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Life-Course Neighborhood Socioeconomic Status and Cardiovascular Events in Black and White Adults in the Atherosclerosis Risk in Communities Study

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It has been reported that residents of low–socioeconomic-status (SES) neighborhoods have a higher risk of developing cardiovascular disease (CVD). However, most of the previous studies focused on 1-time measurement of neighborhood SES in middle-to-older adulthood and lacked demographic diversity to allow for comparisons across different race/ethnicity and sex groups. We examined neighborhood SES in childhood and young, middle, and older adulthood in association with CVD risk among Black and White men and women in the Atherosclerosis Risk in Communities Study (1996–2019). We found that lower neighborhood SES in young, middle, and older adulthood, but not in childhood, was associated with a higher risk of CVD later in life. When compared with the highest quartile, the lowest quartile of neighborhood SES in young, middle, and older adulthood was associated with 18% (hazard ratio (HR) = 1.18, 95% confidence interval (CI): 1.02, 1.36), 21% (HR = 1.21, 95% CI: 1.04, 1.39), and 12% (HR = 1.12, 95% CI: 0.99, 1.26) increases in the hazard of total CVD, respectively. The association between lower neighborhood SES in older adulthood and higher CVD hazard was particularly strong among Black women. Our study findings support the role of neighborhood SES in cardiovascular health in both Black and White adults.

cardiovascular disease; health disparities; life course; neighborhood socioeconomic status

Abbreviations: ARIC, Atherosclerosis Risk in Communities; CHD, coronary heart disease; CI, confidence interval; CVD, cardiovascular disease; HR, hazard ratio; LCSES, Life Course Socioeconomic Status, Social Context and Cardiovascular Disease; SES, socioeconomic status.

Social determinants play a prominent role in cardiovascular health (1, 2). Neighborhood environment is a crucial aspect of social determinants of health, and lower neighborhood socioeconomic status (SES) has been linked with increased cardiovascular disease (CVD) risk. Previous studies suggest that residents of low-SES neighborhoods, as compared with high-SES neighborhoods, have a higher risk of coronary heart disease (CHD) (3–6), stroke (7–9), CVD mortality (10–12), and overall CVD (13, 14) and are more likely to experience delays in diagnosis and hospital admissions (15) and to receive less-than-optimal treatments (16, 17), all of which contribute to higher burdens of CVD in disadvantaged communities.

Both exposure to neighborhood SES and the relationship between neighborhood SES and CVD may change over the life course, but most studies measure neighborhood SES at only a single time point, often when study participants are in middle-to-older adulthood (3–14). Several studies have suggested that early-life socioeconomic disadvantage, including low neighborhood SES, may be associated with higher risk of CVD (18–20) or its risk factors, such as hypertension and obesity (21, 22), independently of neighborhood SES in adulthood. However, limited research has focused on neighborhood SES at different life stages and CVD risks later in life. Such investigations may help us understand the dynamic relationship between neighborhood SES and CVD and assess the cumulative health effects of life-course socioeconomic disadvantage.

In the United States, CVD risks and mortality are higher among Black Americans than among White individuals (23).

Because of historical and structural factors, when compared with their White counterparts, Black Americans, even those in the middle-to-upper classes, are more likely to live in low-SES neighborhoods with persisting poverty and disinvestment (24–26). Several studies examined neighborhood SES in relation to CVD risk in Black Americans specifically (7, 9, 12, 13) and reported mixed findings: Some reported an inverse association between neighborhood SES and CVD (12, 13), while others reported null-to-weak (9, 10) or even positive (7) associations. In addition, an earlier study suggested sex differences in the relationship between neighborhood disadvantage and risk of CVD among Black residents, with the association appearing stronger in Black women than in Black men (13). However, none of these studies examined neighborhood SES at different life stages.

To address the aforementioned research gaps, we examined neighborhood SES in childhood and young, middle, and older adulthood, as well as neighborhood SES patterns across life stages, in relation to incident CVD over 16 years of follow-up among Black and White men and women in the Atherosclerosis Risk in Communities Study (ARIC) Study. We hypothesized that lower neighborhood SES would be associated with higher risk of CVD in both racial/ethnic groups.

METHODS

Study population

The ARIC Study is a multicenter prospective cohort study that was established in 1987 by recruiting adults aged 45–64 years from 4 US communities (Washington County, Maryland; Forsyth County, North Carolina; Jackson, Mississippi; and the suburbs of Minneapolis, Minnesota) (27, 28). Cohort members were contacted yearly to complete annual surveys on hospitalizations and general health. In addition, multiple follow-up visits were conducted from baseline through visit 8 (2020–2021). Between 2001 and 2002, participants additionally reported their residential addresses at different life stages as part of an ARIC ancillary study, the Life Course SES, Social Context and Cardiovascular Disease (LCSES) Study (29, 30). Of the ARIC visits with information on current residential address, visit 4 (1996–1999) occurred most closely in time with the LCSES Study, when neighborhood exposure at earlier life stages was assessed. Thus, we used visit 4 addresses to measure neighborhood SES in older adulthood and considered visit 4 as the baseline of the current analysis. Web Figure 1 (available at https://doi.org/10.1093/aje/kwac070) presents the timeline of the ARIC Study.

Of the 15,792 participants examined at ARIC baseline (1987–1989), 11,656 participated in visit 4. Of these, we excluded 1,804 who developed CVD by visit 4 and 27 who did not self-identify as either Black or White. We also excluded Black participants in Washington County, Maryland, and Minneapolis, Minnesota, because of small numbers (n = 33). Our analytical sample included 9,692 participants (2,165 Black and 7,527 White). The study protocol was approved by the institutional review boards at all participating centers, and all study participants provided written informed consent.

Assessment of life-course neighborhood SES

At visit 4, study participants reported their current residential address, which was considered their address in older adulthood (median age at visit 4, 62 years; range, 52–75). In the LCSES Study, participants were asked to report their addresses in the following age periods: approximately age 10 years (defined as childhood), approximately age 30 years (young adulthood), and age 40–50 years (middle adulthood). All addresses were geocoded and linked to US Census data. Neighborhood SES in older adulthood was assessed using data from the 2000 Census at the census tract level. Neighborhood SES in middle and young adulthood was assessed on the basis of the most proximate Census (1960–1980) at the census tract level. Childhood neighborhood SES was based on the most proximate Census data (1930–1950) at the county level, the smallest geographic unit with aggregated data for all participating areas during this period. Validation studies found high accuracy and repeatability of geocodes in the ARIC Study (31–33).

