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Neighborhood Environments and Coronary Heart Disease: A Multilevel Analysis

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The authors investigated whether neighborhood socioeconomic characteristics are associated with coronary heart disease prevalence and risk factors, whether these associations persist after adjustment for individual-level social class indicators, and whether the effects of individual-level indicators vary across neighborhoods. The study sample consisted of 12,601 persons in four US communities (Washington County, Maryland; Forsyth County, North Carolina; Minneapolis, Minnesota; and Jackson, Mississippi) participating in the baseline examination of the Atherosclerosis Risk in Communities Study (1987–1989). Neighborhood characteristics were obtained from 1990 US Census block-group measures. Multilevel models were used to estimate associations with neighborhood variables after adjustment for individual-level indicators of social class. Living in deprived neighborhoods was associated with increased prevalence of coronary heart disease and increased levels of risk factors, with associations generally persisting after adjustment for individual-level variables. Inconsistent associations were documented for serum cholesterol and disease prevalence in African-American men. For Jackson African-American men living in poor neighborhoods, coronary heart disease prevalence decreased as neighborhood characteristics worsened. Additionally, in African-American men from Jackson, low social class was associated with increased serum cholesterol in "richer" neighborhoods but decreased serum cholesterol in "poorer" neighborhoods. Neighborhood environments may be one of the pathways through which social structure shapes coronary heart disease risk. *Am J Epidemiol* 1997;146: 48–63.

atherosclerosis; cardiovascular diseases; coronary disease; ethnic groups; social class; social conditions; socioeconomic factors

Over the past 2 decades, numerous studies based on individual-level data have shown that in industrialized countries coronary heart disease (CHD) is strongly patterned by social class, with higher CHD incidence, prevalence, and mortality in the lower than in the higher social classes (1–6). Simultaneously, many ecologic studies have also documented important variations in CHD mortality across communities with differing socioenvironmental characteristics (7–15). Although they suggest interesting hypotheses regarding the relation between community environments and cardiovascular disease, these ecologic studies have been unable to draw inferences at the individual level or determine whether the observed community effects are independent of individual-level variables (16).

There is a long tradition of public health research relating community-level factors to patterns of health and disease (14, 17–19), with the underlying hypothesis being that factors operating at the level of communities may affect individual-level health outcomes. Over the past few years, several researchers have revitalized this idea and have suggested that area-level or community-level variables may provide information that is not captured by individual-level variables (20–25). Area-based measures of socioeconomic char-

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Abbreviations: CHD, coronary heart disease; ARIC, Atherosclerosis Risk in Communities.

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acteristics or of neighborhood deprivation have been used increasingly in the investigation of social inequalities in health (26–28) and have been found to be related to mortality and other health outcomes, independent of individual-level indicators (29–33). In a commentary on the potential use of multilevel analysis in epidemiology, Von Korff et al. (34) have argued for the need to investigate both individual-level and macro-level determinants of risk factors and outcomes in chronic disease epidemiology and elucidate their independent and combined effects. Within the field of cardiovascular epidemiology, several researchers have argued that it is important to investigate whether characteristics of communities are related to cardiovascular disease outcomes and risk factors independently of individual-level variables (9, 11, 20). However, no reported epidemiologic studies of cardiovascular disease of which we are aware have included both community- and individual-level variables in the analyses.

Neighborhood environments may be related to CHD risk through a variety of mechanisms. The simplest mechanisms may involve differences in the availability and costs of various types of foods, in the distribution of recreational spaces, or in publicity for cigarettes. In addition, neighborhood characteristics may shape the stressors to which individuals are exposed, the resources available to deal with these stressors, patterns of social interactions, attitudes, and life expectations (18, 35–39). Neighborhoods provide milieus for social interaction from which individuals at least partly derive their values, expectations, consumption habits, and market capacities. Residential differentiation is in turn closely linked to the social structure as an important mediating mechanism whereby class relations and social differentiation are produced and sustained (40).

Using baseline data from the Atherosclerosis Risk in Communities (ARIC) Study (1987–1989) and the 1990 US Census, we investigated the following hypotheses: 1) Neighborhood characteristics are related to CHD prevalence and to the distribution of three major CHD risk factors: blood pressure, smoking, and systolic blood pressure; 2) These associations persist after adjustment for individual-level variables; and 3) Neighborhood and individual-level indicators interact in shaping the outcomes mentioned above. Four neighborhood variables available in the 1990 Census (education, income, house value, and occupation) were explored as indicators of neighborhood economic and social structure potentially related to CHD.

MATERIALS AND METHODS

Information on individual-level social class indicators, CHD prevalence, and risk factors was obtained from the baseline visit of the ARIC Study conducted between 1987 and 1989. The ARIC Study is a prospective investigation of atherosclerosis in four US communities (Forsyth County, North Carolina; Jackson, Mississippi; the northwestern suburbs of Minneapolis, Minnesota; and Washington County, Maryland). The ARIC cohort is composed of 15,792 persons aged 45–64 years at the time of the baseline interview. Each community cohort was selected by probability sampling (41). Three samples reflect the demographic composition of the communities from which they were chosen (virtually all white in Washington County and the Minneapolis suburbs and 85 percent white in Forsyth County). The fourth sample (Jackson, Mississippi) is entirely African American.

Information on individual income, education, and occupation was self-reported by cohort members. Participants selected their total family income (in US dollars) from a list of eight categories (<$5,000, $5,000-$7,999, $8,000-$11,999, $12,000-$15,999, $16,000-$23,999, $24,000-$34,999, $35,000-$40,999, and ≥$50,000). Educational level was classified into seven categories (8th grade or less, 9th–11th grade, complete high school, vocational school, 1–3 years college, complete college, and graduate school). Information on current or most recent occupation was collected for employed, unemployed, and retired participants. No information on occupation was collected for participants who reported themselves as "homemakers." Occupations were coded according to the 1980 Census Alphabetical Index of Occupations (42), and categorized into six groups (43) as follows: I) executive, managerial, and professional specialty occupations; II) technical, sales, and administrative support occupations; III) service occupations; IV) farming, forestry, and fishing occupations; V) precision production, craft, and repair occupations; and VI) operators, fabricators, and laborers.

Information on neighborhood characteristics was obtained from the 1990 US Census. In the 1990 Census, information on population demographic characteristics and housing (including value of houses) was collected on all persons and housing units. Additional information on income, education, and occupation was collected on a random sample of approximately one in six housing units. Sample data were weighted using an iterative ratio estimation procedure to obtain estimates of the actual numbers that would have been obtained from a complete count (44). In our study, census block-groups were used as proxies for neighborhoods. Block-groups are subdivisions of census tracts comprised on average of approximately 1,000 individuals (44), and block-group characteristics may be better indicators of the immediate socioeconomic environment than census-tract measures (45–47). ARIC participants were linked to their block-group of residence by using their home address.

