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Neighbourhood characteristics and mortality in the Atherosclerosis Risk in Communities Study

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Background This study investigates the relationship between neighbourhood characteristics and mortality (all-cause, cardiovascular disease [CVD], and cancer) in the Atherosclerosis Risk in Communities Study (ARIC).

Methods Analysis was limited to African-American and white participants 45–64 years of age at baseline whose records were linked to census data. Deaths ascertained through 31 December 1999 were included in the analysis. Individual-level characteristics were obtained from the baseline interview. A composite index was used to characterize the neighbourhood socioeconomic environment. Proportional hazards regression was used to estimate the effect of neighbourhood socioeconomic status (SES) index and family income on the survival time.

Results The rate of mortality adjusted for age and gender was highest among those who lived in disadvantaged neighbourhoods and were of lower SES. In general, all-cause and CVD mortality rates decreased with increasing neighbourhood SES advantage and family income in all race-gender groups. Although this pattern generally persisted after adjustment for individual socioeconomic factors, statistically significant associations persisted for CVD mortality in whites only (hazard ratio = 1.4, 95% CI: 1.0, 2.0) for most disadvantaged versus most advantaged tertile). When compared with the most affluent participants living in the most advantaged neighbourhoods, the increased risk of all-cause and CVD mortality associated with being poor and living in the most disadvantaged neighbourhoods was equivalent to being 11 and 13 years older at baseline for whites and African Americans, respectively.

Conclusion Our findings indicate that neighbourhood socioeconomic characteristics are associated with modest increases in CVD mortality in white adults. The lack of neighbourhood effects in African Americans needs to be interpreted with caution due to the limited range in the characteristics of the neighbourhood from which these participants were drawn.

Keywords Neighbourhood, mortality, race/ethnicity

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There has been revived interest in the relationship between area of residence and health outcomes.[1–16] It has been hypothesized that living in socioeconomically disadvantaged areas may have negative effects on health. While some studies have failed to find a relationship,[17–20] others have supported the hypothesis that living in socioeconomically deprived areas confers adverse health consequences regardless of individual socioeconomic position.[2,5,7,10,14]

Although area or neighbourhood characteristics have been found to be related to all-cause mortality after accounting for

individual-level socioeconomic indicators,[6,7,9,21–25] the extent to which the association differs for different causes of death has been infrequently examined. The presence of stronger associations with some causes of death than others would provide clues on the causal processes possibly linking area of residence to health.

In this paper, we investigate associations of neighbourhood context with all-cause mortality as well as cardiovascular disease (CVD) and cancer mortality using data from the Atherosclerosis Risk in Communities (ARIC) study. We also examine the independent and joint effects of neighbourhood characteristics and individual-level income and compare the strength with which both indicators are related to mortality.

Methods

ARIC is a prospective study of the aetiology of atherosclerosis in 15 792 people 45–64 years of age at the baseline examination (1987–1989). This study has cohort and surveillance components. The ARIC cohort, on which these analyses are based was selected by probability sampling from four communities in the US: Forsyth County, NC; Jackson, MS; the northwestern suburbs of Minneapolis, MN; and Washington County, MD.[26] Three samples reflect the demographic composition of the communities from which they were chosen (mostly white in Washington County and Minneapolis samples and 85% white in Forsyth County). Only blacks were sampled in the fourth sample (Jackson). Approximately 60% of the potential eligible (26 427) completed the home interview and the clinic examination.[27] Response rates were 46% in Jackson and between 65 and 67% in the other study sites.

Deaths ascertained through 31 December 1999 were included in these analyses. Deaths were identified through annual follow-up phone calls, hospital surveillance, and vital statistics databases and the National Death Index searches. Deaths occurring prior to 1 January 1999 were coded by each State Health department using the International Classification of Diseases System, Ninth Revision (ICD-9). Deaths occurring 1 January 1999 or later were coded using the Tenth Revision (ICD-10) codes. For these analyses, deaths were classified according to underlying cause of death as CVD-related (ICD-9 390–448 and ICD-10 I00–I71), cancer-related (ICD-9 140–208 and ICD-10 C00–C97), and other causes (including 22 deaths attributed to unspecified causes).

Census block-groups were used as proxies for neighbourhoods. Block groups are subdivisions of census tracts with an average of 1000 residents. A neighbourhood SES index was developed based on factor analyses of multiple 1990 US census variables as reported elsewhere.[5,28] Briefly, six variables representing the dimensions of wealth/income (log of the median household income, log of the median value of owner occupied housing units, and the proportion of households receiving interest, dividend, or net rental income), education (the proportion of adults ⩾25 years of age with a high school diploma and the proportion of adults ⩾25 years of age with completed college education), and occupation (the proportion of people employed in executive, managerial, or professional specialty occupations) were combined into the index. Neighbourhood socioeconomic context as assessed using this index was previously found to be related to incidence of coronary heart disease in the ARIC cohort[5] and to other cardiovascular-related outcomes in other cohort.[29,30] The total score for each block group in this sample ranged from −11.3 to 14.4, with increasing values reflecting increasing neighbourhood socioeconomic advantage.