Analytical details about the derivation of neighborhood SES measures at different life stages have been published previously (30, 34). Briefly, composite measures of neighborhood SES were derived by summarizing z scores for multiple Census variables representing neighborhood-level education, occupation, income, home ownership, and property value for different life stages. We also calculated average life-course neighborhood SES as follows:

$$\frac{\frac{(n\mathrm{SES}_{\mathrm{old}}+n\mathrm{SES}_{\mathrm{middle}})}{2}\times D_{\mathrm{old-middle}}+\frac{(n\mathrm{SES}_{\mathrm{middle}}+n\mathrm{SES}_{\mathrm{young}})}{2}\times D_{\mathrm{middle-young}}+\frac{(n\mathrm{SES}_{\mathrm{young}}+n\mathrm{SES}_{\mathrm{childhood}})}{2}\times D_{\mathrm{young-childhood}}}{(D_{\mathrm{old-middle}}+D_{\mathrm{middle-young}}+D_{\mathrm{young-childhood}})},$$

where $n\text{SES}_{\text{old}}$, $n\text{SES}_{\text{middle}}$, $n\text{SES}_{\text{young}}$, and $n\text{SES}_{\text{childhood}}$ represent neighborhood SES at different life stages and $D_{\text{old}-\text{middle}}$, $D_{\text{middle}-\text{young}}$, and $D_{\text{young}-\text{childhood}}$ represent the difference (time gap, in years) between the midpoints of 2 different life stages. Specifically, we used ages 10 and 30 years as the midpoints for childhood and young adulthood, respectively, because participants were asked to report their address information at approximately these ages for these life stages. For middle adulthood, we used age 45 years because it represents the midpoint of the age period (40–50 years) for which address information was collected. For older adulthood, we used the median age at baseline (visit 4). $D_{\text{old}-\text{middle}}$, $D_{\text{middle}-\text{young}}$, and $D_{\text{young}-\text{childhood}}$ are 17 years (age 62 years – age 45 years), 15 years (age 45 years – age 30 years), and 20 years (age 30 years – age 10 years), respectively.

Because White and Black Americans on average reside in vastly different neighborhoods (35), we calculated race/ethnicity-specific quartiles for neighborhood SES at different life stages. We also derived variables for long-term neighborhood SES patterns across life stages based on the race/ethnicity-specific median split of neighborhood SES at each stage. For example, neighborhood SES patterns between middle and older adulthood included 4 categories: low-high or improvement (below the median in middle adulthood and at or above the median in older adulthood), high-low or decline, low-low or stable low, and high-high or stable high. We estimated long-term neighborhood SES patterns for 3 periods: middle-to-older adulthood, young-to-middle adulthood, and childhood to young adulthood.

Outcome assessments

We examined the following incident cardiovascular events as the outcomes: CHD, heart failure, and stroke. The follow-up for CVD outcomes extended through December 31, 2019, for Washington County, Forsyth County, and Minneapolis, while the end of follow-up for Jackson County was December 31, 2017, because of incomplete hospital records in one large Jackson hospital in 2018 and 2019. Details on clinical surveillance and outcome ascertainment in ARIC have been previously published (36, 37). In brief, fatal or nonfatal incident CHD cases were adjudicated by an endpoints committee and included the first occurrence of hospitalized definite or probable myocardial infarction, definite fatal CHD, or silent myocardial infarction based on Minnesota-coded serial electrocardiographic changes over ARIC visits. Incident heart failure included the first occurrence of a hospitalization with an *International Classification of Diseases, Ninth Revision*, discharge diagnosis code of 428 before 2005; after 2005, heart failure cases were centrally adjudicated by an endpoints committee. Incident stroke included the first occurrence of definite or probable stroke according to National Survey of Stroke criteria. We also derived a variable for overall CVD outcome by combining the 3 types of events.

Covariates

At ARIC visit 4, study participants reported their sociodemographic characteristics, lifestyle factors, and medical histories. Anthropometric and blood pressure measurements were obtained by trained study staff. Participants also donated fasting blood samples, from which glucose and high- and low-density lipoprotein cholesterol concentrations were estimated. Self-rated health was reported in annual surveys.

Statistical analysis

The percentage of missingness in neighborhood SES measures ranged from 7% (older adulthood) to 36% (young adulthood). The higher rate of missingness for younger adulthood was due to both a lower proportion of reported addresses successfully geocoded during this life stage and incomplete census tract coverage in the 1960s (32, 33). To address missing data, we used multiple imputation by chained equations (38), including the following variables: all neighborhood SES variables, age, race/ethnicity, sex, education, annual household income, marital status, clinical center, body mass index, alcohol use, smoking, high- and low-density lipoprotein cholesterol levels, hypertension, diabetes, and self-rated health. Ten imputed data sets were created. We present mean values and standard deviations for continuous variables that were normally distributed, median values and interquartile ranges for continuous variables that were skewed, and percentages for categorical variables. Descriptive statistics (Table 1) were calculated on the basis of the original data set without imputation.

We calculated incidence rates using Poisson regression and hazard ratios (HRs) and 95% confidence intervals (CIs) using Cox regression. Results from the 10 imputed data sets were summarized using PROC MIANALYZE (SAS Institute, Inc., Cary, North Carolina). We considered 2 models: model 1, the model adjusting only for age and sex, and model 2, the full model adjusting for potential confounders, which were defined as factors that could influence both the likelihood of living in certain neighborhoods and CVD incidence but were not mediators of the associations. These factors included age, sex, race/ethnicity (not controlled in race/ethnicity-specific analysis), marital status, education, annual household income, and study center. We calculated *P* values for trend by modeling quartiles of neighborhood SES variables numerically (1, 2, 3, 4) and *P* values for interaction using a likelihood ratio test comparing models with and without a cross-product term. All analyses were performed using SAS, version 9.4.

