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## Original Contribution

# Relation between Neighborhood Environments and Obesity in the Multi-Ethnic Study of Atherosclerosis

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This study investigated associations between neighborhood physical and social environments and body mass index in 2,865 participants of the Multi-Ethnic Study of Atherosclerosis (MESA) aged 45–84 years and residing in Maryland, New York, and North Carolina. Neighborhood (census tract) environments were measured in non-MESA participants residing in MESA neighborhoods (2000–2002). The neighborhood physical environment score combined measures of a better walking environment and greater availability of healthy foods. The neighborhood social environment score combined measures of greater aesthetic quality, safety, and social cohesion and less violent crime. Marginal maximum likelihood was used to estimate associations between neighborhood environments and body mass index (kg/m$^2$) before and after adjustment for individual-level covariates. MESA residents of neighborhoods with better physical environments had lower body mass index (mean difference per standard deviation higher neighborhood measure = −2.38 (95% confidence interval (CI): −3.38, −1.38) kg/m$^2$ for women and −1.20 (95% CI: −1.84, −0.57) kg/m$^2$ for men), independent of age, race/ethnicity, education, and income. Attenuation of these associations after adjustment for diet and physical activity suggests a mediating role of these behaviors. In men, the mean body mass index was higher in areas with better social environments (mean difference = 0.52 (95% CI: 0.07, 0.97) kg/m$^2$). Improvement in the neighborhood physical environment should be considered for its contribution to reducing obesity.

atherosclerosis; body mass index; obesity; residence characteristics; social environment

Abbreviations: AHEI, Alternate Healthy Eating Index; CI, confidence interval; MESA, Multi-Ethnic Study of Atherosclerosis; MMLE, marginal maximum likelihood estimation; SD, standard deviation.

High prevalences of overweight and obesity in the United States have been repeatedly documented (1, 2). Features of living environments may contribute to obesity (3, 4). However, the relation of environmental factors to obesity remains

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understudied in part because of difficulties in defining and measuring environments. Several studies linking environmental features to obesity have investigated associations of neighborhood disadvantage with obesity (5–13). These studies have often found that living in disadvantaged neighborhoods is associated with a greater prevalence of obesity or higher body mass index.

The use of indicators of neighborhood socioeconomic position as the neighborhood measure of interest poses several limitations (14–16). Neighborhood socioeconomic position is a rough proxy for more relevant neighborhood features. The use of neighborhood socioeconomic position raises methodological challenges in estimating neighborhood effects independent of individual-level socioeconomic position. Most importantly, neighborhood socioeconomic position measures do not index specific pathways by which neighborhoods may impact obesity. Potential pathways include access to resources conducive to physical activity and healthy eating, unsafe environments that discourage physical activity, and chronic neighborhood stressors that lead to unhealthy eating (as a coping mechanism) or affect body composition through stress processes. Elucidating these pathways is important for drawing causal inferences and for developing interventions.

Although some studies have investigated associations between features of the physical environment (such as urban design, transportation, and access to health-promoting facilities) and obesity (7, 17–26), few studies have measured specific features of neighborhood social environments (27–29) or have simultaneously assessed both physical and social environments in relation to obesity (17, 20). Using data from the Multi-Ethnic Study of Atherosclerosis (MESA), we examined cross-sectional associations between neighborhood environments and body mass index. We hypothesized that neighborhood physical environments (more availability of healthy foods and better walking environments) and social environments (more safety and social cohesion, less violent crime) would be inversely associated with body mass index, independent of individual-level confounders. Additionally, we hypothesized that these associations would be mediated by diet and physical activity.

## MATERIALS AND METHODS

### Study population

MESA is a study of the determinants of subclinical cardiovascular disease. Participants aged 45–84 years, free from clinical cardiovascular disease at baseline, were recruited between 2000 and 2002 from six study sites. Each site recruited participants from locally available sources (lists of residents, list of dwellings, telephone exchanges) (30). The participation rate for those screened and eligible was 59.8 percent. These analyses are restricted to those persons who participated in the MESA Neighborhood Study, an ancillary study to MESA, had geocoded residential addresses available at baseline, and resided within three of the six study sites (New York, New York; Baltimore, Maryland; and Forsyth County, North Carolina) for which additional neighborhood-level data were available. All analyses reported are based on data collected as part of the baseline examination between 2000 and 2002.