Three census variables were chosen a priori as indicators of neighborhood context: area education (percent of adults over age 25 years with incomplete high school), area median household income, and area occupational characteristics (percent of persons in occupational categories II-VI as described above). These variables have the advantages of 1) having been used as socioenvironmental indicators in ecologic studies of CHD in the United States (9, 11), 2) having a more straightforward interpretation than indices combining several variables, and 3) being available at the individual-level for ARIC participants. Although it was not available at the individual-level, median house value was also explored as an alternative indicator of neighborhood wealth.

Participants were defined as having CHD if they had electrocardiographic signs of prevalent myocardial infarction or if they reported a history of physician-diagnosed myocardial infarction, coronary heart surgery, or balloon angioplasty. Total serum cholesterol was measured by enzymatic methods. Systolic pressure was measured by the average of the last two of three seated readings using a random zero sphygmomanometer. On the basis of their responses to questions on smoking history, individuals were classified as current, past, or never smokers. Plasma high density lipoprotein cholesterol and fibrinogen were measured, and low density lipoprotein cholesterol was calculated by standard procedures as described previously (41). Individuals were classified as diabetics if they reported having diabetes, if they were taking medications for diabetes, or if they were found to have fasting plasma glucose of 140 mg/100 ml or more or nonfasting plasma glucose of 200 mg/100 ml or more. Physical activity was assessed using a modified version of the questionnaire of Baecke et al. (48) and summarized in three indices: physical activity during leisure, sport, and work. Keys score (49), a measure of the serum cholesterol elevating potency of the dietary pattern of an individual, was calculated on the basis of dietary information collected using an interviewer-administered version of the food frequency questionnaire developed by Willett et al. (50).

Of the 15,792 persons in the ARIC baseline examination, 14,360 (91 percent) were linked to block-groups in the ARIC Study geographic sites. Individuals were excluded from the analyses if they belonged to racial/ethnic groups other than African American or white (n = 49), if they resided in block-groups where any of the neighborhood measures was based on counts of 50 persons or less (n = 18), or if information on individual indicators of social class (n = 902) or on CHD prevalence (n = 310) was missing. Because the small number of African Americans in field centers other than Jackson made center- and race-specific analyses within these field centers unreliable, 480 African Americans not living in Jackson were also excluded. Some of the analyses were subsequently repeated among the 434 African-American participants in Forsyth County.

Age-adjusted associations of neighborhood indicators with study outcomes were initially investigated stratified by field center and gender. Neighborhood characteristics were explored as continuous variables and categorized on the basis of their center-specific percentile distribution (below the 25th percentile, 25th-75th percentile, and above the 75th percentile). Stratified analyses, with neighborhood characteristics dichotomized at the center-specific median, were used to compare the effects of individual social class across neighborhood contexts.

After center-specific analyses, regression models pooling all field centers were used to investigate associations of neighborhood characteristics with the study outcomes after adjustment for individual-level variables. This study involves individuals nested within neighborhoods. Various strategies have been developed to deal with this type of data structure and account for the possible correlation between individuals within neighborhoods, which may persist even after controlling for individual-level and neighborhood-level variables. In the fields of sociology and demography, these problems have been addressed by using multilevel modeling strategies, termed hierarchical linear modeling (51–55). In our case, these hierarchical models can be conceptualized as follows (although the following description will focus on continuous dependent variables, analogous logistic models can be fitted for binary dependent variables). In the first stage (individual-level), a separate individual-level regression model is defined for each neighborhood,

$$Y_{ij} = \beta_{0i} + \beta_{1i}I_{ij} + \beta_{2i}A_{ij} + e_{ij}$$

$$e_{ij}iid \sim N(0, \sigma^2) \quad (1)$$

where Y_{ij} is the continuous outcome variable for jth individual in ith neighborhood, A is age, and I is the individual-level social class indicator.

The same independent variables are used in all neighborhoods, but regression coefficients are allowed to vary from one neighborhood to another. In the second stage (neighborhood level), these neighborhood-specific regression coefficients are modeled as a function of neighborhood variables and field center.

$$\beta_{0i} = \gamma_{00} + \gamma_{01}N_i + \gamma_{02}C_i + \gamma_{03}N_iC_i + \alpha_{0i}$$
$$\alpha_{0i} \sim N(0, G); \quad (2)$$

$$\beta_{1i} = \gamma_{10} + \gamma_{11}N_i + \gamma_{12}C_i; \quad (3)$$

$$\beta_{2i} = \gamma_{20}. \quad (4)$$

where N_i is the neighborhood socioeconomic characteristic; C_i represents the dummy variable for field center; and α_{0i} is the error term in equation 2, assumed to be normally distributed with variance G.

Variables for field center and their interactions with neighborhood characteristics are included in equation 2 to control for the effects of field center and for variations in the effects of neighborhood characteristics across centers. Field center is also included in equation 3 to allow the effects of individual indicators of social class to vary by center. The coefficient for age (β_{2i}) is assumed to be constant across neighborhoods.

When an error term is included in the second-stage equations (as in equation 2), these models allow for sampling variability in the micro coefficients and for the effects of other neighborhood-level variables that may have an effect on these coefficients but are not included in the model. In our study, error terms are only included in equations for the intercept (β_{0i}).

By substituting equations 2, 3, and 4 in equation 1, we obtain:

$$\gamma_{ij} = \gamma_{00} + \gamma_{01}N_i + \gamma_{02}C_i + \gamma_{03}N_iC_i + \gamma_{10}I_{ij} + \gamma_{11}N_iI_{ij} + \gamma_{12}C_iI_{ij} + \gamma_{20}A_{ij} + \alpha_{0i} + e_{ij}. \quad (5)$$

The final model fitted by the hierarchical linear modeling strategies is essentially a mixed-effects model. Hierarchical models have also been described for binary dependent variables (52). In our study, mixed-effects models with a random intercept for each neighborhood were fitted using SAS (SAS Institute, Inc., Cary, North Carolina) Proc Mixed for continuous dependent variables (systolic pressure and serum cholesterol) and a SAS Macro (GLMMIX) for binary dependent variables (smoking and CHD prevalence) (56).

Final models for each of the study outcomes were stratified by gender. Separate models were fitted for each of the neighborhood characteristics investigated and adjusted for the corresponding socioeconomic indicators measured at the individual level. Associations with neighborhood house value were adjusted for individual-level income. In the case of CHD prevalence, the effects of neighborhood characteristics were also subsequently adjusted for the CHD risk factors low density lipoprotein cholesterol, high density lipoprotein cholesterol, systolic pressure, use of antihypertensive medication, cigarette smoking, body mass index, exercise indices, and Keys score.

Neighborhood indicators were included as continuous variables because they appeared to be linearly related to the outcomes in stratified analyses. When the association of neighborhood characteristics with the outcome differed across the range of neighborhood characteristics investigated, a knot was introduced to allow the slope to vary, reflecting this pattern. Individual-level income and education were included as ordinal covariates representing the categories described above because both appeared to be approximately linearly related to the outcomes. Occupation was categorized into three groups for women (categories I-II, III, and IV-VI) and two groups for men (I-II vs. III-VI). Category III (service workers) was retained as a separate category for women because an earlier study suggested that CHD prevalence may be increased in women service workers (6).