RESULTS

Baseline individual-level study characteristics according to neighborhood SES for Black and White participants are presented in Table 1. For both racial/ethnic groups, neighborhood SES was associated positively with formal education, family income, and self-rated excellent health and inversely with the prevalence of hypertension and diabetes. Black residents of neighborhoods in the lower SES quartiles (quartiles 1 and 2) were also less likely to be married when compared with their counterparts in higher quartiles. Moreover, White residents in the first quartile of neighborhood SES had lower high-density lipoprotein cholesterol levels

Table 1. Characteristics of Study Participants, by Race/Ethnicity, in the Atherosclerosis Risk in Communities Study, 1996–1999

Characteristic	Quartile of Neighborhood SES in Older Adulthood[a]															
	Black Participants (n = 1,960)								White Participants (n = 7,050)							
	Q1		Q2		Q3		Q4		Q1		Q2		Q3		Q4	
	Median (IQR)	%	Median (IQR)	%	Median (IQR)	%	Median (IQR)	%	Median (IQR)	%	Median (IQR)	%	Median (IQR)	%	Median (IQR)	%
Neighborhood SES *z* score[b]	−14.3 to −9.3		−9.2 to −6.6		−6.6 to −4.7		−4.7 to 12.5		−11.7 to −0.5		−0.5 to 1.5		1.6 to 4.9		4.9 to 15.8	
Age, years	61 (58–67)		62 (57–67)		60 (57–65)		59 (56–63)		63 (58–68)		63 (58–68)		62 (58–68)		62 (57–67)	
Female sex		67.5		69.8		65.1		61.3		58.6		56.9		56.4		55.3
College graduation or more		20.6		28.1		45.6		55.5		23.4		31.5		43.9		65.1
Annual family income ≥$25,000		22.7		30.2		50.8		65.0		64.8		73.5		80.8		91.0
Married		46.7		46.7		64.5		65.8		79.5		82.9		82.9		83.4
Current smoker		19.7		22.2		16.3		19.3		15.6		13.0		12.9		13.0
Current alcohol drinker		22.0		24.2		27.8		35.5		42.2		42.5		38.0		32.4
Body mass index[c]	30.2 (26.6–34.6)		30.2 (26.5–34.6)		29.1 (26.2–32.8)		29.3 (26.2–33.0)		27.7 (24.8–31.3)		27.9 (25.0–32.0)		27.0 (24.2–30.6)		26.9 (24.1–30.2)	
Fasting glucose level, mmol/L	5.9 (5.3–6.8)		5.7 (5.3–6.8)		5.7 (5.3–6.5)		5.7 (5.3–6.2)		5.55 (5.2–6.1)		5.5 (5.2–6.0)		5.4 (5.2–5.9)		5.4 (5.1–5.9)	
HDL cholesterol level, mmol/L	1.3 (1.1–1.6)		1.3 (1.1–1.6)		1.3 (1.1–1.7)		1.3 (1.1–1.6)		1.2 (1.0–1.5)		1.2 (1.0–1.5)		1.2 (1.0–1.6)		1.3 (1.0–1.6)	
LDL cholesterol level, mmol/L	3.1 (2.6–3.8)		3.1 (2.6–3.7)		3.2 (2.5–3.8)		3.2 (2.6–3.8)		3.2 (2.7–3.8)		3.1 (2.6–3.7)		3.2 (2.6–3.7)		3.1 (2.6–3.6)	
Excellent self-rated health		21.2		17.6		25.6		35.6		18.9		23.9		26.5		30.7
Hypertension[d]		64.6		66.8		64.3		57.4		32.6		32.4		29.5		24.8
Diabetes[e]		27.5		28.7		21.6		19.4		13.7		12.7		10.9		9.7

Abbreviations: HDL, high-density lipoprotein; IQR, interquartile range; LDL, low-density lipoprotein; Q, quartile; SD, standard deviation; SES, socioeconomic status.
[a] Calculated using data without imputation (n = 9,010).
[b] Values are expressed as range.
[c] Calculated as weight (kg)/height (m)^2.
[d] Hypertension was defined as systolic blood pressure ≥140 mm Hg, diastolic blood pressure ≥90 mm Hg, or use of medication to treat hypertension.
[e] Diabetes was defined as fasting blood glucose concentration ≥126 mg/dL, self-reported diagnosis of diabetes, or use of medication to treat diabetes.

Table 2. Associations Between Life-Course Neighborhood Socioeconomic Status and Incident Cardiovascular Disease Among 9,692 Participants in the Atherosclerosis Risk in Communities Study, 1996–2019

Life Stage[a] and Quartile of Neighborhood SES	Total Cardiovascular Disease (*n* = 2,950)				Heart Failure (*n* = 1,931)				Coronary Heart Disease (*n* = 1,182)				Stroke (*n* = 788)			
	Model 1[b]		Model 2[c]		Model 1		Model 2		Model 1		Model 2		Model 1		Model 2	
	HR	95% CI	HR	95% CI	HR	95% CI	HR	95% CI	HR	95% CI	HR	95% CI	HR	95% CI	HR	95% CI
Older adulthood																
Q1	1.37	1.24, 1.53	1.12	0.99, 1.26	1.51	1.31, 1.73	1.19	1.03, 1.39	1.29	1.09, 1.53	1.03	0.84, 1.26	1.47	1.19, 1.81	1.26	0.99, 1.61
Q2	1.25	1.12, 1.39	1.08	0.96, 1.21	1.26	1.10, 1.44	1.06	0.92, 1.23	1.29	1.09, 1.53	1.09	0.90, 1.31	1.27	1.02, 1.57	1.13	0.89, 1.42
Q3	1.12	0.38, 3.30	0.98	0.87, 1.11	1.09	0.95, 1.26	0.95	0.82, 1.10	1.09	0.92, 1.30	0.96	0.80, 1.15	1.30	1.05, 1.61	1.15	0.92, 1.44
Q4	1.00	Referent	1.00	Referent	1.00	Referent	1.00	Referent	1.00	Referent	1.00	Referent	1.00	Referent	1.00	Referent
P for trend	<0.001		0.03		<0.001		0.007		0.003		0.49		0.003		0.10	
Middle adulthood																
Q1	1.44	1.28, 1.62	1.21	1.04, 1.39	1.56	1.35, 1.80	1.28	1.08, 1.53	1.38	1.15, 1.65	1.11	0.90, 1.38	1.33	1.05, 1.68	1.19	0.90, 1.56
Q2	1.19	1.06, 1.33	1.04	0.92, 1.18	1.31	1.13, 1.51	1.13	0.97, 1.32	1.21	1.01, 1.45	1.03	0.84, 1.26	1.02	0.82, 1.28	0.91	0.72, 1.15
Q3	1.12	0.99, 1.26	1.03	0.91, 1.16	1.13	0.97, 1.32	1.04	0.89, 1.21	1.18	0.98, 1.42	1.06	0.88, 1.29	1.09	0.86, 1.38	1.00	0.79, 1.28
Q4	1.00	Referent	1.00	Referent	1.00	Referent	1.00	Referent	1.00	Referent	1.00	Referent	1.00	Referent	1.00	Referent
P for trend	<0.001		0.02		<0.001		0.006		0.002		0.41		0.03		0.29	
Young adulthood																
Q1	1.33	1.17, 1.51	1.18	1.02, 1.36	1.30	1.10, 1.54	1.13	0.94, 1.35	1.34	1.12, 1.60	1.18	0.97, 1.43	1.33	1.02, 1.75	1.23	0.92, 1.66
Q2	1.25	1.08, 1.45	1.12	0.95, 1.32	1.23	1.04, 1.46	1.08	0.90, 1.30	1.28	1.05, 1.56	1.14	0.93, 1.41	1.20	0.91, 1.58	1.14	0.82, 1.59
Q3	1.09	0.94, 1.26	1.02	0.88, 1.19	1.04	0.86, 1.26	0.97	0.80, 1.17	1.12	0.91, 1.38	1.05	0.85, 1.30	1.08	0.84, 1.40	1.03	0.77, 1.38
Q4	1.00	Referent	1.00	Referent	1.00	Referent	1.00	Referent	1.00	Referent	1.00	Referent	1.00	Referent	1.00	Referent
P for trend	0.0001		0.02		0.001		0.09		0.002		0.07		0.04		0.15	
Childhood																
Q1	1.05	0.93, 1.17	0.92	0.81, 1.04	1.13	0.98, 1.30	0.96	0.82, 1.12	0.97	0.82, 1.16	0.86	0.71, 1.04	0.90	0.72, 1.11	0.80	0.63, 1.01
Q2	1.08	0.96, 1.22	1.02	0.90, 1.15	1.11	0.95, 1.29	1.02	0.87, 1.19	1.01	0.84, 1.21	0.96	0.79, 1.16	1.05	0.83, 1.32	0.99	0.77, 1.26
Q3	1.03	0.92, 1.16	0.92	0.80, 1.04	1.10	0.95, 1.27	0.93	0.79, 1.09	0.96	0.80, 1.16	0.87	0.71, 1.06	0.95	0.76, 1.20	0.85	0.67, 1.09
Q4	1.00	Referent	1.00	Referent	1.00	Referent	1.00	Referent	1.00	Referent	1.00	Referent	1.00	Referent	1.00	Referent
P for trend	0.41		0.53		0.15		0.99		0.89		0.28		0.44		0.19	