### Individual-level measures

Weight and height measurements were obtained during the MESA baseline examination. Body mass index was calculated as weight (kg)/height $(m)^2$. We obtained information via questionnaire on sociodemographic factors, diet, and physical activity. Demographic variables included age, gender, race/ethnicity (White, non Hispanic; African American, non-Hispanic; Hispanic), education (less than high school, high school diploma, some college/technical school, college graduate and beyond), income (<\$20,000, \$20,000–<\$40,000, \$40,000–<\$75,000, \$75,000 or more), and time lived in neighborhood (<20 years, 20 or more years). Diet was measured via a 120-item food frequency questionnaire adapted from the Insulin Resistance Atherosclerosis Study previously validated in multiethnic populations (31, 32). We investigated two measures of diet: total calorie intake (kilocalories) and the Alternate Healthy Eating Index (AHEI) (33). The AHEI is a summary measure of dietary patterns and eating behaviors based on established guidelines (33, 34). The index ranges from 2.5 to 87.5, and higher scores indicate a better quality diet (higher intake of fruits, vegetables, soy, protein, white meat, cereal fiber, polyunsaturated fat, and multivitamins and lower intake of alcohol, saturated fat, and red meat). Physical activity was measured by an activity questionnaire adapted from the Cross-Cultural Activity Participation Study (35). The physical activity measure investigated was intentional activity measured in metabolic equivalent (MET)-hours/day. Higher scores indicate higher levels of moderate (walking, exercising, conditioning, dancing, individual activities) and vigorous (team or dual sports, conditioning) activities.

### Neighborhood-level measures

Through random digit dialing, we identified a sample of 5,988 non-MESA participants who resided in the same neighborhoods (census tracts) as the MESA participants (median of eight respondents per neighborhood; range: 1–62). The respondents to this survey (referred to as the community survey) served as informants of neighborhood conditions in the MESA neighborhoods. The community survey sample was approximately representative of the areas from which it was drawn (36).

Community survey respondents were asked to respond to items on neighborhood dimensions potentially relevant to cardiovascular risk, by referring to the area 1 mile (1.6 km) surrounding their home (36). We assessed six neighborhood dimensions: aesthetic quality (five items), walking environment (seven items), availability of healthy foods (three items), safety (three items), violent crime (four items), and social cohesion (four items). Scale items were adapted from published work whenever possible (25, 37–41). Respondents were asked their agreement with items on a 5-point Likert scale (1 = strongly agree to 5 strongly disagree) with the exception of the items for violent crime that ranged from 1 to 4 (1 = often to 4 = never). Scales had good internal consistency (Cronbach's $\alpha = 0.75$, 0.73, 0.78, 0.77, 0.83, and 0.74 for aesthetic quality, walking environment, availability of healthy foods, safety, violent crime, and social cohesion, respectively) and 2-week test-retest reliabilities (intraclass correlation coefficient = 0.83, 0.60, 0.69, 0.88, 0.72, and 0.65, respectively) (36).

We entered the six scores for each person in a factor analysis with oblique rotation. We identified two factors that account for 73 percent of the variation in the data. Factor 1, which we refer to as the social environment, combines aesthetic quality, safety, violent crime, and social cohesion (accounts for 54.3 percent of the variance). Factor 2, which we refer to as the physical environment, combines walking environment and availability of healthy foods (accounts for 18.9 percent of the variance). Although aesthetic quality can be considered a measure of the physical environment, in our data it correlated better with measures of safety, violent crime, and social cohesion. We created factor-based scores for physical and social environments by summing the respective scales within each factor. We did not weight scales by their respective factor loadings, because all factor loadings were comparable (physical environment loadings: 0.79, 0.87; social environment loadings: 0.75–0.85). The two scales were only moderately correlated ($r = 0.42$). We use gender-specific standardized scores in all analyses by subtracting the mean (physical environment means = 6.97/6.98 and social environment means = 12.92/13.09 for women/men, respectively) and dividing by the standard deviation (physical = 0.83/0.81 and social = 1.93/1.86 for women/men, respectively). Higher scores represent better physical and social environments.

