both characteristics was substantially greater [1.5 km (1.9 miles)]. Living in neighborhoods with better physical activity and healthy food environments or living closer to neighborhoods with favorable environments was associated with white race, lower family history of diabetes, higher income, higher education, lower BMI, generally better physical activity and dietary profiles (except for dietary fiber intake), and lower insulin resistance (Table 1). Study participants traveled a median of 3.5 miles to shop for food and 0.5 miles to exercise (among persons who engaged in physical activity). Participants resided in their neighborhood for a median of 17 years (interquartile range 8–30 years, not shown in tables).

There was only low/moderate correlation between family income and the area-level variables (Pearson $r < 0.25$, bivariate correlations not shown in tables). However, correlations were high (Pearson $r > 0.65$, not shown) between variables for physical activity and healthy food resources, thus prohibiting examination of their independent effects.

Main Associations

Adjusted for age, sex, family history of diabetes, income, and education (column B), insulin resistance was negatively associated with neighborhood resources for physical activity and for healthy foods (Table 2). Improvements in neighborhood resources (corresponding to the difference between 90th and 10th percentiles) were associated with 23% lower insulin resistance for physical activity resources (95% CI = −35% to −8%) and 15% lower for healthy foods resources (CI = −30% to 2%). After adjustment for race/ethnicity (column C), physical activity resources remained robust (−17%; CI = −31% to −1%), however, associations were markedly attenuated for healthy food resources (−6% −22% to 14%).

Insulin resistance also was positively associated with distance to an area with good resources. Distance to resources (corresponding to the difference between the 90th and 10 percentiles) was associated with 10% higher insulin resistance for physical activity resources (1%–18%) and 8% for healthy foods resources (0%–15%), adjusted for age, sex, family history of diabetes, income, and education. Once again, associations were attenuated after adjustment for race/ethnicity.

Potential Mediators

As expected, additional adjustment for person-level physical activity, diet, and BMI reduced associations between insulin resistance and area-level resources (Table 2, column D and E). For example, improvements in neighborhood physical activity environments were associated with 17% lower insulin resistance before adjustment for potential mediators; 11% lower insulin resistance after adding person-level diet and physical activity (CI = −26% to 6%; model 1D), and 1% lower insulin resistance after adding BMI (−15% to 16%; model 1E).

When we examined BMI, physical activity, and diet as outcome variables, we found these outcomes generally were associated with area-level characteristics in the expected directions (Table 3). For example, after adjustment for age, sex, family history of diabetes, income, education, and race/ethnicity (model C), improvements in neighborhood physical activity environments were associated with 2.03 lower BMI (−3.41 to −0.66) and 73% more exercise hours (37%–118%). As expected, associations between area-level variables and BMI were reduced after individual-level physical activity and diet were added to the model (model D). Area-level healthy foods resources were related to better diet, but associations were reduced to null after race/ethnicity was added to the model.

Interactions

Table 4 shows variables for which tests for interactions were $P \leq 0.06$ with either neighborhood or distance to healthy foods. In general, the association between insulin resistance and healthy foods resources was stronger for persons who did not own an automobile, shopped for food within 1 mile of their home, and lived at the New York site. The association between neighborhood physical activity resources and insulin resistance was stronger for persons who exercised within 1 mile of their home [among those who exercised at all, for a change from the 10th to 90th percentiles in neighborhood physical activity resources, insulin resistance decreased 27% (CI = −46% to 0) vs. 39% (−14 to 124) for exercising >1 mile; P for interaction = 0.02]. Associations between physical activity resources and insulin resistance were not modified by automobile ownership or study site (all tests for interaction $P \geq 0.2$). Years in the neighborhood did not modify associations between insulin resistance and healthy food nor physical activity resources (all tests for interaction $P \geq 0.1$).

Sensitivity Analyses

Results were similar when participants treated for diabetes were included in analyses—using impaired fasting glucose/diabetes in place of the homeostasis model as a measure of insulin resistance (Table 5; n = 2226). For example, adjusted for age, sex, family history of diabetes, race/ethnicity, income and education (column B), the prevalence was 21% lower (−41% to 6%) with improvements in physical activity resources and 17% higher (4%–31%) with farther distances to a neighborhood with good physical activity resources.