Individual-level socioeconomic indicators were obtained from the baseline interview of the ARIC cohort. Each participant selected his or her total combined family annual income from eight categories (<$5000; $5000–$7999; $8000–$11 999; $12 000–$15 999; $16 000–$24 999; $25 000–$34 999; $35 000–$49 999; and ⩾$50 000). Income was missing for 6.0% of the sample and was coded as a separate category. Three race-specific income categories were constructed as follows: <$25 000 (25% of the sample), $25 000–$49 999 (41%) and ⩾$50 000 (30%) for whites, and <$12 000 (36%), $12 000–$34 999 (38%) and ⩾$35 000 (16%) for African Americans.

Educational attainment was coded as <8th grade; 8th–11th grade; high school diploma or general equivalence diploma; some vocational school; 1–3 years of college; 4 years of college completed; and some graduate or professional school. Information on occupation was coded using the 1980 US Census into the following groups: (I) executive, managerial, and professional; (II) technical, sales, and administrative support; (III) service; (IV) farming, forestry, and fishing; (V) precision production, craft, and repair; (VI) operators, fabricators, and labourers; and homemakers.[31]

Prevalence of CVD (coronary heart disease, stroke, and congestive heart failure) at baseline was determined based on self-reported history and ECG baseline interview. Information on the main cardiovascular risk factors (smoking, systolic blood pressure, diastolic blood pressure, antihypertensive medication within the past 2 weeks, diabetes, body mass index, and lipids values) was obtained at the baseline examination. Smoking status was classified as current, former, or never smoker. Systolic and diastolic blood pressure were measured as an average of the last two of three seated readings using a random zero sphygmomanometer. People were defined as diabetic if they had fasting plasma glucose ⩾126 mg/dl, a non-fasting plasma glucose >200 mg/dl, and/or a self-reported history of diabetes and/or were currently taking medications for diabetes.

Of baseline participants, 90%, (n = 14 163) were linked to block-group data using their home address. We excluded the few individuals who were neither African American nor white or African American from Minneapolis or Washington County (n = 103), or missing information on education and/or occupation (n = 56). A total of 14 004 participants in 597 block-groups (with a median of 17 participants per block group, range 1–159) were available for analysis. The Institutional Review Board at each centre approved the study protocol and informed consent was obtained for each participant.

Statistical analysis

Due to differences in distributions of neighbourhood socioeconomic indicators by race, the neighbourhood SES index was divided into race-specific tertiles and analyses were stratified by race. Selected analyses were repeated using the neighbourhood score divided into tertiles for the whole sample. Linear and logistic regressions were used to estimate the strength of the associations between neighbourhood and personal socioeconomic indicators and mortality. Poisson regression was used to estimate age- and centre-adjusted mortality rates per 1000 person-years by neighbourhood and personal income

level. Cox proportional hazards regression was used to estimate hazard ratios (HR) and 95% CI relating mortality risk at the two lowest tertiles of the neighbourhood SES score or personal income to the highest tertile, after controlling for various combinations of individual-level characteristics.

To examine the combined effects of neighbourhood characteristics and income, race-specific death rates for nine cross-classified categories of neighbourhood and personal income were also estimated. Interactions between neighbourhood characteristics and personal income were tested by including appropriate interaction terms in the models. In models for specific causes of death, other deaths were treated as censored at the time the death occurred. Trend tests were conducted by including the neighbourhood SES score tertiles and personal income categories as ordinal variables. Interactions between sex and neighbourhood SES score tertiles and personal income categories were tested through the likelihood ratio test comparing the models with and without interactions. Models for CVD mortality were rerun after adjustment for prevalence of CVD and cardiovascular risk factors at baseline.

In order to compare directly the strength of neighbourhood SES and personal income associations with mortality, three neighbourhood score categories were constructed to mimic the per cent distribution of the individual-level income categories in each race group. This approach allows comparison of categories for neighbourhood score and income which have the same relative position within the distribution. The percentile cut-offs were 25% and 67% in whites; and 36% and 74% in African Americans. In addition, we compared the effects of neighbourhood median household income and personal income by constructing neighbourhood median household income categories using the same absolute value cut-offs as the personal income categories. We also investigated associations between mortality and neighbourhood characteristics and personal income using tertiles based on the whole sample in each racial group.

The rate advancement period (RAP) for mortality associated with living in a block group with a neighbourhood score in the lowest tertile compared with the highest tertile was derived from the estimated coefficients of the Cox regression models. The derivation of the RAP has been described in detail by Brenner *et al.*[32] Briefly, the RAP represents the advancement in time of the rate of death or how much sooner the rate of death is reached among subjects exposed to some risk factor assuming no competing causes of death. The fundamental assumption underlying the RAP is that death rates exhibit a monotonic increase with age. The RAP is calculated as a ratio of the point estimate associated with the exposure (in our case, living in a neighbourhood with a summary neighbourhood score in the lowest score tertile) and the point estimate for baseline age. Robust sandwich estimation for the covariance matrix was used to account for intra-neighbourhood correlation of outcomes, using the COVSANDWICH option in SAS PROC PHREG.[33]

Results

Over a median of 11.1 years of follow-up, 1470 deaths (including 561 CVD and 556 cancer deaths) occurred among the cohort of 14 004 participants. African-American men and women exhibited higher age-adjusted mortality rates (15.1 and 10.6 per 1000 person-years, respectively) than whites (8.9 and 5.0 per 1000 person-years for men and women, respectively).