We used census tracts as proxies for neighborhoods on the basis of prior work indicating that there is good agreement across individuals residing within the same census tracts for our neighborhood measures of interest (36). Because there is no absolute metric for the neighborhood scores, we report associations for a difference equivalent to a 1-standard deviation unit in each neighborhood scale. A limitation of this approach is that similarly constructed measures may not have the same standard deviation in other samples. Nevertheless, this approach remains useful for quantifying the strength of the associations in our sample.

### Statistical analysis

We examined the bivariate associations between neighborhood physical and social environments and the sociodemographic characteristics of MESA participants. In these analyses, each MESA participant's neighborhood (census tract) was characterized by taking the mean of the person-level factor scores of all community survey respondents within the tract.

Testing our hypotheses regarding associations between neighborhood physical and social environments and body mass index requires estimating coefficients in the following model:

$$E(Y_{ij} | \theta_{j\text{physical}}, \theta_{j\text{social}}, X_{ij})_{ij} = \beta_0 + \beta_1 \theta_{j(\text{physical})} + \beta_2 \theta_{j(\text{social})} + \beta_3 X_{ij}, \quad (1)$$

where $Y_{ij}$ is body mass index for person $i$ in neighborhood $j$, $\theta_{j\ (\text{physical})}$ is the true physical environment score for neighborhood $j$, $\theta_{j\ (\text{social})}$ is the true social environment score for neighborhood $j$, and $X_{ij}$ is a vector of covariates for individual $i$ in neighborhood $j$.

Note that the estimate of the true characteristic, $\hat{\theta}_j$, derived by taking the mean of the responses of the community survey participants is subject to sampling variability (measurement error); that is,

$$\theta_j = \hat{\theta}_j + \varepsilon_j, \quad (2)$$

where $\varepsilon_j$ is random error resulting from use of an estimate based on a sample of residents that may be small in some neighborhoods. Traditional approaches such as multilevel models that directly use $\hat{\theta}_j$ in equation 1 ignore the sampling variability in this estimate of the true neighborhood characteristic and may therefore yield biased estimates of the regression coefficients of interest.

We used marginal maximum likelihood estimation (MMLE) methods to estimate the parameters in equation 1. MMLE simultaneously models data from the community survey and the MESA sample. Thus, MMLE allows for incorporation of the additional source of random error in the neighborhood-level predictors due to the sampling variability in the community survey responses. This approach also accounts for residual correlation between outcomes within neighborhoods (42). We use MMLE to provide estimates of associations between body mass index and neighborhood environments before and after adjustment for a series of individual-level factors (age, race/ethnicity, education, income, time lived in neighborhood, total calorie intake, AHEI diet, and total physical activity). Age squared was retained in the models based on exploratory analyses that suggested a nonlinear relation between age and body mass index. We also tested for interactions between neighborhood physical and social environments and all sociodemographic measures. Statistically significant interactions between gender and neighborhood variables were present ($p$ value for interaction between physical environment and gender and social environment and gender $< 0.001$), so all analyses were stratified by gender. We also tested for heterogeneity across study site by including appropriate interactions terms in regression models. We found no evidence of significant heterogeneity across sites ($p$ values for additive interaction = 0.70 for study site and physical environment and 0.99 for study site and social environment).

For a sensitivity analysis, we used propensity score matching methods to create propensity scores for living in the lowest category of neighborhood environment compared with the highest category (43, 44). For physical environment, we modeled the odds of living in the lowest tertile (based on mean tract values) compared with the highest tertile (based on the mean scores for the tract) as a function of age, education, income, and race/ethnicity. We ran similar models for social environment. Individuals were matched (highest to lowest tertile) by use of the propensity score distance method (45, 46). This matching process identified 283/234 pairs for physical/social environment for females and 193/174 pairs for physical/social environment for