Table continues

Table 2. Continued

Life Stage[a] and Quartile of Neighborhood SES	Total Cardiovascular Disease (n = 2,950)				Heart Failure (n = 1,931)				Coronary Heart Disease (n = 1,182)				Stroke (n = 788)			
	Model 1[b]		Model 2[c]		Model 1		Model 2		Model 1		Model 2		Model 1		Model 2	
	HR	95% CI	HR	95% CI	HR	95% CI	HR	95% CI	HR	95% CI	HR	95% CI	HR	95% CI	HR	95% CI
Average life course																
Q1	1.42	1.26, 1.60	1.17	1.01, 1.35	1.50	1.29, 1.74	1.19	1.00, 1.42	1.33	1.11, 1.59	1.07	0.87, 1.32	1.50	1.18, 1.90	1.31	0.99, 1.73
Q2	1.21	1.08, 1.37	1.04	0.92, 1.19	1.24	1.06, 1.45	1.04	0.88, 1.24	1.25	1.04, 1.50	1.06	0.87, 1.30	1.09	0.85, 1.39	0.96	0.73, 1.25
Q3	1.10	0.98, 1.29	1.01	0.89, 1.15	1.08	0.93, 1.27	0.99	0.84, 1.16	1.08	0.88, 1.31	0.98	0.80, 1.20	1.29	1.02, 1.64	1.18	0.93, 1.51
Q4	1.00	Referent	1.00	Referent	1.00	Referent	1.00	Referent	1.00	Referent	1.00	Referent	1.00	Referent	1.00	Referent
P for trend	$<$0.0001		0.04		$<$0.0001		0.04		0.002		0.41		0.01		0.19	

Abbreviations: CI, confidence interval; HR, hazard ratio; Q, quartile; SES, socioeconomic status.

[a] Older adulthood: baseline (median age, 62 years); middle adulthood: age 40–50 years; young adulthood: age 30 years; childhood: age 10 years. Average life-course neighborhood SES was calculated as the mean of neighborhood SES at each life stage, weighted by the duration of each stage.

[b] Results were adjusted for age (years; continuous) and sex (male or female).

[c] Results were adjusted for age (years; continuous), sex (male or female), race/ethnicity (Black or White), marital status (married, widowed, divorced, separated, or never married), education (less than high school, high school or vocational school, or college or higher), annual household income ($<$\$25,000, \$25,000–\$49,999, \$50,000–\$74,999, or $\geq$\$75,000), and study center (Washington County, Maryland; Forsyth County, North Carolina; Jackson, Mississippi; or the suburbs of Minneapolis, Minnesota).