The associations of neighborhood characteristics with the study outcomes did not differ significantly in Forsyth County, Minneapolis, or Washington County, so interactions between these field centers and neighborhood characteristics were dropped from the models. However, in Jackson participants, associations differed from those of the other field centers for some of the outcomes. Interactions between a dummy variable for Jackson and neighborhood characteristics were therefore retained in the models. Interactions between individual-level social class indicators and neighborhood variables were retained in the models only when the direction of the associations of individual-level indicators with the outcomes differed by neighborhood characteristics (qualitative interaction) in stratified analyses.

RESULTS

The final study sample was composed of 12,601 persons (80 percent of the entire cohort) distributed in 567 block-groups, with a median number of 16 participants per block-group. Neighborhood indicators were generally more favorable in Minneapolis and less favorable in Jackson (table 1). Similar patterns were present for individual-level social class indicators (table 2).

As expected, as the socioeconomic indicators of neighborhoods improved, so did the distribution of social class indicators of participants within those neighborhoods (data not shown). Spearman correlation coefficients between continuous neighborhood variables and the corresponding individual indicator (as ordinal variables representing the categories de-

TABLE 1. Neighborhood socioeconomic characteristics of study participants by field center, the Atherosclerosis Risk in Communities Study, 1987–1989

Location	No. of block-groups	% of adults who did not complete high school		Median household income (US dollars)		Median house value (US dollars)		% of occupational categories II–IV*	
		Median	Interquartile range	Median	Interquartile range	Median	Interquartile range	Median	Interquartile range
Forsyth County, NC	180	16.3	10.7–25.4	34,464	29,853–42,163	79,300	68,600–96,100	69.6	57.5–79.2
Minneapolis, MN, suburbs	172	8.9	4.7–13.7	42,818	35,368–49,954	89,900	82,500–106,300	70.3	61.4–77.2
Washington County, MD	96	28.7	21.3–35.5	31,850	26,612–36,369	82,600	72,000–92,000	81.9	72.1–85.3
Jackson, MS	119	41.9	26.4–52.0	16,618	11,607–23,777	38,600	33,700–48,800	82.5	74.7–87.5

* As defined in the text.

scribed in Materials and Methods) were 0.53 for income, 0.41 for education, and 0.28 for occupation.

In Forsyth County, Minneapolis, and Washington County, increased neighborhood disadvantage was generally associated with increased age-adjusted prevalence of current smoking, increased age-adjusted systolic pressure, and increased age-adjusted serum cholesterol. Similar patterns were documented in Jackson participants, with the exception of serum cholesterol, which was highest in the intermediate category of neighborhood characteristics. Systolic pressure was notably higher in Jackson than in the other field centers. Age-adjusted risk factors by neighborhood house value are shown in figure 1. Similar patterns were observed for the other neighborhood indicators.

Table 3 shows multivariate-adjusted odds ratios of current smoking, mean differences in systolic pressure, and mean differences in serum cholesterol associated with neighborhood characteristics. In Forsyth County, Minneapolis, and Washington County, increased neighborhood disadvantage was associated with increased levels of risk factors after adjustment for individual-level indicators of social class, although associations were sometimes not statistically significant (11 of 24 estimates differed significantly from the null at an alpha level of 0.05). Similar findings were documented for smoking and systolic pressure in Jackson participants (seven of 16 estimates were statistically significant). The most consistent associations were documented for smoking in Jackson women and Forsyth County, Minneapolis, and Washington County men.

Since the relation between neighborhood disadvantage and serum cholesterol was not monotonically increasing in Jackson (figure 1), multivariate-adjusted mean differences in serum cholesterol for Jackson participants were stratified by neighborhood characteristics dichotomized at the median (table 4). In Jackson women living in relatively "better-off" neighborhoods (as defined by the Jackson median), serum cholesterol increased with worsening neighborhood indicators. However, in Jackson women living in comparatively "worse-off" neighborhoods, serum cholesterol decreased as neighborhood socioeconomic characteristics worsened. This difference in the association in better-off and worse-off neighborhoods was statistically significant ($p < 0.03$) for all indicators except neighborhood occupation. Similar patterns were documented in Jackson men (table 4), but findings were further complicated by the presence of qualitative additive interactions between neighborhood and individual indicators. In Jackson men living in the most favorable neighborhoods, being of low social class was associated with increased serum cholesterol, but in poorer neighborhoods low, social class was associated with decreased serum cholesterol (table 5). These interactions were statistically significant ($p < 0.02$) for all neighborhood variables except occupation. Differences in the associations for neighborhoods above and below the median (as illustrated in table 4) virtually disappeared after accounting for these interactions.

In most center-gender groups, increased neighborhood disadvantage was also associated with increased age-adjusted CHD prevalence. However, in Jackson men, the highest prevalence rates were consistently found among those in the middle 50 percent of the distribution of neighborhood characteristics. Age-adjusted CHD prevalence rates by categories of neighborhood house value are shown in figure 2. There were no systematic variations in the effects of individual indicators of social class across neighborhood contexts.

Tables 6 and 7 show multivariate-adjusted odds ratios of CHD prevalence associated with neighborhood characteristics. In Forsyth County, Minneapolis, and Washington County women, increased neighborhood disadvantage was associated with increased CHD prevalence odds after adjustment for individual-level social class indicators. These associations persisted and even increased after additional adjustment for cardiovascular risk factors. In Forsyth County, Minneapolis, and Washington County men, increased neighborhood disadvantage was also associated with increased odds of CHD for three of the four indicators, but associations were substantially weaker than those

TABLE 2. Percentage distributions of individual-level social class indicators by field center and gender, the Atherosclerosis Risk in Communities Study, 1987–1989*

Location	No.	Education (% distribution)			Annual family income (% distribution) (US dollars)			Occupation (% distribution)†					
		Did not complete high school	High school or vocational school	Some college or more	<$16,000	$16,000–$49,999	≥$50,000	Executive/management	Technical/sales	Services	Farming/forestry/fishing	Precision production	Operators/laborers
Women													
Forsyth County, NC	1,588	15.4	49.0	35.6	16.7	53.6	29.7	28.7	45.7	9.9	0.2	3.1	12.5
Minneapolis, MN, suburbs	1,783	4.9	54.8	40.3	7.7	57.5	34.8	30.5	48.5	11.4	0.2	2.3	7.1
Washington County, MD	1,656	26.6	49.8	23.6	23.1	59.5	17.4	28.9	40.0	17.3	0.5	3.2	13.1
Jackson, MS	1,907	42.0	28.3	29.7	60.3	35.1	4.6	25.6	15.8	44.7	0.1	2.8	11.1
Men													
Forsyth County, NC	1,402	17.0	35.2	47.8	8.4	51.7	39.9	40.5	20.9	3.4	1.1	21.3	12.6
Minneapolis, MN, suburbs	1,693	7.2	39.4	53.5	3.4	53.2	43.4	44.1	23.5	3.7	0.5	17.8	10.4
Washington County, MD	1,458	29.8	41.9	28.3	13.9	64.1	22.1	27.6	19.4	6.5	2.9	22.7	20.9
Jackson, MS	1,114	44.9	25.1	30.0	45.3	44.9	9.8	19.9	9.9	15.1	2.3	19.9	33.0

* Percentages may not add to 100% due to rounding.
† Categories as defined in the text.

observed in women and were not statistically significant. They were reduced slightly after adjustment for CHD risk factors.