**TABLE 1. Selected characteristics of the 2,865 participants included in the analyses by gender, Multi-Ethnic Study of Atherosclerosis, 2000–2002**

| | Overall (no.) | Female* (%) | Male* (%) |
|---|---|---|---|
| Study site | | | |
| North Carolina | 905 | 31.2 | 32.0 |
| New York | 983 | 35.3 | 33.2 |
| Maryland | 977 | 33.5 | 34.8 |
| Age, years† | 2,865 | 62.1 (10.01) | 62.6 (9.96) |
| Categorized age, years | | | |
| 45–54 | 791 | 28.8 | 26.2 |
| 55–64 | 801 | 28.1 | 27.8 |
| 65–74 | 893 | 30.1 | 32.5 |
| 75–84 | 380 | 13.0 | 13.5 |
| Race/ethnicity | | | |
| Hispanic | 462 | 16.1 | 16.2 |
| African American | 1,205 | 44.2 | 39.5 |
| Caucasian | 1,198 | 39.7 | 44.3 |
| Income, US $ | | | |
| <20,000 | 584 | 24.9 | 14.9 |
| 20,000–<40,000 | 805 | 31.8 | 23.7 |
| 40,000–<75,000 | 871 | 27.8 | 33.5 |
| ≥75,000 | 605 | 15.5 | 27.9 |
| Education | | | |
| Less than high school | 414 | 14.5 | 14.3 |
| Completed high school/GED‡ | 584 | 22.5 | 17.9 |
| Some college/technical school | 857 | 33.0 | 26.2 |
| Bachelor's/graduate degree | 1,010 | 30.0 | 41.6 |
| Body mass index, kg/$m^2$†,§ | 2,865 | 29.7 (6.3) | 28.3 (4.3) |
| Alternative Healthy Eating Index, score† | 2,489 | 43.4 (11.6) | 42.7 (11.3) |
| Energy intake, calories/day†,§ | 2,489 | 1,500 (790) | 1,900 (880) |
| Total intentional activity, MET‡-hours/day†,§ | 2,489 | 3.5 (5.41) | 4.8 (7.63) |

* Of the 2,865 participants, 1,565 were females and 1,300 were males.

† Mean (standard deviation) provided instead of %.

‡ GED, general equivalency diploma; MET, metabolic equivalent.

§ Based on restricted sample of 1,354 females and 1,135 males.

males. Matched paired *t* tests were used to test for differences in body mass index between individuals in the highest and lowest tertiles of the matched sets.

## RESULTS

Of the 3,265 individuals in the three study sites, 2,865 were geocoded and had complete information on key covariates of interest. Mediation analyses were further restricted to 2,489 participants because of missing information on diet and physical activity. Table 1 shows the distribution of sociodemographic factors, diet, physical activity, and body mass index by gender. The majority of the sample was female (55 percent), the mean age was 62.4 (standard deviation (SD) = 10) years, and 41.8, 42.1, and 16.1 percent were White, African American, and Hispanic, respectively. The mean body mass index was 29.7 (SD = 6.3) kg/$m^2$ and 28.3 (SD = 4.3) kg/$m^2$ for females and males.

All sociodemographic factors (excluding age) were associated with neighborhood environments (all *p*s $< 0.001$) (table 2). African Americans lived in neighborhoods with worse physical environments, followed by Hispanics and Whites. Hispanics lived in neighborhoods with worse social environments, followed by African Americans and Whites. Higher levels of education and income were associated with better neighborhood environments for both men and women. Residents of North Carolina lived in neighborhoods with the worst average physical environments, and residents of New York lived in neighborhoods with the worst average social environments. The intraneighborhood correlation coefficient for body mass index (before adjustment

**TABLE 2. Mean neighborhood environment scores by sociodemographic characteristics of participants, Multi-Ethnic Study of Atherosclerosis, 2000–2002*,†**