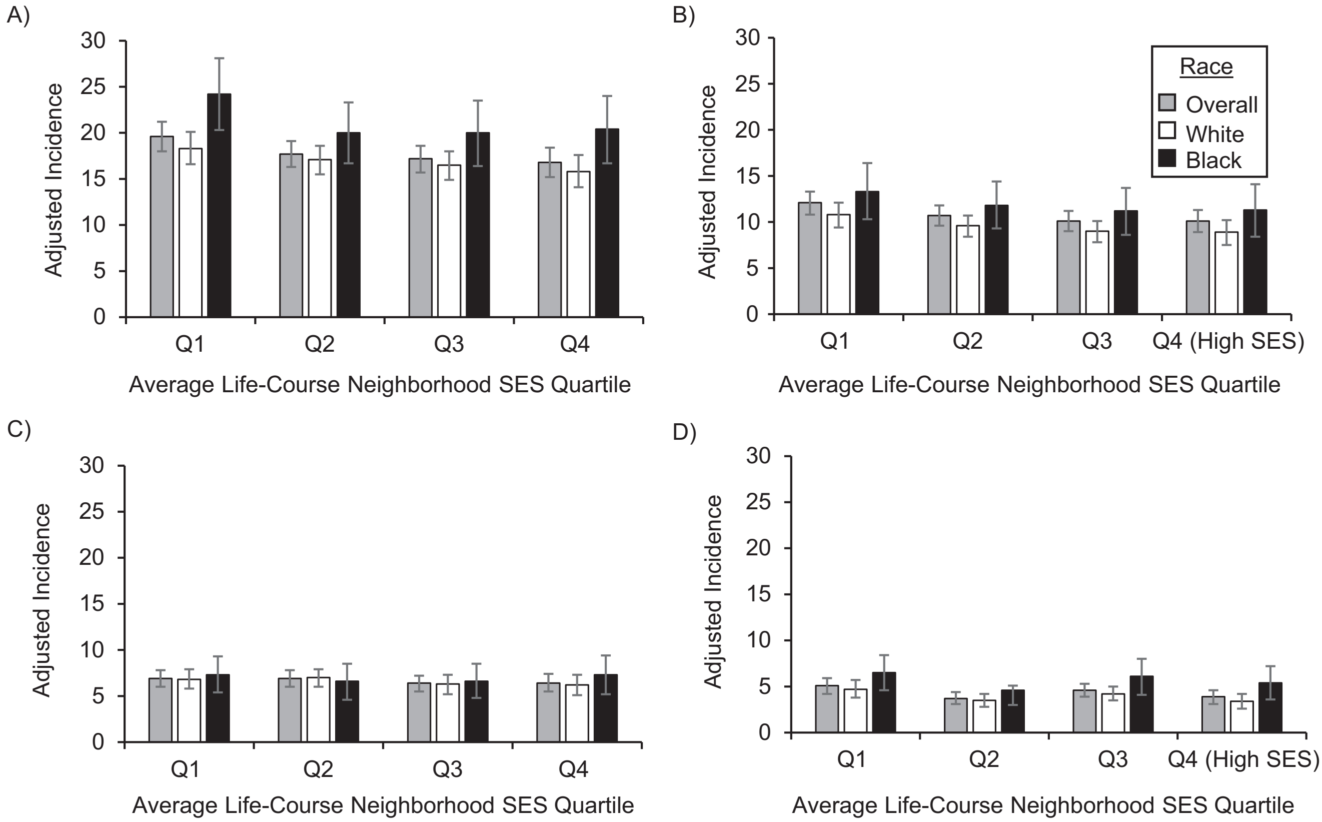

Figure 1. Adjusted incidence rates (per 1,000 person-years) of A) total cardiovascular disease, B) heart failure, C) coronary heart disease, and D) stroke according to quartiles (Q) of average life-course neighborhood socioeconomic status (SES), overall (*n* = 9,692) and in the White (*n* = 7,527) and Black (*n* = 2,165) populations of the Atherosclerosis Risk in Communities Study, 1996–2019. Incidence rates were adjusted for age (years; continuous), sex (male or female), race/ethnicity (Black or White; not adjusted in race/ethnicity-specific results), marital status (married, widowed, divorced, separated, or never married), education (less than high school, high school or vocational school, or college or higher), annual household income (<\$25,000, \$25,000–\$49,999, \$50,000–\$74,999, or ≥\$75,000), and study center (Washington County, Maryland; Forsyth County, North Carolina; Jackson, Mississippi; or the suburbs of Minneapolis, Minnesota). Average life-course neighborhood SES was calculated as the mean of neighborhood SES in older, middle, and young adulthood and in childhood, weighted by the duration of each life stage. Bars, 95% confidence intervals.

and higher low-density lipoprotein cholesterol levels than those in quartiles 2–4. Finally, when compared with lower quartiles, the highest quartile of neighborhood SES was associated with a higher prevalence of alcohol drinking among Black participants, but a lower prevalence among White participants.

Over the course of a mean 16.4 (standard deviation, 6.7) years of follow-up, there were 2,950 incident CVD events (448 among Black women, 280 among Black men, 1,154 among White women, and 1,068 among White men). Results from minimally adjusted models suggested that being in the lowest neighborhood SES quartile, as compared with the highest, in older, middle, and young adulthood was associated with an increased risk of total CVD (model 1, Table 2). After adjustment for additional sociodemographic factors and individual-level SES characteristics, the associations were attenuated in magnitude but the trend across quartiles remained similar (model 2, Table 2). When compared with the highest quartiles (denoted Q), the lowest quartiles of neighborhood SES in older, middle, and young adulthood were associated with 12% ($HR_{Q1\ vs.\ Q4}$ = 1.12 (95% CI: 0.99, 1.26); *P* for trend = 0.03), 21% ($HR_{Q1\ vs.\ Q4}$ = 1.21 (95% CI: 1.04, 1.39); *P* for trend = 0.02), and 18% ($HR_{Q1\ vs.\ Q4}$ = 1.18 (95% CI: 1.02, 1.36); *P* for trend = 0.02) increases in the risk of total CVD, respectively. Associations for individual CVD outcomes differed. For example, neighborhood SES in older and middle adulthood showed a stronger association with heart failure than with CHD. Childhood neighborhood SES was not associated with total CVD or CVD subtypes. Finally, lower average life-course neighborhood SES was associated with higher risks of total CVD ($HR_{Q1\ vs.\ Q4}$ = 1.17 (95% CI: 1.01, 1.35); *P* for trend = 0.04) and heart failure ($HR_{Q1\ vs.\ Q4}$ = 1.19 (95% CI: 1.00, 1.42); *P* for trend = 0.04).

When compared with White participants, Black participants had a higher incidence of total CVD, heart failure, and stroke in all quartiles of life-course neighborhood SES (Figure 1). Among both racial/ethnic groups, the incidence of total CVD and heart failure appeared to decrease with increased neighborhood SES (Figure 1). In analysis stratified by race and sex (Table 3), we found that associations between total CVD and neighborhood SES in older and middle adulthood, as well as average life-course neighborhood SES, appeared the strongest among Black women, while the results among other race-sex groups were weaker or null. Specifically, Black women in the lowest quartiles of neighborhood SES in older and middle adulthood and average life-course neighborhood SES had 58% ($HR_{Q1\ vs.\ Q4}$ = 1.58, 95% CI: 1.15, 2.17), 42% ($HR_{Q1\ vs.\ Q4}$ = 1.42, 95% CI: 1.05, 1.91), and 37% ($HR_{Q1\ vs.\ Q4}$ = 1.37, 95% CI: 1.00, 1.88) higher risks of total CVD when compared with those in the highest quartiles. Similarly, stronger results among Black women were also observed for CVD subtypes (Web Tables 1–3). For example, the lowest neighborhood SES in older adulthood was associated with 85% and 90% increases in risk of heart failure and stroke, respectively. Finally, among Black men, lower childhood neighborhood SES was associated with *lower* risks of total CVD ($HR_{Q1\ vs.\ Q4}$ = 0.61 (95% CI: 0.41, 0.91); *P* for trend = 0.02) (Table 3), heart failure ($HR_{Q1\ vs.\ Q4}$ = 0.59 (95% CI: 0.35, 0.99); *P* for trend = 0.05) (Web Table 1), and stroke ($HR_{Q1\ vs.\ Q4}$ = 0.44 (95% CI: 0.20, 0.99); *P* for trend = 0.08) (Web Table 3). However, such a pattern was not observed among other race-sex groups.