In Jackson women, worsening neighborhood characteristics were associated with increasing CHD odds after adjustment for individual-level social class indicators for two of the four neighborhood variables studied. However, confidence intervals were wide, and differences in the magnitude of the associations between Jackson women and other women were not statistically significant. The effects of risk factor adjustment on these associations were inconsistent across indicators.

In Jackson men, the relation between neighborhood characteristics and CHD odds differed in "richer" and "poorer" neighborhoods (table 7). Among men living in relatively better-off neighborhoods, CHD prevalence odds increased with increased neighborhood disadvantage, but in the worse-off neighborhoods, CHD prevalence odds decreased as neighborhood disadvantage increased. This difference in the direction of the association between richer and poorer neighborhoods was consistent across indicators, but was only statistically significant ($p < 0.04$) for income.

Because of the low correlation between individual-level outcomes within neighborhoods after accounting for explanatory variables, results described above for mixed-effects models were similar to those obtained using standard regression methods. The only cases in which the variance of the random intercepts was found to differ significantly from zero were models for CHD prevalence in women.

DISCUSSION

This study is one of the first to investigate the effects of neighborhood context on CHD prevalence and risk factors after adjustment for individual-level variables. Previous studies conducted in the United States found that area socioenvironmental characteristics are related to CHD mortality but were unable to determine whether these associations persist after controlling for individual-level variables (8–11). In addition, the geographic areas investigated were broader than the ones used as proxies for neighborhoods in our study. Neighborhood environments have also been found to be related to blood pressure, smoking habits, and diet (57–61), and some studies have suggested that these associations may be independent of individual-level social class indicators (46, 62). On the other hand, at least one study has suggested that neighborhood environments play a relative minor role in shaping the distribution of smoking (63).

Our study suggests that neighborhood context may be important in shaping the distribution of CHD prev-

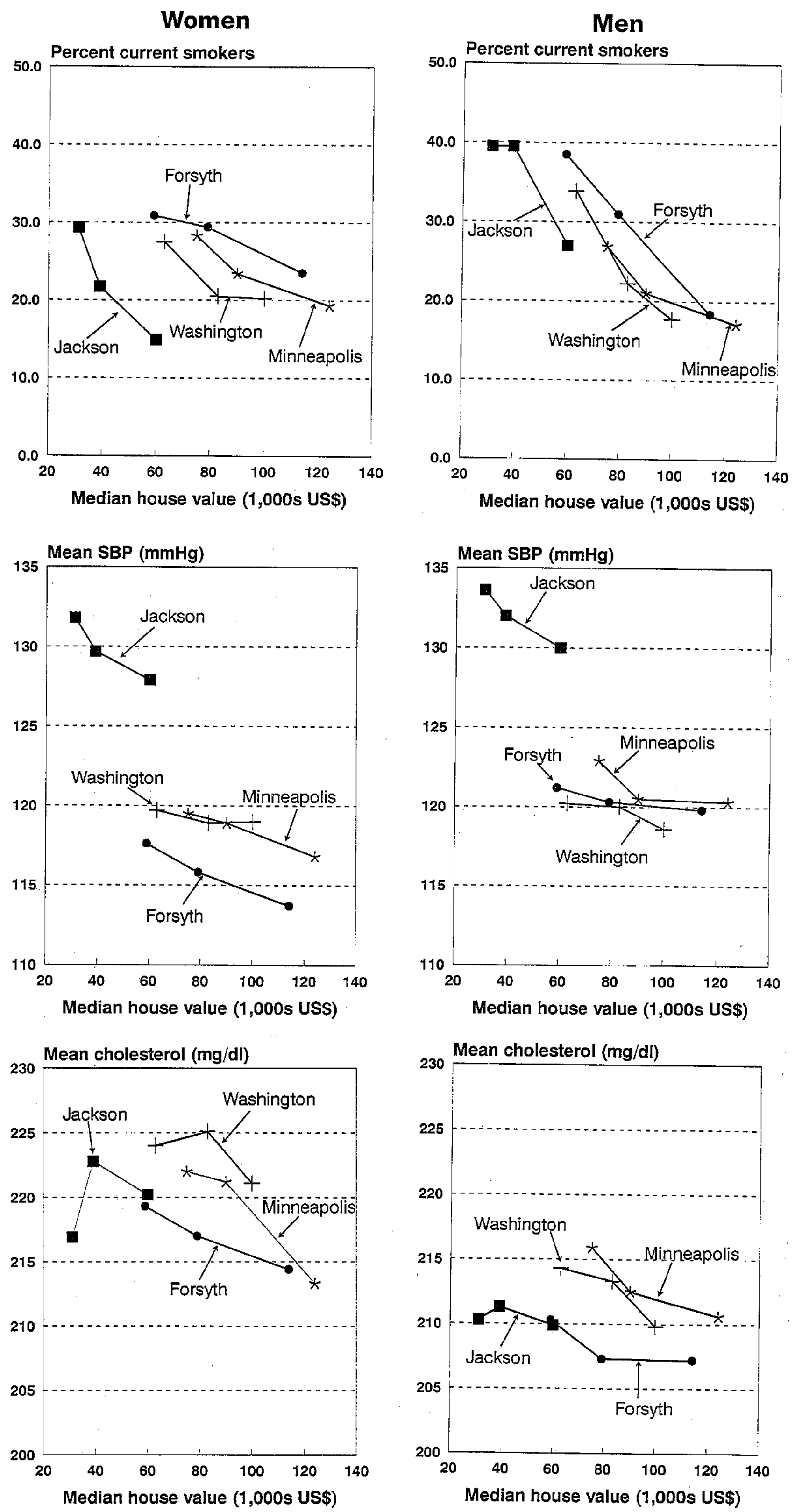

FIGURE 1. Age-adjusted prevalence of current smoking, age-adjusted mean systolic pressure, and age-adjusted mean serum cholesterol by categories of neighborhood house value, the Atherosclerosis Risk in Communities Study, 1987–1989. Adjusted to age 55 years. Categories based on the center-specific percentile distribution (<25, 25–75, and >75 percentiles). Prevalence rates and means are plotted at the median for each category. SBP, systolic blood pressure.