| | Physical environment | | Social environment | |
|---|---|---|---|---|
| | Female | Male | Female | Male |
| Age, years | | | | |
| 45–54 | −0.08 | −0.04 | −0.13 | −0.02 |
| 55–64 | −0.02 | 0.00 | 0.01 | 0.09 |
| 65–74 | 0.00 | 0.01 | 0.00 | 0.10 |
| 75–84 | 0.09 | 0.18 | −0.11 | 0.05 |
| $p_{\text{trend}}$ | 0.24 | 0.11 | 0.09 | 0.30 |
| Race | | | | |
| Hispanic | 0.05 | 0.03 | −0.88 | −0.92 |
| African American | −0.34 | −0.31 | −0.17 | −0.02 |
| Caucasian | 0.32 | 0.31 | 0.41 | 0.49 |
| $p$ value | <0.0001 | <0.0001 | <0.0001 | <0.0001 |
| Income, US $ | | | | |
| <20,000 | −0.24 | −0.23 | −0.41 | −0.56 |
| 20,000–<40,000 | −0.05 | −0.17 | −0.16 | −0.24 |
| 40,000–<75,000 | 0.05 | −0.02 | 0.09 | 0.21 |
| ≥75,000 | 0.30 | 0.36 | 0.52 | 0.45 |
| $p_{\text{trend}}$ | <0.0001 | <0.0001 | <0.0001 | <0.0001 |
| Education | | | | |
| Less than high school | −0.18 | −0.24 | −0.52 | −0.69 |
| Completed high school | −0.17 | −0.13 | −0.15 | −0.05 |
| Some college/technical school | −0.02 | −0.09 | −0.02 | 0.08 |
| Bachelor's/graduate degree | 0.19 | 0.24 | 0.22 | 0.35 |
| $p_{\text{trend}}$ | <0.0001 | <0.0001 | <0.0001 | <0.0001 |
| Site | | | | |
| North Carolina | −0.11 | −0.11 | 0.74 | 0.81 |
| New York | 0.14 | 0.20 | −0.81 | −0.73 |
| Maryland | −0.09 | −0.03 | 0.01 | 0.12 |
| $p$ value | <0.0001 | <0.0001 | <0.0001 | <0.0001 |

* Of the 2,865 participants, 1,565 were females and 1,300 were males.

† $p$ values obtained by analysis of variance. $p_{\text{trend}}$ obtained by including ordinal variables as a continuous variable in the regression models.

for any individual-level variables) was 0.07 for females and males.

Tables 3 and 4 show associations between body mass index and neighborhood environments before and after adjustment for individual-level factors. Estimates represent differences in mean body mass index for a 1-standard deviation increase in neighborhood scores. Individuals who resided in better physical environments had a lower mean body mass index (estimate = −2.38 (95 percent confidence interval (CI): −3.38, −1.38) for females and −1.20 (95 percent CI: −1.84, −0.57) for males) than those residing in worse environments, after adjustment for age and social environment (model 1). These associations were weakened but remained statistically significant after additional adjustments for education and income (model 2), race/ethnicity (model 3), and race/ethnicity, education, and income (model 4) for both females and males (model 4 estimate = −1.06 (95 percent CI: −1.36, −0.12) for women and −0.73 (95 percent CI: −1.36, −0.10) for men). Associations were generally stronger for females than for males.

Associations between neighborhood social environments and body mass index were less consistent. In women, a higher social environment score was associated with lower body mass index in age-adjusted models, but confidence intervals were wide and point estimates were close to the null value after adjustment for individual-level factors (table 3). Conversely, statistically significant associations between the social environment and body mass index were present for men in the unexpected direction (table 4). For example, men who resided in better social environments had a higher mean body mass index (estimate = 0.52 (95 percent CI: 0.07, 0.97)) than those residing in worse environments, after adjustment for age and physical environment (model 1). These results persisted after control for race/ethnicity, education, and income (model 4 estimate = 0.65 (95 percent CI: 0.18, 1.13)). Estimates were approximately similar when components of the social environment scale were investigated separately (model 4 point estimates = 0.56, 0.29, 0.62, and 0.72 for aesthetic quality, safety, violent crime, and social cohesion, respectively). Results for physical and social environments were similar when income was adjusted for by use of 12 categories instead of four.