We examined patterns of change in neighborhood SES across life stages in relation to CVD in the overall population (Table 4) and among race-sex groups (Table 5). In general, when compared with the stable-high groups of neighborhood SES, the stable-low groups consistently showed higher risks for total CVD and heart failure, while the results for the neighborhood SES decline and improvement groups were mixed (Table 4). Although we observed a suggestive trend for an increased risk associated with neighborhood SES decline (high-low vs. high-high) and a decreased risk with neighborhood improvement (low-high vs. low-low), most of the results were not statistically significant. In stratified analysis (Table 5), the results were generally stronger among Black women. For example, when compared with those in the stable-high group, Black women residing in neighborhoods with a stable-low or declining neighborhood SES from middle adulthood to older adulthood had 47% ($HR_{Q1\ vs.\ Q4}$ = 1.47, 95% CI: 1.16, 1.85) and 59% ($HR_{Q1\ vs.\ Q4}$ = 1.59, 95% CI: 1.08, 2.35) increased risks of total CVD when compared with their counterparts living in stable-high neighborhoods.

DISCUSSION

In this large cohort of residents of 4 geographically defined areas in the United States, we found that those living in neighborhoods with low SES during various stages in adulthood, but not in childhood, were more likely to develop CVD later in life than study participants living in high–neighborhood-SES communities. We also detected differences across race/ethnicity and sex, such that the associations between neighborhood SES in older and middle adulthood and CVD risk were particularly strong among Black women.

The inverse association between neighborhood SES in adulthood and CVD is consistent with previous findings from numerous large cohort studies. For example, in an earlier investigation in the ARIC cohort with shorter follow-up (mean = 9.1 years), when compared with the highest tertile, the lowest tertile of baseline neighborhood SES was associated with 70% ($HR_{Q1\ vs.\ Q4}$ = 1.7, 95% CI: 1.3, 2.3) and 40% ($HR_{Q1\ vs.\ Q4}$ = 1.4, 95% CI: 0.9, 2.0) increases in incident CHD in White and Black study participants, respectively (3). Similarly, a study that included 3.7 million Swedish adults aged 35–74 years who were free of prevalent CHD suggested that those living in neighborhoods with high socioeconomic deprivation, as compared with low socioeconomic deprivation (1 standard deviation above the mean), were more likely to develop CHD (odds ratios were 1.28 (95% CI: 1.24, 1.33) for women and 1.21 (95% CI: 1.18, 1.24) for men) over 5 years (1996–2000) (5). In the Reasons for Geographic and Racial Differences in Stroke (REGARDS) Study, the lowest quartile of neighborhood SES was associated with a 25% increase in stroke risk, with borderline statistical significance (HR = 1.25 (95% CI: 0.99, 1.56); *P* for trend = 0.085) (9). A similar inverse association between neighborhood SES and stroke was observed in a large Japanese cohort of middle-aged to older adults with long follow-up (approximately 16 years) (8). Finally, in the NIH-AARP Diet and Health Study, men and women residing in neighborhoods with the lowest quintile of neighborhood SES were 33% and 18% more likely to die from CVD, respectively, when compared with their counterparts residing in neighborhoods in the highest quintile (11). The consistency in findings across studies that focused on a variety of CVD outcomes and diverse populations suggests that neighborhood SES is probably a fundamental contributor to CVD disparities in the United States and other high-income countries. Our investigation extended previous research by showing that neighborhood SES in young, middle, and older adulthood was similarly associated with CVD risk, suggesting that the processes that link neighborhood disadvantage with CVD may begin early in adulthood. Therefore, any interventions aimed at improving neighborhood conditions to reduce CVD burden may benefit populations with a wide age range.

Our analysis revealed no association between neighborhood SES in childhood and incidence of CVD in adulthood. In contrast, many previous studies suggested that early life is an important stage and that childhood socioeconomic conditions may have a unique and lasting impact on disease risk in adulthood: In a systematic review including 24 prospective and 11 case-control studies on childhood SES and adult CVD outcomes, Galobardes et al. (39) concluded that more adverse socioeconomic conditions during childhood were a risk factor for incident CHD, stroke, and overall CVD risk and mortality. However, all of the studies measured childhood SES at the individual or family level (mostly by father's occupation), and there are few investigations of childhood neighborhood conditions and cardiovascular health. One example is a recent analysis based on data from the New England Family Study, which found that high neighborhood SES at birth and in adulthood was associated with a favorable cardiovascular risk profile (i.e., lower blood pressure and body mass index), while neighborhood SES in childhood (mean age = 7.1 years) was not associated with CVD risk factors in adulthood (18). In contrast, in a

Table 3. Associations[a] Between Life-Course Neighborhood Socioeconomic Status and Total Incident Cardiovascular Disease, by Race/Ethnicity and Sex, in the Atherosclerosis Risk in Communities Study, 1996–2019