TABLE 3. Adjusted odds ratios of being a current smoker, mean differences in systolic blood pressure (mmHg), and mean differences in serum cholesterol (mg/dl) associated with neighborhood socioeconomic characteristics, the Atherosclerosis Risk in Communities Study, 1987–1989*

Neighborhood characteristics‡	Odds ratios and mean differences for 90th percentile vs. 10th percentile of neighborhood characteristics†											
	Women						Men					
	Current smoking		Systolic pressure (mmHg)		Serum cholesterol (mg/dl)		Current smoking		Systolic pressure (mmHg)		Serum cholesterol (mg/dl)	
	OR§	95% CI§	Mean difference	95% CI	Mean difference	95% CI	OR	95% CI	Mean difference	95% CI	Mean difference	95% CI
Forsyth County, Minneapolis, and Washington County												
% of adults who did not complete high school (37% vs. 4%)	1.10	0.88 to 1.36	1.6	−0.2 to 3.4	3.5	−0.9 to 7.9	1.44	1.10 to 1.80	1.4	−0.5 to 3.2	4.2	−0.0 to 8.3
Median household income ($25,000 vs. $52,000 US dollars)	1.11	0.95 to 1.32	1.0	−0.2 to 2.3	1.8	−1.3 to 4.8	1.60	1.32 to 1.91	0.3	−0.9 to 1.6	2.2	−0.8 to 5.1
Median value of houses ($64,000 vs. $124,000 US dollars)	1.19	1.00 to 1.34	0.9	−0.3 to 2.0	4.4	1.6 to 7.2	1.68	1.42 to 2.08	0.8	−0.4 to 2.0	2.4	−0.6 to 5.4
% of persons in occupational categories II–VI (86% vs. 52%)	1.42	1.14 to 1.76	3.2¶	1.5 to 4.0	4.6	0.7 to 8.6	1.61	1.30 to 2.02	1.8	0.7 to 3.2	5.2	1.8 to 8.6
Jackson												
% of adults who did not complete high school (60% vs. 17%)	1.73	1.33 to 2.38	1.4	−0.8 to 3.6	−1.3	−6.7 to 4.1	1.18	0.84 to 1.61	2.6	−0.1 to 5.2	1.4	−5.0 to 7.8
Median household income ($8,500 vs. $31,000 US dollars)	1.58	1.17 to 2.17	1.7	−0.4 to 3.7	−2.5	−7.5 to 2.5	1.12	0.82 to 1.52	0.7	−1.5 to 3.0	3.6	−1.9 to 9.1
Median value of houses ($30,000 vs. $63,000 US dollars)	1.36	1.00 to 1.79	0.1	−1.9 to 2.1	−1.0	−5.9 to 3.9	1.17	0.88 to 1.56	0.6	−1.6 to 2.8	4.7	−0.7 to 10.0
% of persons in occupational categories II–VI (93% vs. 62%)	1.50	1.06 to 2.15	3.1¶	0.5 to 5.7	1.6	−5.0 to 8.3	1.54	1.06 to 2.20	2.9	0.1 to 5.7	2.9	−3.9 to 9.7

* Odds ratios and mean differences were simultaneously adjusted for age, field center, individual indicators of social class, and the interactions of individual social class with field center. The interaction between the Jackson field center and neighborhood characteristics was retained in all models. Models were fitted separately for each neighborhood characteristic and adjusted for the corresponding individual-level variable. Models allowed for a random intercept for each block-group.

† For income and house value, percentiles are based on distribution in order of decreasing income and decreasing house value (i.e., the 90th percentile has a lower income and house value than the 10th percentile). For Forsyth County, Washington County, and Minneapolis, percentiles are based on the distributions in the three field centers combined. Percentiles for Jackson refer to the distribution in the Jackson field center.

‡ Numbers in parentheses correspond to the 90th and 10th percentiles. The second value in parentheses is the reference category (more-disadvantaged neighborhoods are compared with less-disadvantaged neighborhoods).

§ OR, odds ratio; CI, confidence interval.

¶ Based on ordinary least squares due to lack of convergence of the random effects models.

TABLE 4. Adjusted mean differences in serum cholesterol (mg/dl) associated with neighborhood characteristics in Jackson, MS, African-American participants, stratified by neighborhood characteristics dichotomized at the median, the Atherosclerosis Risk in Communities Study, 1987–1989*

Neighborhood characteristics†	Mean differences for median vs. 10th percentile or 90th percentile vs. median‡			
	Women		Men	
	Mean difference	95% CI§	Mean difference	95% CI
% of adults who did not complete high school				
Better-off neighborhoods (42% vs. 17%)	6.6	0.7 to 12.4	5.4	−1.4 to 12.1
Worse-off neighborhoods (60% vs. 42%)	−7.4	−12.5 to −2.2	−4.5	−11.3 to 2.3
Median household income (US dollars)				
Better-off neighborhoods ($16,600 vs. $31,000)	2.1	−2.4 to 6.5	4.6	0.0 to 9.3
Worse-off neighborhoods ($8,500 vs. $16,600)	−7.0	−12.3 to −1.6	−3.6	−10.3 to 3.1
Median value of houses (US dollars)				
Better-off neighborhoods ($38,600 vs. $63,000)	2.3	−2.3 to 6.9	5.4	0.7 to 10.1
Worse-off neighborhoods ($30,000 vs. $38,600)	−5.7	−10.7 to −0.7	−3.3	−9.4 to 2.9
% of persons in occupational categories II–VI				
Better-off neighborhoods (82.5% vs. 62%)	2.4	−3.8 to 8.7	5.7	−0.4 to 11.9
Worse-off neighborhoods (93% vs. 82.5%)	−1.1	−6.9 to 4.7	−4.6	−11.2 to 2.0

* In addition to the variables mentioned in table 3, * footnote, models included a knot at the median of neighborhood characteristics, allowing associations to differ in "better-off" and "worse-off" neighborhoods. Neighborhoods are stratified into "better-off" and "worse-off" on the basis of the Jackson, MS, median of the neighborhood indicator in question.

† Numbers in parentheses correspond to median and 10th percentile for better-off neighborhoods and to 90th percentile and median for worse-off neighborhoods. The second value in parentheses is the reference category. (More-disadvantaged neighborhoods are compared with less-disadvantaged neighborhoods).

‡ Percentiles based on the Jackson City sample. For income and house value, percentiles are based on distribution in order of decreasing income and decreasing house value (i.e., the 90th percentile has a lower income and house value than the 10th percentile). In "better-off" neighborhoods, mean differences correspond to median versus 10th percentile of the neighborhood characteristic in question. In "worse-off" neighborhoods, mean differences correspond to 90th percentile versus median.

TABLE 5. Adjusted mean differences in serum cholesterol (mg/dl) associated with individual-level indicators of social class among Jackson, MS, African-American men, stratified by neighborhood characteristics, the Atherosclerosis Risk in Communities Study, 1987–1989*

Percentile of neighborhood indicators†	Neighborhood education			Neighborhood income			Neighborhood house value			Neighborhood occupation		
	Neighbor-hood character-istic‡	Difference per unit decrease in individual level education§		Neighbor-hood character-istic‡	Difference per unit decrease in individual level income§		Neighbor-hood character-istic‡	Difference per unit decrease in individual income level§		Neighbor-hood character-istic‡	Difference between occupation categories III-VI and I-II§	
		Mean	95% CI¶		Mean	95% CI		Mean	95% CI		Mean	95% CI
10th	17%	1.0	−0.8 to 2.7	$31,000	0.7	−1.1 to 2.6	$63,000	0.6	−1.2 to 2.4	62%	1.4	−7.0 to 9.9
90th	60%	−3.4	−5.6 to −1.2	$8,500	−2.3	−0.6 to −4.0	$30,000	−2.1	−3.7 to −0.5	93%	−5.9	−13.7 to 1.8

* In addition to the variables listed in table 4,* footnote, models included interactions between neighborhood and individual-level indicators. To show variations in the effects of individual indicators across neighborhood contexts, the effects of individual indicators were estimated for the 10th and 90th percentiles of neighborhood indicators in Jackson, MS.