There was some evidence that associations between the physical environment and body mass index are mediated at least in part through diet and physical activity (tables 3 and 4). The mean change in body mass index decreased from −1.06/−0.73 (females/males) in model 4, which controls for age, race/ethnicity, income, and education, to −0.69/−0.44 (females/males) in model 5, which additionally controls for total energy intake, AHEI, and total intentional activity. Additionally, associations between the physical environment and body mass index are no longer statistically significant in model 5. Of the 10 interactions tested between neighborhood measures (physical and social environments) and each of age, race/ethnicity, education, income, and time lived in neighborhood, we found no statistically significant interactions (all $p > 0.10$). Propensity score results were similar in direction, except for the physical environment in men for which no association was observed. The mean differences in body mass index between individuals in the top versus bottom tertile were −1.59 (95 percent CI: −2.55, −0.62) and −0.04 (95 percent CI: −0.81, 0.74) for physical environment and −0.38 (95 percent CI: −1.78, 1.03) and 1.00 (95 percent CI: 0.05, 1.96) for social environment in women and men, respectively.

## DISCUSSION

Living in neighborhoods with better walking environments and availability of healthy foods was associated with lower body mass index, independent of age, race/ethnicity,

**TABLE 3. Adjusted mean differences in body mass index associated with neighborhood factors, sociodemographic characteristics, diet, and physical activity in women, Multi-Ethnic Study of Atherosclerosis, 2000–2002*,†**

| | Model 1 | | Model 2 | | Model 3 | | Model 4 | | Model 5 | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Adjusted mean | 95% confidence interval | Adjusted mean | 95% confidence interval | Adjusted mean | 95% confidence interval | Adjusted mean | 95% confidence interval | Adjusted mean | 95% confidence interval |
| Physical environment | −2.38 | −3.38, −1.38 | −2.09 | −3.07, −1.11 | −1.35 | −2.29, −0.40 | −1.06 | −1.99, −0.12 | −0.69 | −1.67, 0.29 |
| Social environment | −0.44 | −1.07, 0.20 | −0.07 | −0.72, 0.58 | −0.04 | −0.68, 0.61 | 0.16 | −0.48, 0.80 | −0.08 | −0.75, 0.58 |
| Race | | | | | | | | | | |
| African American | | | | | 3.34 | 2.62, 4.07 | 3.22 | 2.49, 3.95 | 2.98 | 2.22, 3.74 |
| Hispanic | | | | | 1.62 | 0.60, 2.65 | 1.09 | 0.03, 2.15 | 1.03 | −0.09, 2.14 |
| White | | | | | Referent | | Referent | | Referent | |
| Income, US $ | | | | | | | | | | |
| <20,000 | | | 1.96 | 0.76, 3.16 | | | 1.27 | 0.07, 2.44 | 1.40 | 0.17, 2.62 |
| 20,000–<40,000 | | | 2.15 | 1.10, 3.19 | | | 1.62 | 0.60, 2.65 | 1.57 | 0.52, 2.62 |
| 40,000–<75,000 | | | 1.39 | 0.39, 2.38 | | | 1.13 | 0.15, 2.10 | 1.12 | 0.13, 2.11 |
| ≥75,000 | | | Referent | | | | Referent | | Referent | |
| Education | | | | | | | | | | |
| Less than high school | | | 1.03 | −0.08, 2.14 | | | 1.47 | 0.36, 2.59 | 1.20 | 0.02, 2.38 |
| High school diploma/GED‡ | | | 0.99 | 0.08, 1.90 | | | 1.35 | 0.46, 2.24 | 0.79 | −0.14, 1.72 |
| Some college | | | 0.95 | 0.16, 1.73 | | | 1.08 | 0.32, 1.85 | 1.03 | 0.23, 1.82 |
| Bachelor's/graduate degree | | | Referent | | | | Referent | | Referent | |
| Alternative Healthy Eating Index, score | | | | | | | | | −0.04 | −0.07, −0.01 |
| Energy intake, kcal | | | | | | | | | 0.93 | 0.52, 1.33 |
| Total intentional activity, MET‡-hours/day | | | | | | | | | −0.14 | −0.20, −0.08 |

* There were 1,565 women.

† Estimates were provided by use of marginal maximum likelihood estimation methods. Models were additionally adjusted for age and age squared (continuous). Physical and social environment measures were standardized.

‡ GED, general equivalency diploma; MET, metabolic equivalent.

education, and income in men and women. Associations of neighborhood social environment with body mass index were less consistent, and in men, in the direction opposite of expectation.