Spatial dependence statistics indicated no statistically significant dependence among model residuals[37] and spatial autocorrelation models yielded similar results, although CIs were wider. The direction of associations between insulin resistance and neighborhood resources remained the same when two-mile averages and tract-level aggregations were used in place of spatial interpolation estimates, even though CI widths changed (wider for physical activity resources and narrower for healthy foods, not shown).

DISCUSSION

In this cross-sectional study, insulin resistance was negatively associated with suitable residential environments for physical activity and for purchasing healthy foods. Associations between insulin resistance and physical activity environments persisted after adjustment for individual level-variables. For example, adjusted for age, sex, family history of diabetes, race/ethnicity, income and education, insulin

TABLE 2. Percent Differences in Insulin Resistance* for a Change Between the 90th and 10th Percentile in Area-Level Characteristics, Adjusted for Person-Level Covariates (n = 2026)

Model No.	Area-Level Variables	Expected Sign of the Association	Person-Level Covariates % Difference (95% CI) A: No Person-Level Covariates	B: Age, Sex, Family History, Income, Education	C: Age, Sex, Family History, Income, Education, Race/Ethnicity	D: Age, Sex, Family History, Income, Education, Race/Ethnicity, Physical Activity, Diet†	E: Age, Sex, Family History, Income, Education, Race/Ethnicity, Physical Activity, Diet†, Body Mass Index
1	Neighborhood physical activity resources	−	−32 (−42 to −19)	−23 (−35 to −8)	−17 (−31 to −1)	−11 (−26 to 6)	−1 (−15 to 16)
2	Neighborhood healthy foods resources	−	−25 (−38 to −11)	−15 (−30 to 2)	−6 (−22 to 14)	−1 (−18 to 20)	5 (−11 to 24)
3	Distance to a neighborhood with good physical activity resources‡	+	15 (6 to 24)	10 (1 to 18)	6 (−2 to 15)	4 (−4 to 12)	2 (−5 to 9)
4	Distance to a neighborhood with good healthy foods resources‡	+	12 (4 to 21)	8 (0 to 16)	3 (−5 to 11)	1 (−7 to 9)	0 (−6 to 7)
	Model fit: adjusted R-squared§		<0.01	0.02	0.03	0.06	0.28

*Insulin resistance measured as the homeostasis model assessment index, derived from the following formula: [fasting insulin (μU/mL) × fasting glucose (mmol/L)]/22.5.
†Continuous dietary variables (total dietary fiber and servings per day of low-fat dairy) were adjusted for caloric intake.
‡Distance variables are the Euclidean distance to the nearest neighborhood that has good (above-median) levels of neighborhood resources.
§Adjusted model R-squared differed only with progressive adjustment shown in the columns; it was identical across rows.

TABLE 3. Mean Differences in Body Mass Index, Percent Differences in Hours per Day of Exercise and in a Favorable Diet Index per Change Between the 90th and 10th Percentiles in Area-Level Characteristics, Adjusted for Person-Level Covariates (n = 2026), Multi-Ethnic Study of Atherosclerosis, 2000–2002