† For income and house value, percentiles are based on distribution in order of decreasing income and decreasing house value (i.e., the 90th percentile has a lower income and house value in the 10th percentile).

‡ Values correspond to the 10th and 90th percentiles of the neighborhood characteristic in question (percent of adults who did not complete high school, median household income, median house value, or percent of persons in occupational categories II-VI for education, income, house value, and occupation, respectively).

§ Mean differences associated with individual-level social class indicators stratified by neighborhood characteristics. Categories for individual-level education, income, and occupation categories are as defined in the text.

¶ CI, confidence interval.

alence and risk factors, independent of individual-level variables. With some exceptions in the Jackson field center, living in more disadvantaged neighborhoods was associated with increased odds of smoking, increased systolic pressure, and increased serum cholesterol after adjustment for individual-level indicators. Neighborhood effects were usually small and were sometimes not statistically significant, but their

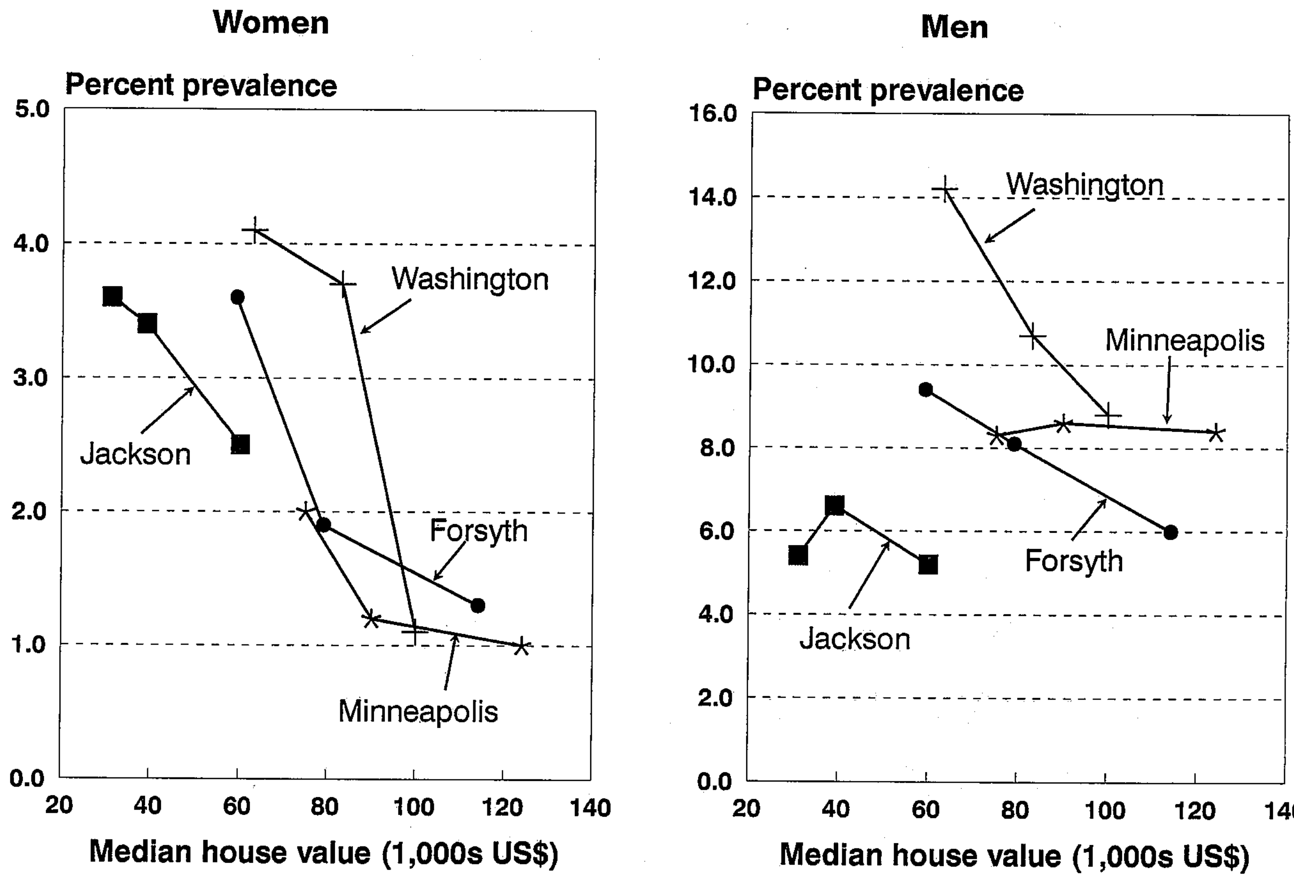

FIGURE 2. Age-adjusted CHD prevalence by categories of neighborhood house value, the Atherosclerosis Risk in Communities Study, 1987–1989. Adjusted to age 55 years. Categories based on the center-specific percentile distribution (<25, 25–75, and >75 percentiles). Prevalence rates are plotted at the median for each category.

presence was generally consistent across genders and the four neighborhood indicators studied. Living in disadvantaged neighborhoods was also clearly associated with increased CHD odds in Forsyth County, Minneapolis, and Washington County women and weakly associated with CHD odds in Forsyth County, Minneapolis, and Washington County men after adjustment for individual-level indicators. Except for serum cholesterol among Jackson men, there was no evidence of heterogeneity in the effects of individual indicators of social class across neighborhood contexts.

The specific mechanisms responsible for the associations of neighborhood characteristics with CHD and CHD risk factors remain to be explored. Certain neighborhood characteristics, such as availability and price of foods, publicity for cigarettes, recreation spaces, and neighborhood stressors, may be related to the prevalence of CHD risk factors in the area and are also likely to be associated with the neighborhood indicators we studied. Recent reports have documented differences in the availability and price of foods across neighborhoods (64–67), and grocery store environments have been found to be related to the dietary practices of individuals (68). In Forsyth County, Minneapolis, and Washington County women, associations of neighborhood characteristics with CHD odds persisted after adjustment for CHD risk factors, suggesting that neighborhood environments may also affect CHD risk through pathways involving other factors, such as stress and social support (69–71) (although residual confounding due to measurement error in the traditional risk factors cannot be categorically ruled out). Analogous to what has been documented in the literature on work environments and cardiovascular disease (72), several dimensions of neighborhood environments, including neighborhood demands, resources, and people's control over these environments, may be important in understanding the relation of neighborhood environments to health outcomes (73).