Life Stage and Quartile of Neighborhood SES[b]	Risk of Cardiovascular Disease											
	Black Participants						White Participants					
	Overall (n = 728)		Black Women (n = 448)		Black Men (n = 280)		Overall (n = 2,222)		White Women (n = 1,154)		White Men (n = 1,068)	
	HR	95% CI	HR	95% CI	HR	95% CI	HR	95% CI	HR	95% CI	HR	95% CI
Older adulthood												
Q1	1.30	1.02, 1.66	1.58	1.15, 2.17	1.00	0.66, 1.50	1.07	0.93, 1.24	1.16	0.95, 1.42	0.98	0.80, 1.21
Q2	1.17	0.91, 1.50	1.42	1.03, 1.96	0.86	0.55, 1.35	1.06	0.93, 1.21	1.17	0.97, 1.41	0.95	0.78, 1.15
Q3	1.08	0.85, 1.38	1.10	0.80, 1.52	1.09	0.76, 1.56	0.96	0.83, 1.10	1.05	0.87, 1.27	0.86	0.71, 1.04
Q4	1.00	Referent	1.00	Referent	1.00	Referent	1.00	Referent	1.00	Referent	1.00	Referent
P for trend	0.03		0.003		0.71		0.15		0.11		0.75	
P for interaction (SES × sex)[c]				0.009						0.11		
P for interaction (SES × race/ethnicity)[d]						0.24						
Middle adulthood												
Q1	1.32	1.03, 1.68	1.42	1.05, 1.91	1.21	0.82, 1.78	1.14	0.96, 1.36	1.13	0.88, 1.45	1.14	0.90, 1.44
Q2	1.05	0.83, 1.33	1.11	0.83, 1.50	0.98	0.67, 1.43	1.02	0.88, 1.18	1.01	0.81, 1.25	1.01	0.82, 1.26
Q3	0.98	0.77, 1.25	0.97	0.71, 1.33	0.98	0.69, 1.40	1.04	0.90, 1.19	1.03	0.83, 1.28	1.03	0.84, 1.25
Q4	1.00	Referent	1.00	Referent	1.00	Referent	1.00	Referent	1.00	Referent	1.00	Referent
P for trend	0.03		0.02		0.37		0.17		0.34		0.33	
P for interaction (SES × sex)				0.21						0.40		
P for interaction (SES × race/ethnicity)						0.23						
Young adulthood												
Q1	1.21	0.92, 1.60	1.19	0.82, 1.72	1.28	0.87, 1.88	1.16	0.99, 1.36	1.10	0.88, 1.39	1.21	0.99, 1.49
Q2	1.09	0.78, 1.51	1.15	0.78, 1.69	1.00	0.62, 1.63	1.13	0.97, 1.32	1.11	0.89, 1.40	1.14	0.93, 1.40
Q3	0.94	0.72, 1.22	0.93	0.66, 1.31	0.96	0.64, 1.43	1.05	0.90, 1.24	1.01	0.79, 1.28	1.10	0.90, 1.35
Q4	1.00	Referent	1.00	Referent	1.00	Referent	1.00	Referent	1.00	Referent	1.00	Referent
P for trend	0.16		0.22		0.29		0.05		0.28		0.08	
P for interaction (SES × sex)				0.89						0.97		
P for interaction (SES × race/ethnicity)						0.61						

Table continues

Table 3. Continued

Life Stage and Quartile of Neighborhood SES[b]	Risk of Cardiovascular Disease											
	Black Participants						White Participants					
	Overall (*n* = 728)		Black Women (*n* = 448)		Black Men (*n* = 280)		Overall (*n* = 2,222)		White Women (*n* = 1,154)		White Men (*n* = 1,068)	
	HR	95% CI	HR	95% CI	HR	95% CI	HR	95% CI	HR	95% CI	HR	95% CI
Childhood												
Q1	0.88	0.69, 1.12	1.08	0.78, 1.48	0.61	0.41, 0.91	0.94	0.82, 1.08	1.00	0.82, 1.22	0.88	0.72, 1.07
Q2	1.00	0.79, 1.27	1.14	0.83, 1.56	0.82	0.56, 1.19	1.03	0.89, 1.19	1.02	0.83, 1.26	1.04	0.85, 1.26
Q3	0.90	0.68, 1.19	0.95	0.66, 1.36	0.83	0.54, 1.28	0.94	0.81, 1.08	1.04	0.85, 1.26	0.85	0.69, 1.05
Q4	1.00	Referent	1.00	Referent	1.00	Referent	1.00	Referent	1.00	Referent	1.00	Referent
P for trend	0.52		0.30		0.02		0.66		0.91		0.65	
P for interaction (SES × sex)				0.01						0.67		
P for interaction (SES × race/ethnicity)						0.57						
Average life course												
Q1	1.19	0.91, 1.55	1.37	1.00, 1.88	1.00	0.66, 1.51	1.15	0.97, 1.36	1.13	0.89, 1.43	1.15	0.90, 1.48
Q2	0.97	0.76, 1.23	1.10	0.80, 1.50	0.82	0.57, 1.19	1.07	0.91, 1.25	1.08	0.86, 1.35	1.03	0.84, 1.28
Q3	0.97	0.74, 1.27	1.01	0.70, 1.44	0.94	0.64, 1.40	1.03	0.89, 1.19	1.00	0.81, 1.24	1.04	0.83, 1.30
Q4	1.00	Referent	1.00	Referent	1.00	Referent	1.00	Referent	1.00	Referent	1.00	Referent
P for trend	0.17		0.04		0.84		0.12		0.25		0.29	
P for interaction (SES × sex)				0.06						0.44		
P for interaction (SES × race/ethnicity)						0.74						

Abbreviations: CI, confidence interval; HR, hazard ratio; Q, quartile; SES, socioeconomic status.

[a] Results were adjusted for age (years; continuous), sex (male or female), marital status (married, widowed, divorced, separated, or never married), education (less than high school, high school or vocational school, or college or higher), annual household income (<\$25,000, \$25,000–\$49,999, \$50,000–\$74,999, or ≥\$75,000), and study center (Washington County, Maryland; Forsyth County, North Carolina; Jackson, Mississippi; or the suburbs of Minneapolis, Minnesota).

[b] Older adulthood: baseline (median age, 62 years); middle adulthood: age 40–50 years; young adulthood: age 30 years; childhood: age 10 years. Average life-course neighborhood SES was calculated as the mean of neighborhood SES at each life stage, weighted by the duration of each stage.

[c] *P* value for the interaction term between neighborhood SES variables and sex in each racial/ethnic group.

[d] *P* value for the interaction term between neighborhood SES variables and race/ethnicity in the overall sample.

Table 4. Associations Between Neighborhood Socioeconomic Status Patterns Across Life Stages and Incident Cardiovascular Disease Among 9,692 Participants in the Atherosclerosis Risk in Communities Study, 1996–2019