African Americans were generally from more disadvantaged neighbourhoods than whites (Table 1). Compared with those who did not die, African Americans and whites who died from all-cause and CVD rated worse for each neighbourhood and individual socioeconomic indicator (all P-values < 0.05) (Tables 2a and 2b). Similar patterns were observed in men and women. Findings for cancer were not as consistent. Fewer differences in socioeconomic indicators between those who died of cancer and survivors were evident. Other causes deaths are not shown due to small numbers.

An inverse association was found between personal income and mortality rate (Figure 1). Within income categories, people living in disadvantaged neighbourhoods generally had a higher death rate than those living in advantaged neighbourhoods.

Table 1 Mean neighbourhood characteristics at baseline according to neighbourhood socioeconomic status (SES) index score: Atherosclerosis Risk in Communities Study

	Whites			African Americans		
	Lowest tertile (z-score, −10.7 to 0.73)	Middle tertile (z-score, 0.74 to 3.6)	Highest tertile (z-score, 3.7 to 14.4)	Lowest tertile (z-score, −11.3 to −6.0)	Middle tertile (z-score, −6.1 to −2.0)	Highest tertile (z-score, −2.1 to 9.8)
No. of study participants	3391	3378	3441	1170	1326	1298
No. of neighbourhoods	137	126	126	48	72	88
Neighbourhood score	−1.45	2.18	6.4	−7.8	−4.4	0.72
Median household income ($)	28 027	36 213	49 215	10 355	18 451	30 775
Median value of housing units ($)	69 654	85 742	112 370	32 397	39 703	59 796
Households with interest, dividends or rental income (%)	35	50	62	6	12	22
Adult residents who completed high school (%)	68	83	92	44	59	80
Adult resident who completed college (%)	9	18	39	6	13	32
Employed residents with executive, managerial, or professional occupations (%)	16	27	42	11	17	30

Table 2a Neighbourhood and personal socioeconomic characteristics at baseline in participants who died and did not die over follow-up adjusted for age and centre: Whites[a]

	Men				**Women**			
		Died				Died		
Characteristics	Did not die (n = 4241)	Total (n = 577)	CVD (n = 224)	Cancer (n = 222)	Did not die (n = 5054)	Total (n = 338)	CVD (n = 97)	Cancer (n = 163)
Neighbourhood characteristics (means)								
Neighbourhood score	2.51	1.92*	1.87*	1.76*	2.42	1.64*	1.12*	1.93
Median household income ($)	38 272	36 827*	36 482**	36 515**	37 802	35 825*	35 204**	36 631
Median value of housing units ($)	90 095	86 063*	86 072**	84 888*	89 475	84 481*	83 341**	86 336
Households with interest, dividends, or rental income (%)	49	47*	47*	47	49	46*	43*	47
Adult residents who completed high school (%)	81	80*	79*	79	81	79*	78**	79**
Adult resident who completed college (%)	23	21*	21	20	22	20*	18*	21
Employed residents with executive, managerial, or professional occupations (%)	28	26*	27**	26	28	26*	24**	27
Individual-level characteristics								
Annual income ⩾$35 000 (%)	62.4	48.0*	51.2*	48.4*	50.3	30.2*	25.2*	33.4*
College graduate (%)	27.9	17.2*	20.1**	13.1**	14.9	8.8*	2.5*	10.9
Executive, managerial, or professional occupations (%)	37.4	31.2*	33.0	32.1	21.1	13.8	12.0*	14.1*

[a] *P*-values obtained from linear and logistic regression comparing those who died (all-cause, cardiovascular disease [CVD], and cancer) with those who did not die: * ⩽0.01, ** ⩽0.05.

Table 2b Neighbourhood and personal socioeconomic characteristics at baseline in participants who died and did not die over follow-up adjusted for age and centre: African Americans[a]