Our results with a composite measure of the physical environment are consistent with the findings of Boehmer et al. (17) regarding the association between greater walkability and lower prevalence of obesity. Our results are also consistent with prior work showing that healthy food availability, as proxied by the presence of supermarkets in the neighborhood, is associated with lower body mass index (7, 21, 47, 48). We found that associations between neighborhood physical environment and body mass index were attenuated when measures of diet (total calories, AHEI) and physical activity (total intentional activity) were adjusted for in analyses. Although the presence and strength of the mediating relations cannot be examined well in observational and cross-sectional analyses (and conclusions regarding mediation require the assumption that confounders of the mediator-outcome associations are absent or trivial in magnitude) (49), these results are compatible with a mediating role of these behaviors.

We found no evidence that a poorer social environment was associated with greater body mass index. In fact, the opposite was true for men. However, other studies have found associations between adverse social environments (such as disorder and low collective efficacy) and higher body mass index or obesity (17, 20, 27–29). These studies have either focused only on women (20, 27) or have reported associations for men and women combined (17, 28, 29). Our results for social environment for women were consistent with those of other studies in unadjusted models, but the associations disappear after controlling for individual-level variables (20, 27). The unexpected associations observed in men require replication in other samples. Propensity score analyses also yielded opposite results in men and women. However, residual confounding by individual socioeconomic position (which is associated with neighborhood social environment and is differentially related to body mass index in men and women) remains a possibility.

The strengths of this study include the large and diverse population-based sample, the availability of detailed information on neighborhood environments from an informant sample, and the use of marginal maximum likelihood

**TABLE 4. Adjusted mean differences in body mass index associated with neighborhood factors, sociodemographic characteristics, diet, and physical activity in men, Multi-Ethnic Study of Atherosclerosis, 2000–2002*,†**

| | Model 1 | | Model 2 | | Model 3 | | Model 4 | | Model 5 | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Adjusted mean | 95% confidence interval | Adjusted mean | 95% confidence interval | Adjusted mean | 95% confidence interval | Adjusted mean | 95% confidence interval | Adjusted mean | 95% confidence interval |
| Physical environment | −1.20 | −1.84, −0.57 | −1.12 | −1.76, −0.48 | −0.87 | −1.50, −0.23 | −0.73 | −1.36, −0.10 | −0.44 | −1.09, 0.22 |
| Social environment | 0.52 | 0.07, 0.97 | 0.61 | 0.13, 1.09 | 0.61 | 0.18, 1.04 | 0.65 | 0.18, 1.13 | 0.53 | 0.03, 1.02 |
| Race | | | | | | | | | | |
| African American | | | | | 0.76 | 0.32, 1.20 | 0.73 | 0.18, 1.27 | 0.64 | 0.07, 1.21 |
| Hispanic | | | | | 0.10 | −0.37, 0.57 | −0.11 | −0.94, 0.72 | 0.04 | −0.85, 0.93 |
| White | | | | | Referent | | Referent | | Referent | |
| Income, US $ | | | | | | | | | | |
| <20,000 | | | 0.01 | −0.91, 0.93 | | | −0.09 | −0.92, 0.74 | −0.35 | −1.30, 0.61 |
| 20,000–<40,000 | | | 0.34 | −0.40, 1.07 | | | 0.26 | −0.40, 0.92 | 0.37 | −0.36, 1.09 |
| 40,000–<75,000 | | | 0.32 | −0.31, 0.94 | | | 0.35 | −0.20, 0.90 | 0.37 | −0.23, 0.98 |
| ≥75,000 | | | Referent | | | | Referent | | Referent | |
| Education | | | | | | | | | | |
| Less than high school | | | 0.19 | −0.66, 1.03 | | | 0.37 | −0.47, 1.21 | 0.21 | −0.68, 1.10 |
| High school diploma/GED‡ | | | 0.17 | −0.53, 0.87 | | | 0.27 | −0.40, 0.94 | 0.15 | −0.56, 0.85 |
| Some college | | | 0.12 | −0.49, 0.73 | | | 0.02 | −0.56, 0.60 | 0.20 | −0.41, 0.82 |
| Bachelor's/graduate degree | | | Referent | | | | Referent | | Referent | |
| Alternative Healthy Eating Index, score | | | | | | | | | −0.03 | −0.05, −0.01 |
| Energy intake, kcal | | | | | | | | | 0.62 | 0.34, 0.91 |
| Total intentional activity, MET‡-hours/day | | | | | | | | | −0.04 | −0.07, −0.00 |

* There were 1,300 men.