Model No.	Area-Level Variables	Expected Sign of the Association	Person-Level Covariates: A — No Person-Level Covariates	B — Age, Sex, Family History of Diabetes, Income, Education	C — Age, Sex, Family History of Diabetes, Income, Education, Race/Ethnicity	D — Age, Sex, Family History of Diabetes, Income, Education, Race/Ethnicity, Physical Activity, Diet*
			Outcome is Body Mass Index (kg/m²)			
			Mean Difference (95% CI)	Mean Difference (95% CI)	Mean Difference (95% CI)	Mean Difference (95% CI)
Model 1	Neighborhood physical activity resources	−	−4.16 (−5.44 to −2.88)	−3.34 (−4.67 to −2.02)	−2.03 (−3.41 to −0.66)	−1.35 (−2.71 to 0.01)
Model 2	Neighborhood healthy foods resources	−	−3.40 (−4.79 to −2.01)	−2.57 (−3.98 to −1.15)	−0.93 (−2.39 to 0.53)	−0.42 (−1.87 to 1.02)
Model 3	Distance to a neighborhood with good physical activity resources	+	1.27 (0.69 to 1.84)	0.94 (0.35 to 1.52)	0.35 (−0.25 to 0.94)	0.08 (−0.51 to 0.67)
Model 4	Distance to a neighborhood with good healthy foods resources	+	1.13 (0.56 to 1.69)	0.83 (0.26 to 1.40)	0.07 (−0.52 to 0.67)	−0.13 (−0.72 to 0.45)
			Outcome is Hours Per Day of Exercise†			
			% Difference (95% CI)	% Difference (95% CI)	% Difference (95% CI)	
Model 1	Neighborhood physical activity resources	+	86 (50 to 130)	68 (35 to 110)	73 (37 to 118)	
Model 3	Distance to a neighborhood with good physical activity resources	−	−17 (−24 to −9)	−14 (−22 to −5)	−14 (−22 to −5)	
			Outcome is Favorable Diet Index‡			
			% Difference (95% CI)	% Difference (95% CI)	% Difference (95% CI)	
Model 2	Neighborhood healthy foods resources	+	12 (3 to 21)	8 (0 to 18)	−2 (−10 to 7)	
Model 4	Distance to a neighborhood with good healthy foods resources	−	−6 (−9 to −3)	−6 (−9 to −2)	−2 (−5 to 2)	

*When the outcome was BMI and dietary variables were used as adjustment-variables, dietary variables were total dietary fiber (a continuous variable) and servings per day of low-fat dairy. These models were adjusted for caloric intake.

†Total exercise hours per day derived from metabolic equivalent task-minutes for walking and moderate and vigorous intensity sports and conditioning activities. Hours per day of exercise was log-transformed.

‡When used as an outcome variable, the dietary index was the log-transformed mean of 2 dietary variables: servings per day of low-fat dairy (low-fat milk, yogurt, cottage cheese) and servings per day of whole grains/cereal fiber. These models also adjusted for caloric intake.

TABLE 4. Stratified Percent Differences in Insulin Resistance* for a Difference Between the 90th and 10th Percentile in Neighborhood Resources for Healthy Foods and for Distance to a Neighborhood With Good Resources for Healthy Foods

		Neighborhood Healthy Foods†		Distance to a Neighborhood With Good Healthy Foods Resources‡	
	No.	% Difference (95% CI)	P for Interaction§	% Difference (95% CI)	P for Interaction§
Pooled estimate	2026	−6 (−22 to 14)		3 (−5 to 11)	
Stratification variables					
Automobile ownership					
No	428	−18 (−47 to 27)	0.60	30 (5 to 61)	0.04
Yes	1589	−6 (−25 to 18)		0 (−8 to 9)	
Shop for food within 1 mile of residence					
No	1064	7 (−19 to 42)	0.07	−2 (−12 to 9)	0.05
Yes	962	−17 (−38 to 12)		10 (−3 to 25)	
Study site					
Baltimore, MD	659	9 (−28 to 65)	0.06	−8 (−22 to 7)	0.10
Forsyth County, NC	682	19 (−14 to 65)		0 (−11 to 13)	
Northern Manhattan and Bronx, NY	685	−34 (−54 to −4)		21 (1 to 44)	

*Insulin resistance measured as the homeostasis model assessment index, derived from the following formula: [fasting insulin (μU/mL) × fasting glucose (mmol/L)]/22.5. All analyses adjusted for age, sex, family history of diabetes, income, education, and race/ethnicity.
†Expected a negative association.
‡Expected a positive association.
§*P* values for interactions tested whether the interaction parameter in regression was different from zero.