	Men				**Women**			
		Died				Died		
Characteristics	Did not die (n = 1164)	Total (n = 263)	CVD (n = 107)	Cancer (n = 90)	Did not die (n = 2075)	Total (n = 292)	CVD (n = 133)	Cancer (n = 81)
Neighbourhood characteristics (means)								
Neighbourhood score	−3.17	−4.12*	−4.07**	−3.96	−3.83	−4.43**	−4.55**	−4.64
Median household income ($)	21 470	19 253*	19 198**	19 891	19 860	18 011*	18 264	17 843
Median value of housing units ($)	46 345	43 243*	42 642**	44 107	43 668	41 891**	42 012	41 242
Households with interest, dividends, or rental income (%)	15	12*	13	12**	13	12**	11**	13
Adult residents who completed high school (%)	64	61*	61	61	61	60	59	58
Adult resident who completed college (%)	19	16*	15*	18	17	15*	14*	14
Employed residents with executive, managerial, or professional occupations (%)	21	19*	18*	19	19	18**	17**	17
Individual-level characteristics								
Annual Income ⩾$35 000 (%)	24.2	13.4*	11.2*	19.8	12.1	6.7**	3.8**	14.1
College graduate (%)	20.9	14.1**	14.0	17.4	21.6	15.2**	14.2	16.7
Executive, managerial, or professional occupations (%)	21.1	10.9*	9.1*	16.3	22.6	13.1*	13.0*	14.0

[a] *P*-values obtained from linear and logistic regression comparing those who died (all-cause, [CVD], and cancer) with those who did not die: * ⩽0.01, ** ⩽0.05.

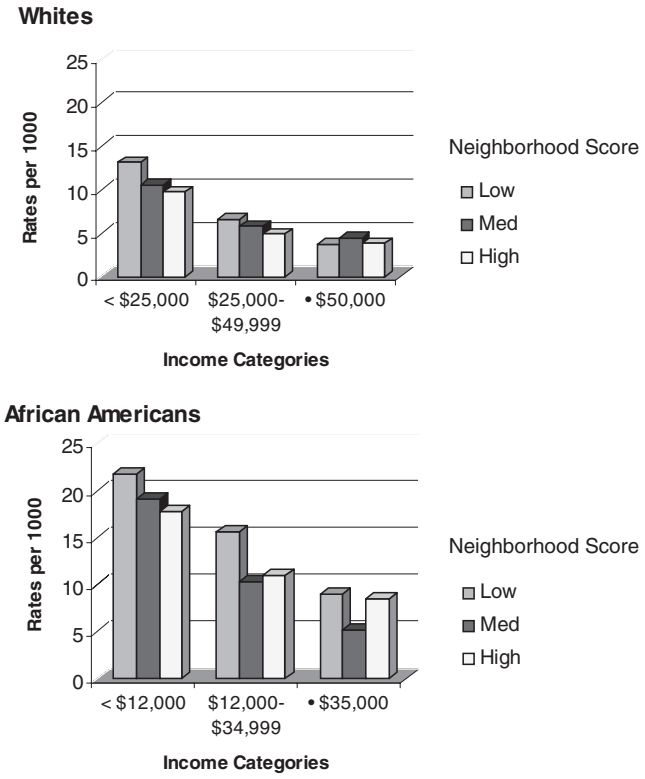

Figure 1 All-cause mortality rates by neighbourhood socioeconomic status index score[a] adjusted for age, sex, and centre according to personal income in whites and African Americans

[a] Neighbourhood index score was categorized using race-specific tertile: −10.7 to 0.73, 0.74–3.6 and 3.7–14.4 for whites, and −11.3 to −6.0, −6.1 to −2.0 and −2.1 to 9.8 for African Americans.

In general, differences across neighbourhoods appeared to be smaller and less consistent in the highest personal income category than in the lowest category but the test for interaction was not statistically significant.

In general, all-cause mortality rate decreased with increasing neighbourhood score and personal income (Table 3). HR of mortality by neighbourhood categories were reduced after adjustment for personal income, education, and occupation (Table 3), but remained significant for CVD deaths in white participants. Whites living in the most disadvantaged neighbourhoods had a 40% higher rate of CVD death over the follow-up period than those living in the most advantaged neighbourhood. This association remained after additional adjustment for prevalent clinical disease and cardiovascular risk factors at baseline (HR = 1.4, 95% CI: 1.0, 2.0). Associations between CVD mortality and neighbourhood socioeconomic characteristics were significantly stronger in white women (HR = 2.0; 95% CI: 1.1, 3.9) than in white men (HR = 1.2; 95% CI: 0.8, 1.9) (P-value for interaction = 0.01). There was no evidence of increased rate of cancer mortality in the most disadvantaged neighbourhood for whites. African Americans living in the most disadvantaged neighbourhood had 10–30% higher rate of all-cause, CVD, and cancer deaths, but differences did not achieve statistical significance nor differ significantly by sex ($P > 0.05$ for all models, analysis not shown). Stronger associations of mortality with neighbourhood score were observed in African Americans when the neighbourhood SES index tertiles were based on the whole sample (instead of race-specific tertiles) (HR for lowest tertile = 1.6 [95% CI: 0.9, 2.9] and 1.8 [95% CI: 1.1, 2.8] for CVD and cancer deaths, respectively) after adjustment for socioeconomic indicators, but analyses were limited by the small number of participants in the highest neighbourhood score tertile (only 250 individuals and 18 events).