In Forsyth County, Minneapolis, and Washington County, the effects of neighborhood context on CHD odds were stronger in women than in men. This gender difference was also apparent before adjustment for individual-level variables (data not shown) and may be

TABLE 6. Adjusted odds ratios of coronary heart disease prevalence associated with neighborhood characteristics, the Atherosclerosis Risk in Communities Study, 1987–1989

Neighborhood characteristics*	Odds ratios for 90th percentile vs. 10th percentile†							
	Adjusted for age and individual-level indicators‡				Adjusted for age, individual-level indicators, and CHD§ risk factors¶			
	Women		Men		Women		Men	
	OR§	95% CI§	OR	95% CI	OR	95% CI	OR	95% CI
Forsyth County, Minneapolis, and Washington County								
% of adults who did not complete high school (37% vs. 4%)	1.88	1.00 to 3.52	0.82	0.55 to 1.17	2.54	1.21 to 5.31	0.89	0.58 to 1.36
Median household income (US dollars) ($25,000 vs. $52,000)	1.61	1.11 to 2.87	1.17	0.88 to 1.53	1.97	1.07 to 3.62	1.12	0.81 to 1.56
Median value of houses (US dollars) ($64,000 vs. $124,000)	2.17	1.20 to 3.94	1.15	0.88 to 1.50	2.58	1.37 to 4.86	1.11	0.80 to 1.53
% of persons in occupational categories II–VI (66% vs. 52%)	2.82	1.29 to 6.16	1.26	0.92 to 1.71	4.05	1.56 to 10.40	1.16	0.81 to 1.66
Jackson								
% of adults who did not complete high school (60% vs. 17%)	1.02	0.46 to 2.29	0.92	0.45 to 1.82	1.05	0.41 to 2.72	0.87	0.37 to 2.05
Median household income (US dollars) ($8,500 vs. $31,000)	0.91	0.43 to 1.92	0.76	0.41 to 1.38	1.01	0.41 to 2.52	0.88	0.41 to 1.89
Median value of houses (US dollars) ($30,000 vs. $63,000)	1.21	0.55 to 2.68	1.03	0.54 to 1.94	1.45	0.54 to 3.87	1.08	0.48 to 2.40
% of persons in occupational categories II–VI (93% vs. 62%)	1.42	0.36 to 5.59	1.08	0.50 to 2.36	0.85	0.18 to 3.97	1.28	0.47 to 3.49

* Numbers in parentheses correspond to the 90th and 10th percentiles. The second value in parentheses is the reference category (more-disadvantaged neighborhoods are compared with less-disadvantaged neighborhoods).

† For income and house value, percentiles are based on distribution in order of decreasing income and decreasing house value (i.e., the 90th percentile has lower income and house value than the 10th percentile). For Forsyth County, Washington County, and Minneapolis, percentiles are based on the distributions in the three field centers combined. Estimates for Jackson refer to the distribution in the Jackson field center.

‡ Odds ratios were simultaneously adjusted for age, field center, individual indicators of social class, and the interactions of individual social class with field center. The interactions between field center and neighborhood characteristics were retained for Jackson. Models were fitted separately for each neighborhood characteristic and adjusted for the corresponding individual-level variable. Models allowed for a random intercept for each block group.

§ CHD, coronary heart disease; OR, odds ratio; CI, confidence interval.

¶ Odds ratios were adjusted for CHD risk factors (low density lipoprotein cholesterol, high density lipoprotein cholesterol, cigarette smoking, systolic blood pressure, antihypertensive medication, diabetes, body mass index, Keys score, leisure index, sport index, work index, and serum fibrinogen) in addition to the variables mentioned above. Presence of diabetes, use of antihypertensive medication, and smoking status (current, former, never) were included as dummy variables. All others were adjusted for as continuous variables.

related to higher CHD prevalence rates in men: Even if the absolute effects of neighborhood environments on CHD prevalence are similar across genders, a weaker relative effect is to be expected at higher prevalences. In any case, the reasons for these gender differences still need to be explored.

Patterns for Jackson participants differed somewhat from those observed in the other field centers. The Jackson sample is representative of a poor, southern, urban community and is comprised exclusively of African Americans. Because race and field center were confounded in the analyses, it was impossible to determine whether the patterns observed in Jackson are generalizable to African Americans living in other areas or under other circumstances. Although analyses are limited by small sample size, the patterns observed in Jackson did not appear to be present in the 434 Forsyth County African Americans excluded from the study population, who had slightly more favorable neighborhood indicators than did the Jackson sample.

In Jackson men living in very poor neighborhoods, CHD prevalence appeared to decrease as neighborhood characteristics worsened. The highest CHD prevalence was observed in the intermediate neighborhood categories. Although these findings need to be confirmed in other settings, three tentative hypotheses can be postulated to account for these patterns. In extremely poor neighborhoods, increasing neighborhood poverty may be associated with decreased survival of persons with CHD. Several reports have suggested that survival after a coronary event and treatment of CHD may differ by race and economic factors (74–80), although differences across neighborhoods within African-American communities have not been specifically addressed, and it is unclear whether these differences in survival are large enough to account for the patterns observed. Alternatively, Jackson men living in very poor neighborhoods may actually be at decreased risk of CHD. In many nonindustrialized countries, the lowest CHD rates are found in the poorest sectors of society, which have not yet reaped the "benefits" of the high-fat diets and stressful living circumstances associated with industrialization (81, 82). Dressler (83) has posited that there are parallels between so-called "developing" countries and African-American communities in the southern United

TABLE 7. Adjusted odds ratios of coronary heart disease prevalence associated with neighborhood characteristics in Jackson, MS, African-American men stratified by neighborhood characteristics dichotomized at the median, the Atherosclerosis Risk in Communities Study, 1987–1989*

Neighborhood characteristics†	Odds ratios for median vs. 10th percentile or 90th percentile vs. median‡			
	Adjusted for age and individual-level indicators§		Adjusted for age, individual-level indicators, and CHD risk factors¶	
	OR#	95% CI#	OR	95% CI
% of adults who did not complete high school				
Better-off neighborhoods (42% vs. 17%)	1.46	0.68 to 3.09	1.96	0.73 to 5.31
Worse-off neighborhoods (60% vs. 42%)	0.61	0.29 to 1.31	0.39	0.13 to 1.19
Median household income (US dollars)				
Better-off neighborhoods ($16,600 vs. $31,000)	1.15	0.65 to 2.02	1.36	0.66 to 2.83
Worse-off neighborhoods ($8,500 vs. $16,600)	0.48	0.22 to 1.04	0.45	0.15 to 1.24
Median value of houses (US dollars)				
Better-off neighborhoods ($38,600 vs. $63,000)	1.25	0.66 to 2.38	1.39	0.60 to 3.19
Worse-off neighborhoods ($30,000 vs. $38,600)	0.71	0.36 to 1.38	0.64	0.26 to 1.60
% of persons in occupational categories II–VI				
Better-off neighborhoods (82.5% vs. 62%)	1.18	0.46 to 3.02	1.43	0.54 to 3.81
Worse-off neighborhoods (93% vs. 82.5%)	0.88	0.41 to 1.92	0.83	0.30 to 2.21

* Neighborhoods are stratified into "better off" and "worse off" on the basis of the Jackson median of the neighborhood indicator in question.