TABLE 5. Percent Differences in Prevalence of Impaired Fasting Glucose/Diabetes* for a Change Between the 90th and 10th Percentile in Area-Level Characteristics, Adjusted for Person-Level Covariates (n = 2226)

		Person-Level Covariates % Difference (95% CI)				
		A	B	C	D	E
Model No.	Area-Level Variables	No Person-Level Covariates	Age, Sex, Family History, Income, Education	Age, Sex, Family History, Income, Education, Race/ Ethnicity	Age, Sex, Family History, Income, Education, Race/ Ethnicity, Physical Activity, Diet†	Age, Sex, Family History, Income, Education, Race/ Ethnicity, Physical Activity, Diet,† Body Mass Index
1	Neighborhood physical activity resources‡	−39 (−54 to 17)	−28 (−45 to −4)	−21 (−41 to 6)	−14 (−36 to 17)	−6 (−30 to 27)
2	Neighborhood healthy foods resources‡	−26 (−45 to 1)	−11 (−33 to 20)	5 (−23 to 43)	10 (−20 to 50)	22 (−10 to 64)
3	Distance to a neighborhood with good physical activity resources§¶	29 (14 to 46)	20 (7 to 34)	17 (4 to 31)	15 (2 to 30)	14 (2 to 27)
4	Distance to a neighborhood with good healthy foods resources§¶	17 (4 to 32)	9 (−3 to 22)	2 (−9 to 15)	0 (−11 to 13)	3 (−7 to 14)

*Results from log binomial regression where the outcome variable is impaired fasting glucose (glucose 100-125 mg/dL) or diabetes (glucose ≥126 mg/dL and/or being treated for diabetes).
†Continuous dietary variables (total dietary fiber and servings per day of low-fat dairy) were adjusted for caloric intake.
‡Expected a negative relationship.
§Expected a positive relationship.
¶Distance variables are the Euclidean distance to the nearest neighborhood that has good (above-median) levels of neighborhood resources.

resistance was 17% lower per increase from the 10th to 90th percentile in neighborhood physical activity resources (CI = −31% to −1%). Neighborhood healthy food resources were similarly inversely associated with insulin resistance although the association was attenuated after adjustment for race/ethnicity. Results also suggested that individual-level diet and physical activity mediate the observed associations, both directly and via obesity (BMI). Residing farther from area resources was also associated with insulin resistance, although associations were weaker than for the neighborhood measures.

The magnitude of the association observed (eg, 17% lower insulin resistance with improvements in the physical activity environment) roughly is equivalent to a cross-sectional increase in insulin resistance associated with a 2.4 kg/m^2 decrease in BMI in this sample. A 1-unit increase in BMI (from 25 to 26 kg/m^2) has been associated with at least a 14% increased risk of diabetes over a 20-year period.[38] These results suggest that residing within or near zones where people can engage in physical activity may be protective of insulin resistance and, conversely, the absence of these resources may promote insulin resistance. Based on the items measured in the physical activity scale, the health benefits we observed could be due to factors that promote walking (eg, having walking destinations and a pleasing environment for walking) and availability of facilities such as sports clubs and other places to exercise. These findings are consistent with prior work that documented positive associations between physical activity and neighborhood density of facilities for physical activity,[7,8] having walking destinations,[6,39] and a pleasant/attractive environment.[40–42]

Based on the items measured in the healthy foods scale, associations between insulin resistance and availability of healthy foods could be due to the presence of high quality fruits and vegetables and low-fat foods. There is growing evidence that availability and quality of healthy foods is not uniform throughout residential environments[27,43] and that availability of good quality fresh foods promotes healthy food choices.[44] Associations with insulin resistance were weaker for healthy food environments than for physical activity environments, but a direct comparison of the 2 exposures is limited due to greater measurement error in the healthy foods resource scale. The healthy foods scale comprised only 3 items (compared with 6 for physical activity) and did not include the range of foods potentially protective of insulin resistance (such as availability/quality of whole-grain foods). Additionally, most study participants reported food-shopping far outside of the 1 mile neighborhood about which residential survey participants had reported. Generally, our stratified results (shopped for food within 1 mile and not owning an automobile) suggested that neighborhood resources for healthy foods had a stronger relationship with insulin resistance when persons were less mobile or unwilling to travel far distances to shop for healthy foods.