Whites in the lowest income category had a 90–110% higher rate of death from all-cause, CVD, and cancer, after controlling for age, education, occupation, centre, and neighbourhood characteristics (Table 3). Associations between all-cause and CVD mortality with personal income were stronger for white women (HR of 3.1 [95% CI: 2.0, 4.7] and 4.0 [95% CI: 1.8, 9.2], respectively) than for white men (HR of 1.8 [95% CI: 1.3, 2.4] and 1.6 [95% CI: 1.1, 2.4], respectively) (P-values for interactions = 0.03 and 0.02, respectively). African Americans in the lowest income category were approximately twice as likely as those in the highest income category to die from any cause or from CVD after adjustment for other socioeconomic indicators and neighbourhood score (HR of 1.9 [95% CI: 1.3, 2.7] and 2.2 [95% CI: 1.2, 4.1], respectively). These associations did not differ by sex. No associations with income were observed for cancer deaths in African Americans.

In whites, the greatest RAP associated with neighbourhood characteristics was observed for CVD-related mortality (4.1 years) (Table 4). Due to sample size limitations, all estimates for African Americans had very wide CI. With the exception of cancer in African Americans, values of the RAP were substantially greater for personal income categories than for neighbourhood categories (7.7 and 8.0 years for all-cause mortality in whites and African Americans, respectively).

When comparing similar percentile (neighbourhood index score) or identical absolute (median neighbourhood household income) cut-offs for neighbourhood characteristics and personal income, associations with mortality were stronger for personal income in both racial groups after adjustment for age, gender, other socioeconomic indicators, and centre (Table 5). The strongest associations with all-cause mortality were observed when people in the highest category for income and neighbourhood score were compared with those in the lowest category for both indicators (HR = 2.87 [95% CI: 2.13, 3.86] in whites and 2.61 [95% CI: 1.14, 5.98] in African Americans). When compared with affluent participants living in the better-off neighbourhoods, being poor and living in the most disadvantaged neighbourhoods was equivalent to being 11 years older (95% CI: 7.0, 14.6) in whites and 13.1 years older (95% CI: 0.6, 25.6) in African Americans at baseline after adjusting for age, sex, personal education, occupation, and centre.

Discussion

Both neighbourhood and personal socioeconomic characteristics were inversely associated with mortality rates in the ARIC cohort. Living in the most economically disadvantaged neighbourhoods related to a 40% increase in risk of CVD mortality for whites, after accounting for personal socioeconomic indicators. Although not statistically significant, a

Table 3 Race-specific mortality rates, rate ratios (all-cause, cardiovascular disease [CVD], and cancer) and their 95% CI according to race-specific categories of neighbourhood SES index score and personal income categories

			Hazard ratios (95% CI)						
			All-Cause		CVD			Cancer	
Characteristics	**Total no. of deaths**	**All-cause mortality rate per 1000 person-years (95% CI)**[a]	Adjusted for age, gender, and centre	Adjusted for age, gender, centre, and other SEI[b]	Adjusted for age, gender, and centre	Adjusted for age, gender, centre, and other SEI[b]	Adjusted for age, gender, centre, other SEI,[b] CVD risk factors, and prevalence of CHD[c] at baseline[d]	Adjusted for age, gender, and, centre	Adjusted for age, gender, centre, and other SEI[b]
Whites									
Neighbourhood index									
1 (Low)	383	8.5 (7.3, 9.7)	1.6 (1.3, 1.9)	1.1 (0.9, 1.4)	1.9 (1.4, 2.7)	1.4 (1.0,, 2.0)	1.4 (1.0, 2.0)	1.5 (1.2, 2.0)	1.1 (0.8, 1.5)
2	296	6.6 (5.8, 7.5)	1.2 (1.0, 1.5)	1.0 (0.9, 1.2)	1.3(0.9, 1.8)	1.1(0.8, 1.6)	1.1(0.7, 1.5)	1.1(0.8, 1.4)	0.9(0.7, 1.2)
3 (High)	236	4.2 (3.5, 5.1)	1.0	1.0	1.0	1.0	1.0	1.0	1.0
P-value for trend			<0.0001	0.17	<0.0001	0.03	0.01	0.001	0.37
Personal income									
1 (Low)	387	11.5 (9.9, 12.3)	2.5 (2.1, 3.1)	2.1 (1.7, 2.7)	2.5 (1.8, 3.5)	1.9 (1.4, 2.7)	1.4 (1.0, 1.9)	2.3(1.7, 3.2)	2.0 (1.4, 2.8)
2	337	5.8 (5.0, 6.6)	1.4 (1.2, 1.7)	1.3 (1.1, 1.6)	1.3 (0.9, 1.8)	1.2 (0.8, 1.6)	1.0 (1.7, 1.3)	1.5 (1.1, 2.0)	1.4 (1.0, 1.9)
3 (High)	150	4.0 (3.3, 4.7)	1.0	1.0	1.0	1.0	1.0	1.0	1.0
P-value for trend			<0.0001	<0.0001	<0.0001	0.005	0.16	<0.0001	0.001
African Americans									
Neighbourhood Index									
1 (Low)	219	18.0 (15.4, 21.1)	1.5 (1.2, 1.8)	1.1 (0.9, 1.4)	1.5(1.0, 2.1)	1.1(0.8, 1.6)	0.9(0.7, 1.3)	1.4 (1.0, 2.1)	1.3(0.9, 1.8)
2	186	11.9 (10.0, 14.2)	1.1(0.9, 1.4)	0.9 (0.8, 1.1)	1.3 (0.9, 1.8)	1.1 (0.8, 1.5)	1.0 (0.7, 1.4)	1.0 (0.7, 1.5)	0.9 (0.6, 1.3)
3 (High)	150	11.5 (9.8, 13.5)	1.0	1.0	1.0	1.0	1.0	1.0	1.0
P-value for trend			<0.0002	0.16	0.02	0.46	0.52	0.03	0.14
Personal income									
1 (Low)	278	20.1 (17.3, 23.4)	2.4 (1.8, 3.4)	1.9 (1.3, 2.7)	3.1(1.7, 5.4)	2.2.(1.2, 4.1)	1.5 (0.8 2.7)	1.2 (0.7, 2.0)	0.9(0.5, 1.8)
2	175	11.9 (10.1, 14.0)	1.5 (1.1, 2.1)	1.3 (0.9, 1.8)	2.2 (1.2, 3.9)	1.9 (1.1, 3.1)	1.5 (0.9, 2.5)	0.9 (0.5, 1.5)	0.7 (0.4, 1.3)
3 (High)	44	7.9 (6.0, 10.4)	1.0	1.0	1.0	1.0	1.0	1.0	1.0
P-value for trend			0.001	0.04	0.01	0.11	0.59	0.67	0.94