† Estimates were provided by use of marginal maximum likelihood estimation methods. Models were additionally adjusted for age and age squared (continuous). Physical and social environment measures were standardized.

‡ GED, general equivalency diploma; MET, metabolic equivalent.

estimation. There is uncertainty regarding how neighborhoods should be defined in neighborhood effects research (16, 50). Very little theory exists regarding the neighborhood definition and spatial scale relevant to different processes. We chose census tracts because they were the administrative areas available to us with sufficient sample size for the community survey and reasonable within area agreement in responses. We recognize the limitations of census tracts, including the fact that they vary in size across regions. However, measures for census tracts are likely to be correlated with more relevant spatial scales, and therefore results using census tracts are still informative.

We found no evidence of statistically significant heterogeneity by site; however, these analyses were limited by sample size and the range of scales within sites; hence, additional work with larger sample sizes and a broader regional representation is necessary to investigate heterogeneity in neighborhood effects by urbanicity or other regional attributes.

Although we obtained information on a separate sample of individuals, these measures were still based on individual perceptions. There was some evidence that responses to questionnaire items varied on the basis of the characteristics of the respondents (36). However, aggregating across multiple respondents within a neighborhood is likely to average out random error introduced by individual subjectivity. Previous research has documented good intra-neighborhood agreement for our neighborhood measures, indicating that individuals within the same neighborhood tended to be in agreement regarding the neighborhood conditions. Additional work is needed to determine whether similar results are obtained with measures that do not rely on resident perceptions. An important innovation of our study over prior work is the use of statistical methods that explicitly account for measurement error in the neighborhood-level measures.

Because of the cross-sectional and observational design of our study, we are unable to establish a causal relation between neighborhood environments and obesity. It is difficult to rule out selection factors that may systematically place certain types of individuals in certain neighborhoods. We attempted to control for some of these factors such as age, race/ethnicity, education, and income in analyses. Sensitivity analyses using propensity score matching suggest that results for physical environment in women and social environment in both genders are not due to unsupported extrapolations. We note, however, that the propensity score methods used in these analyses are limited to a selected (and perhaps unrepresentative) sample and require dichotomizing the exposure. In addition, propensity score analyses do not incorporate the benefits of the MMLE approach. For these reasons, we report results using the full sample and the MMLE approach as our primary results.

Obesity develops over long periods, so cumulative exposures over time are likely to be more relevant than exposures at a given time. In our sample, 45.4 percent of respondents have resided in the current neighborhood for 20 or more years, and there was no evidence of an interaction between neighborhood environments and time lived in neighborhood. The absence of effect modification by time lived in neighborhood could have resulted from individuals being exposed to similar conditions in previous neighborhoods. We did not have information on the physical and social environment characteristics of the neighborhoods where our participants lived previously. An additional limitation is that individuals may spend various amounts of time in the neighborhood. A large percentage (40 percent) of this MESA subsample was retired at the time of the baseline examination, and individuals reported spending an average of 75 (SD = 25) percent of their time in their neighborhood.

Although neighborhood environments are often identified as potentially important factors in understanding the obesity epidemic, little research provides evidence of this importance. We documented associations between neighborhood physical environments and obesity, particularly for women. The magnitude of the associations we report is not trivial. For example, in women, a one-unit increase in body mass index (comparable to the magnitude of the associations we report) is associated with an 8 percent increase in coronary heart disease risk (51). Moreover, in the case of variables that are approximately linearly related to outcomes over a substantial part of the range (as some have argued may be the case for body mass index) (52), even a small change in the mean may have large public health consequences (53). However, longitudinal studies, evaluation of natural experiments, and (when feasible) experimental designs will be necessary to corroborate these findings. Our results confirm the need for continued investigation into the contribution of neighborhood environments to obesity and the potential for improvements in such environments to reduce the prevalence of obesity in the United States.

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