There was no evidence that site confounded the relationship between area-resources and insulin resistance (results were the same before and after site-adjustment, not shown). However, associations between insulin resistance and healthy food resources differed by study site—possibly due to site differences in scale and transportation. The magnitude of the healthy foods effect was strongest for residents in New York, where participants reporting shopping for food close to their home and not owning an automobile. Associations did not differ by study site for physical activity resources.

The relationship between area characteristics and insulin resistance likely involves multiple pathways. Teasing apart specific mediating pathways is difficult because of the distal relationships and time lags involved, as well as problems inherent in separating direct and indirect effects in regression analyses.[32,45] Nevertheless, our results suggest that diet, physical activity, and BMI are mediating variables in the association between area resources and insulin resistance. Associations were attenuated after adjustment for diet and physical activity, and were greatly reduced after adjustment for BMI. In addition, area resources were associated with BMI, person-level physical activity, and diet. Direct physiologic consequences of adiposity are manifested by the high correlation between BMI and insulin resistance.[46] BMI is most proximal to insulin resistance in the causal chain leading from area features, through behaviors, to insulin resistance. Thus, it is not surprising that BMI appeared to be the strongest mediator in the pathways we examined between area resources and insulin resistance. In addition, BMI may have accounted for unmeasured aspects of individual-level behaviors or other (unmeasured) pathways that influence insulin resistance.

All estimates of area effects were weakened after adjustment for race/ethnicity (over and above person-level age, sex, income, and education). Whether area-effects should or should not be adjusted for race/ethnicity is debatable. There are several ways through which race/ethnicity may be related to insulin resistance: cultural traditions and preferences that relate to diet and physical activity, genetic influences, or socioeconomic status that can determine residential location.[47–50] Because neighborhoods are segregated by income and race/ethnicity, it may be difficult or impossible to isolate the independent effects of area resources and race/ethnicity,[51–53] and thus, adjustment for race/ethnicity could result in underestimation of area effects.

A main strength of this study is its ability to test specific processes through which neighborhood factors may influence health. In contrast to past studies that used census socioeconomic data to characterize areas, our data allowed testing of specific hypotheses that link residential environments with biologic processes. For example, a recent study reported positive associations between insulin resistance and living far from a high-income neighborhood.[54] Our study provides some evidence that those associations could be due to high-income areas having more resources for physical activity and better availability of healthy foods. In contrast to existing work that has used "objectively" measured resources to characterize areas (eg, proximity to parks and food stores[8,41,55,56]), our survey data represented the "lived" experience of residents. Survey items included neighborhood safety and access to and quality of resources—thereby representing multiple dimensions of the ways residential environments may impact health.

Another strength of this study is the large population-based, multiethnic sample. However, exclusion criteria may have resulted in underestimates of associations if excluded persons were more likely to be both insulin resistant and live in lower-resource areas. By design, persons with a history of clinical cardiovascular disease (a condition associated with insulin resistance) were excluded. Persons excluded during analyses due to missing information had higher BMI (likely more insulin resistant) and were more demographically disadvantaged (potentially more likely to live in lower-resource areas). Additionally, because we were interested in predictors of early manifestations of insulin resistance (before the process becomes clinically symptomatic) the main analyses excluded persons treated for diabetes; however, results were generally insensitive to this exclusion (assessed by using impaired fasting glucose/diabetes in place of the homeostasis index as a measure of insulin resistance). Alternately, self-selection into neighborhoods could account for some of the observed results (eg, active individuals tend to self-select themselves into neighborhoods that are suitable for being physical active).[6,57] Because the ability of persons to choose their neighborhood likely depends on income and race/ethnicity, we attempted to minimize self-selection by adjusting the multivariable model for person-level characteristics. Finally, because this is a cross-sectional study, we cannot determine whether exposure to area features preceded the development of insulin resistance. Insulin resistance likely develops slowly over a long period,[38] making long-term chronic exposures more relevant than current exposures.

Type 2 diabetes and metabolic abnormalities are becoming more common. This makes it all the more urgent to identify environmental features that may improve diet and physical activity, which in turn may reduce the risk of type 2 diabetes. If the availability of healthy foods and attractive walking destinations can in fact improve insulin resistance, such environmental features may offer an effective health intervention at the neighborhood level.

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