[a] Mortality rates are adjusted for age, gender, and centre.

[b] Adjusted for other socioeconomic indicators (SEI) : income (<$5000; $5000–$7999; $8000–$11 999; $12 000–$15 999; $16 000–$24 999; $25 000–$34 999; $35 000–$49 999; and ⩾$50 000), education (<8th grade; 8th–11th grade; high school diploma or general equivalence diploma; some vocational school; 1–3 years of college; 4 years of college completed; and some graduate or professional school) and occupation (executive, managerial, and professional; technical, sales, and administrative support; service; farming, forestry, and fishing; precision production, craft, and repair; operators, fabricators, and labourers; and homemakers) in the case of neighbourhood categories and adjusted for neighbourhood tertiles, occupation, and education in the case of income categories.

[c] Additional adjustment for CVD risk factors such as smoking, lipid values, systolic and diastolic blood pressures, antihypertensive medications within the past 2 weeks, and diabetes.

Table 4 Rate advancement period (RAP) and their 95% CI in years for mortality (all-cause, cardiovascular disease [CVD], and cancer) according to personal income and neighbourhood groups

	RAP (95% CI)			
	Neighbourhood score		Personal income[a]	
Mortality	Adjusted for age, sex, and centre	Adjusted age, gender, centre, and other SEI[b]	Adjusted age, sex, and centre	Adjusted age, gender, centre, and other SEI[b]
Whites				
All-cause				
1 (Low)	4.3 (2.5, 6.0)	1.6 (−0.6, 3.7)	9.4 (6.7, 12.2)	7.7 (4.8, 10.6)
2	1.9 (0.3, 3.6)	0.4 (−1.6, 2.4)	3.7 (1.5, 5.9)	2.7 (0.5, 4.9)
3 (High)	Ref.	Ref.	Ref.	Ref.
CVD				
1 (Low)	6.1 (2.8, 9.3)	4.1 (0.1, 8.0)	9.5 (4.8, 14.1)	7.2 (2.6, 11.7)
2	2.4 (−0.5, 5.3)	1.3 (−2.6, 5.2)	2.9 (−0.8, 6.5)	1.6 (−2.0, 5.2)
3 (High)	Ref.	Ref.	Ref.	Ref.
Cancer				
1 (Low)	4.2 (1.3, 7.1)	1.4 (−1.8, 4.7)	9.3 (4.8, 13.9)	7.5 (2.7, 12.3)
2	0.4 (−1.6, 3.7)	−0.9 (−3.9, 2.0)	4.6 (1.0, 8.3)	3.3 (−0.3, 7.0)
3 (High)	Ref.	Ref.	Ref.	Ref.
African Americans				
All-cause				
1 (Low)	4.3 (1.6, 7.0)	1.6 (−1.2, 4.5)	11.2 (6.0, 16.4)	8.0 (2.5, 13.5)
2	1.1 (−1.4, 3.7)	−0.8 (−3.1, 1.4)	5.2 (0.7, 9.8)	3.4 (−0.8, 7.6)
3 (High)	Ref.	Ref.	Ref.	Ref.
CVD				
1 (Low)	4.1 (0.06, 8.2)	1.6 (−3.1, 6.4)	13.8 (5.0, 22.6)	10.7 (1.1, 20.2)
2	2.9 (−0.9, 6.8)	0.8 (−3.7, 5.3)	9.7 (1.8, 17.7)	8.3 (0.7, 15.9)
3 (High)	Ref.	Ref.	Ref.	Ref.
Cancer				
1 (Low)	4.2 (−0.8, 9.3)	2.9 (−1.7, 7.5)	2.5 (−3.9, 8.9)	−0.7 (−8.5, 7.0)
2	−0.23 (−5.0, 4.6)	−0.9 (−5.3, 3.4)	−1.3 (−7.4, 4.7)	−3.4 (−9.8, 2.9)
3 (High)	Ref.	Ref.	Ref.	Ref.