† Numbers in parentheses correspond to median and 10th percentile for better-off neighborhoods and to 90th percentile and median for worse-off neighborhoods. The second value in parentheses is the reference category (more-disadvantaged neighborhoods are compared with less-disadvantaged neighborhoods).

‡ Percentiles based on Jackson sample. For income and house value, percentiles are based on distribution in order of decreasing income and decreasing house value (i.e., the 90th percentile has a lower income and house value than the 10th percentile). In "better-off" neighborhoods, odds ratios correspond to median vs. 10th percentile of the neighborhood characteristic in question. In "worse-off" neighborhoods, odds ratios correspond to 90th percentile vs. median.

§ In addition to the variables mentioned in table 6, ‡ footnote, models included a knot at the median of neighborhood characteristics for Jackson, allowing the association of neighborhood characteristics with coronary heart disease (CHD) odds to differ in "better-off" and "worse-off" neighborhoods.

¶ Odds ratios were adjusted for CHD risk factors (low density lipoprotein cholesterol, high density lipoprotein cholesterol, cigarette smoking, systolic blood pressure, antihypertensive medication, diabetes, body mass index, Keys score, leisure index, sport index, work index, and serum fibrinogen) in addition to the variables mentioned above. Presence of diabetes, use of antihypertensive medication, and smoking status (current, former, never) were included as dummy variables. All others were adjusted for as continuous variables.

\# OR, odds ratio; CI, confidence interval.

States, and the shift in the social class distribution of CHD may have occurred later in African Americans than in whites (84). Finally, the decreased prevalence observed in very deprived neighborhoods may also be related to the effects of competing causes of death. The high mortality rates from other causes documented in young African-American men living in poor neighborhoods may imply that only a comparatively "healthy" subgroup could be included in the ARIC Study. This selection bias may be augmented by differences between respondents and nonrespondents. Overall response rates were lower in Jackson (46 percent) than in the other field centers (63–69 percent), but variations in response rates across neighborhoods cannot be assessed with available data. Although a similar inverted V-shaped pattern was not observed for prevalence rates in Jackson women, the associations of neighborhood characteristics with CHD odds were less consistent in Jackson women than in other women, suggesting that processes similar to those described above for Jackson men may be operating.

Among Jackson participants, serum cholesterol was also found to be highest toward the middle of the distribution of neighborhood characteristics. It is plausible that in extremely deprived neighborhoods, increasing neighborhood wealth is associated with increasing serum cholesterol, but that the direction of this association changes once a given level of neighborhood wealth is achieved. However, in Jackson men, this pattern appeared to be at least partly accounted for by the interaction between neighborhood and individual-level indicators. Previous studies of social class differences in serum cholesterol among black men have documented either inconsistent associations or lower serum cholesterol in the lower social classes (85, 86). Our study suggests that in Jackson men, the association of social class with serum cholesterol may differ across neighborhood contexts. This pattern is reminiscent of differences in the social class distribution of CHD between rich and poor countries and within countries over time (82, 87). Just as the social class distribution of CHD varies according to each country's "socioeconomic context," among Jackson men the social class distribution of serum cholesterol appeared to vary according to neighborhood context. In comparatively "rich" neighborhoods, individual increases in income may be associated with changes in diet, exercise, or stress levels conducive to lower levels of serum cholesterol. On the other hand, in poorer neighborhoods, individual increases in income may lead to changes in diet (for example, greater incorporation into the "consumer economy" and consumption of fast foods) or other factors, such as increased stress levels possibly resulting from status inconsistency, which may also be associated with increased serum cholesterol (88).

Several issues regarding these interactions require additional investigation. First, interactions were only observed in Jackson. This may be related to the characteristics of the Jackson sample, which was poorer than those from the other communities included in the study. Second, among Jackson participants, interactions were documented for men but not for women. Although the reasons for this gender difference are unclear, it is worth noting that the change in the social class distribution of CHD in industrialized countries has been clearly documented in men, but not in women (1, 82, 89). Finally, qualitative interactions were documented for serum cholesterol, but not for CHD prevalence, smoking, or blood pressure. This finding is consistent with observations by other authors that the change in the social class distribution of serum cholesterol may have lagged behind the change in the social class distribution of CHD (90).

Several factors may have led to underestimation of neighborhood effects in our study. Block-groups may not be adequate proxies of a person's neighborhood environment, and the variables used to characterize them may not adequately capture differences across neighborhoods. There has been considerable debate on the use of derived variables (constructed by aggregating the characteristics of individuals within groups) in contextual analyses (analyses relating group characteristics to individual outcomes) (91–94). A key assumption is that these aggregate characteristics are indirect indicators of group properties that affect all persons within the group. We used derived variables based on the block-group as indirect indicators of neighborhood environments. These variables are limited in that they are not direct measures of the neighborhood properties potentially related to CHD: They do not measure neighborhood stressors, types of social interactions, availability and price of foods, public recreation spaces, etc. In addition, most neighborhood measures were based on sample estimates for the area rather than complete counts, adding a component of sampling error to their measurement.

One of the main criticisms leveled at contextual analysis is related to residual confounding by individual-level variables (95–97). In our study, neighborhood effects were adjusted for the corresponding individual-level variable (except for house value, which was not available at the individual level). The form in which individual indicators were included in the models was chosen to best reflect their relation to the outcomes studied. Moreover, if persons of low income, education, or occupation are at higher risk of CHD partly because they live in deprived neighborhoods, we may be adjusting away part of the neighborhood effect when we control for the individual-level variables.

Confounding may also occur at the "contextual" or neighborhood level. Individuals may form part of a variety of contexts, many of which may overlap (97). For example, if neighborhoods are strongly segregated on the basis of people's relation to the organization of work, persons within a neighborhood may share similar work environments, and characteristics of these environments may be related to CHD. In addition, in our study the four neighborhood dimensions were investigated separately. Because the four variables were used as alternate indicators of the same underlying construct (social inequalities across neighborhoods), it made little sense to attempt to tease apart their effects by including them all in the same model.

Owing to its cross-sectional nature, our study was unable to determine whether exposure to the neighborhood characteristics investigated preceded the development of the outcomes. Although studies based on individual-level indicators have suggested that changes in social class occurring as a result of disease (the downward drift hypothesis) are an unlikely explanation for social class differences in health (98, 99) or in atherosclerosis (6), our findings need to be confirmed using a longitudinal design. This will be possible as incidence data for the ARIC cohort becomes available. If survival after a coronary event is prolonged in better-off neighborhoods, associations of neighborhood context with CHD prevalence may actually underestimate associations with CHD incidence or mortality.

Our study suggests that neighborhood social context may be among the many factors linking social structure to CHD. From a more pragmatic perspective, neighborhood measures were found to provide information on the socioeconomic environment that is not captured by similar indicators measured at the individual level. Both neighborhood and individual-level social class indicators appear to be important in shaping cardiovascular risk.

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