[a] For these analyses, personal income was categorized into 3 groups (<$25 000, $25 000–$49 999 and ⩾$50 000 for whites, and <$12 00, $12 000–$34 999 and ⩾$35 000 for African Americans).

[b] Adjusted for income, education and occupation in the case of neighbourhood categories and adjusted for neighbourhood tertiles, occupation, and education in the case of income categories.

similar 30% increase in cancer mortality was found for African Americans. When categories based on identical percentile cut-offs or absolute values were compared, associations of neighbourhood characteristics with mortality were weaker than those observed for personal income.

Several previous studies in the US and other countries have found a positive association between neighbourhood disadvantage and mortality,[6–10,21–23] although others have not.[17,24] Studies in the US have generally used census tracts (mean population 4000) or clusters of census tracts as proxies for relevant areas.[34–41] We initially chose block-groups for our analyses because previous studies had suggested that block-groups would identify smaller areas more akin to neighbourhoods than census tracts.[34,40] Recent analyses suggest that estimates of contextual effects are generally similar for block-groups or census tracts.[28,29] Results were generally similar when census tract scores instead of block-group scores were used. The area variables investigated have included median household income, education, occupation, wealth, poverty, per cent of minority, per cent receiving public assistance, crime and violence, or indices combining some of these variables.[5,6,8,9,12,14,22,34,39,42] In general, these studies have found weak to moderate effects on mortality after controlling for personal socioeconomic indicators. For example, Haan and colleagues, using data from the Alameda County Study, found that individuals in federally designated poverty area in Oakland, CA, experienced a 50% higher rate of death than those living in non-poverty areas after adjusting for age, sex, race, baseline health status, personal SES indicators, access to medical care, health-related behaviours, social isolation, and

Table 5 Hazard ratios and 95% CI for all-cause mortality according to similar race-specific income and neighbourhood categories, and combined categories.[a]

Characteristics	Hazard ratios (95% CI)	
	Adjusted for age, gender, and centre	Adjusted for age, gender, centre, education, and occupation[b]
Whites		
Neighbourhood score		
Low	1.70 (1.40, 2.08)	1.17 (0.95, 1.43)
High	1.0	1.0
Neighbourhood median household income[c]		
Low	1.61 (1.31, 1.97)	1.27 (1.02, 1.57)
High	1.0	1.0
Income		
Low	2.55 (2.09, 3.11)	2.14 (1.70, 2.68)
High	1.0	1.0)
Joint effect[d]		
Low–Low	3.47 (2.62, 4.58)	2.87 (2.13, 3.86)
High–High	1.0	1.0
African Americans		
Neighbourhood score		
Low	1.67 (1.31, 2.12)	1.28 (1.03, 1.59)
High	1.0	1.0
Neighbourhood median household income[c]		
Low	1.76 (1.38, 2.26)	1.32 (1.05, 1.66)
High	1.0	1.0
Income		
Low	2.44 (1.76, 3.40)	1.87 (1.30, 2.70)
High	1.0	1.0
Joint effect[d]		
Low–Low	3.03 (1.34, 6.86)	2.61 (1.14, 5.98)
High–High	1.0	1.0

[a] For these analyses, personal income was categorized into three race-specific groups (<$25 000, $25 000 − $49 999 and ⩾$50 000 for whites, and <$12 000, $12 000 − $34 999 and ⩾$35 000 for African Americans). Neighbourhood score categories were constructed to mimic the % distribution of the personal income categories.

[b] Models for personal income were also adjusted for neighbourhood index score. Models for neighbourhood index score and median household income were adjusted for personal income.

[c] Median household income categories are identical to the personal income ones.

[d] Refers to the joint effect of income and neighbourhood score categories. These models are adjusted for education and occupation.

psychological factors.[8] Anderson *et al*. also found an increased rate of death for both African Americans (26%) and whites (44%) living in low-income census tracts after adjusting for family income.[6] However, this association was significant for those aged 25–65 years only. Findings from other countries have generally been similar to those in the US with most[6–10,21–23, 42] though not all studies[17,24] finding evidence of contextual area effects.

Few studies have investigated whether contextual effects differ by cause of death. Davey Smith *et al*. found an association between area deprivation and CVD mortality that persisted after adjustment for individual socioeconomic indicators but disappeared after additional adjustment for cardiovascular risk factors. This association was observed in men and women between the ages of 45 and 64 years.[10] Waitzman and Smith,[9] using data from the first National Health and Nutrition Examination Survey (NHANES I, 1971–9174) and NHANES I Epidemiologic Follow-Up Survey (1987), found associations between living in a poverty area and CVD mortality in the entire sample, and cancer mortality among those aged 25–54 only, after adjustment for several individual demographic and socioeconomic characteristics. LeClere and colleagues[42] found that women living in communities with high concentration of female-headed families were more likely to die of heart disease, independent of their own socioeconomic status, marital status, and pre-existing health risk factors. However, this effect was only significant in women under 65 years of age. Thus, although several studies have documented associations between neighbourhood characteristics and CVD mortality, differences by cause of death have not been previously reported. We found associations with CVD death but not with cancer deaths. Although this difference by cause of death needs to be verified in other studies (especially studies with longer follow-up periods and more events) there are several plausible mechanisms through which neighbourhood conditions could be especially relevant to cardiovascular health, including access to recreational resources and healthy foods, social support, and sources of psychosocial stress. It is also true that some of these neighbourhood factors (for example those related to diet and physical activity) may also be relevant to cancer. Therefore, if confirmed, the reasons for these differences by cause of death need to be further investigated. Associations with CVD death are consistent with prior work showing associations between neighbourhood conditions and CHD prevalence and incidence.[2,5]

Living in a disadvantaged neighbourhood was significantly associated with mortality in whites only. The lack of significant associations between mortality and neighbourhood characteristics in African Americans could result from the fact that African Americans were drawn from more disadvantaged neighbourhoods generally. In fact, there was very little overlap between African-American and white neighbourhoods: the best-off African-American neighbourhoods were similar to the worst-off white neighbourhoods. This finding is consistent with previous analysis of the 171 largest cities in the US.[43] Sampson and Wilson concluded that 'The worst context in which whites reside was considerably better than the average context of black communities'. When similar neighbourhood category cut-offs were used in both racial groups, stronger associations of neighbourhood characteristics with all-cause and cancer mortality emerged in African-American participants, suggesting that race differences in the range of the race-specific categories could explain the lack of associations observed in African Americans when race-specific categories were used. However, CI were wide and analyses were limited by small sample size in the most advantaged neighbourhood group in African Americans due to little overlap in the two distributions. An additional limitation is that African Americans participating in

ARIC were drawn predominantly from a single site (Jackson, MS) and whites were drawn from three communities. Thus, race comparisons of associations are inevitably confounded by site. For all these reasons, our findings regarding weaker associations in African Americans should be interpreted with caution and further investigated.

Associations of mortality with personal income were stronger than associations of mortality with neighbourhood socioeconomic characteristics when race-specific categories based on identical percentile cut-offs or absolute values were compared. Few studies have systematically compared the strength with which area- and individual-level socioeconomic characteristics are associated with mortality. Anderson *et al*. reported stronger associations of family income than census tract income with mortality when similar percentile cut-offs were used at both levels. Our findings were consistent with Anderson and colleagues' findings. This suggests that socioeconomic differentials at the individual-level may be underestimated when area-based proxies for unavailable individual-level measures are used. Although it is difficult to draw inferences regarding the relative importance of area- and individual-level socioeconomic factors based on these data, results suggest that individual income is more strongly associated with mortality than area socioeconomic characteristics. However, these results need to be interpreted cautiously given the greater misspecification of neighbourhood or area-level constructs. In addition, because personal and area socioeconomic indicators are inextricably linked in the real world, the best estimate of socioeconomic differentials in mortality is obtained by comparing people high in both indicators with those low in both indicators. Our study found that being poor and living in disadvantaged neighbourhoods advance the death rate by 11 and 13 years in whites and African Americans, respectively.

Among the strengths of our study are the population-based nature of the sample and the availability of information on underlying causes of death, prevalent disease at baseline, and cardiovascular risk factors. Important limitations are the crude definitions of neighbourhoods used and the use of aggregate census measures as indirect proxies for the specific neighbourhood attributes that may be relevant. Finally, observational studies are clearly limited in their ability to account for individual-level factors related to place of residence which may also be related to mortality. Although we used standard multivariate adjustment strategies to control for individual-level socioeconomic position, this approach has important limitations, and the possibility of residual confounding remains.[44] Ultimately, the question of whether neighbourhood environments are causally related to death can only be answered by studies that examine the specific processes involved, and by approaches that combine different study designs, including observational studies and the evaluation of interventions aimed at modifying residential environments.

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KEY MESSAGES

- Neighbourhood socioeconomic characteristics are associated with modest increases in cardiovascular disease (CVD) mortality in white adults, after controlling for personal socioeconomic indicators.
- Low personal income was associated with increased all-cause, CVD, and cancer mortality.
- Within income categories, people living in disadvantaged neighbourhoods generally had a higher death rate than those living in advantaged neighbourhoods.
- Being poor and living in disadvantaged neighbourhoods advances the death rate by 11–13 years compared with people in the highest income categories living in the most advantaged neighbourhoods.

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