Quartile of Neighborhood SES Over the Life Course[a]	Total Cardiovascular Disease				Heart Failure				Coronary Heart Disease				Stroke			
	Model 1[b]		Model 2[c]		Model 1		Model 2		Model 1		Model 2		Model 1		Model 2	
	HR	95% CI	HR	95% CI	HR	95% CI	HR	95% CI	HR	95% CI	HR	95% CI	HR	95% CI	HR	95% CI
Middle-to-older adulthood																
Low-low	1.31	1.20, 1.43	1.14	1.03, 1.26	1.44	1.30, 1.61	1.23	1.09, 1.40	1.28	1.11, 1.47	1.08	0.92, 1.28	1.19	1.01, 1.40	0.94	0.78, 1.14
Low-high	1.17	1.03, 1.33	1.08	0.95, 1.23	1.25	1.07, 1.47	1.16	0.99, 1.37	1.22	1.00, 1.50	1.11	0.90, 1.37	0.92	0.71, 1.18	0.81	0.63, 1.05
High-low	1.21	1.06, 1.38	1.14	0.99, 1.31	1.26	1.06, 1.49	1.19	0.99, 1.41	1.37	1.12, 1.68	1.26	1.03, 1.54	1.05	0.81, 1.36	0.91	0.69, 1.19
High-high	1.00	Referent	1.00	Referent	1.00	Referent	1.00	Referent	1.00	Referent	1.00	Referent	1.00	Referent	1.00	Referent
Young-to-middle adulthood																
Low-low	1.35	1.23, 1.49	1.17	1.05, 1.31	1.46	1.29, 1.65	1.24	1.08, 1.42	1.31	1.13, 1.52	1.11	0.94, 1.32	1.26	1.03, 1.53	0.89	0.71, 1.11
Low-high	1.18	1.03, 1.35	1.1	0.96, 1.27	1.21	1.01, 1.44	1.12	0.93, 1.34	1.17	0.95, 1.45	1.11	0.90, 1.37	1.19	0.88, 1.61	0.98	0.76, 1.25
High-low	1.18	1.02, 1.35	1.04	0.90, 1.20	1.34	1.14, 1.59	1.16	0.97, 1.38	1.1	0.88, 1.37	0.97	0.77, 1.22	1.02	0.77, 1.34	0.81	0.60, 1.08
High-high	1.00	Referent	1.00	Referent	1.00	Referent	1.00	Referent	1.00	Referent	1.00	Referent	1.00	Referent	1.00	Referent
Childhood to young adulthood																
Low-low	1.26	1.12, 1.42	1.14	1.01, 1.30	1.31	1.12, 1.52	1.16	0.99, 1.37	1.23	1.04, 1.45	1.1	0.93, 1.31	1.19	0.94, 1.50	0.91	0.70, 1.18
Low-high	1.06	0.93, 1.21	1.01	0.89, 1.16	1.11	0.91, 1.35	1.05	0.86, 1.28	1.03	0.86, 1.24	0.99	0.82, 1.19	0.91	0.72, 1.16	0.79	0.59, 1.05
High-low	1.27	1.10, 1.47	1.14	0.98, 1.32	1.31	1.06, 1.62	1.14	0.92, 1.43	1.27	1.07, 1.52	1.14	0.95, 1.37	1.17	0.91, 1.50	0.96	0.76, 1.22
High-high	1.00	Referent	1.00	Referent	1.00	Referent	1.00	Referent	1.00	Referent	1.00	Referent	1.00	Referent	1.00	Referent

Abbreviations: CI, confidence interval; HR, hazard ratio; SES, socioeconomic status.

[a] Low and high neighborhood SES were defined on the basis of the median neighborhood SES at each life stage. Older adulthood: baseline (median age, 62 years); middle adulthood: age 40–50 years; young adulthood: age 30 years; childhood: age 10 years.

[b] Results were adjusted for age (years; continuous) and sex (male or female).

[c] Results were adjusted for age (years; continuous), sex (male or female), race/ethnicity (Black or White), marital status (married, widowed, divorced, separated, or never married), education (less than high school, high school or vocational school, or college or higher), annual household income (<$25,000, $25,000–$49,999, $50,000–$74,999, or ≥$75,000), and study center (Washington County, Maryland; Forsyth County, North Carolina; Jackson, Mississippi; or the suburbs of Minneapolis, Minnesota).

Table 5. Associations[a] Between Neighborhood Socioeconomic Status Patterns Across Life Stages and Total Incident Cardiovascular Disease, by Race/Ethnicity and Sex, in the Atherosclerosis Risk in Communities Study, 1996–2019

Quartile of Neighborhood SES Over the Life Course[b]	Total Cardiovascular Disease Risk											
	Black Participants						White Participants					
	Overall (n = 728)		Black Women (n = 448)		Black Men (n = 280)		Overall (n = 2,222)		White Women (n = 1,154)		White Men (n = 1,068)	
	HR	95% CI	HR	95% CI	HR	95% CI	HR	95% CI	HR	95% CI	HR	95% CI
Middle-to-older adulthood												
Low-low	1.24	1.03, 1.48	1.47	1.16, 1.85	0.98	0.72, 1.32	1.09	0.97, 1.23	1.11	0.94, 1.31	1.07	0.89, 1.28
Low-high	1.25	0.95, 1.65	1.22	0.83, 1.79	1.33	0.90, 1.96	1.01	0.86, 1.18	1.04	0.83, 1.30	0.97	0.78, 1.22
High-low	1.26	0.93, 1.71	1.59	1.08, 2.35	0.83	0.48, 1.46	1.12	0.96, 1.31	1.23	0.99, 1.52	1.00	0.79, 1.26
High-high	1.00	Referent	1.00	Referent	1.00	Referent	1.00	Referent	1.00	Referent	1.00	Referent
P for interaction (SES × sex)[c]					0.04						0.33	
P for interaction (SES × race/ethnicity)[d]							0.27					
Young-to-middle adulthood												
Low-low	1.30	1.02, 1.67	1.40	1.05, 1.87	1.20	0.81, 1.77	1.11	0.98, 1.27	1.10	0.92, 1.31	1.12	0.93, 1.34
Low-high	1.07	0.82, 1.40	1.13	0.79, 1.61	0.99	0.65, 1.49	1.12	0.96, 1.30	1.08	0.86, 1.36	1.14	0.92, 1.42
High-low	1.07	0.83, 1.39	1.19	0.88, 1.62	0.92	0.60, 1.40	1.01	0.85, 1.20	0.98	0.77, 1.24	1.04	0.83, 1.31
High-high	1.00	Referent	1.00	Referent	1.00	Referent	1.00	Referent	1.00	Referent	1.00	Referent
P for interaction (SES × sex)					0.37						0.59	
P for interaction (SES × race/ethnicity)							0.38					
Childhood to young adulthood												
Low-low	1.16	0.89, 1.51	1.4	1.02, 1.93	0.90	0.61, 1.33	1.13	0.97, 1.30	1.09	0.89, 1.34	1.15	0.95, 1.40
Low-high	0.94	0.72, 1.23	1.19	0.87, 1.62	0.66	0.43, 1.03	1.03	0.87, 1.21	1.00	0.80, 1.25	1.06	0.86, 1.30
High-low	1.13	0.79, 1.61	1.26	0.87, 1.83	1.00	0.60, 1.67	1.13	0.96, 1.34	1.12	0.89, 1.41	1.13	0.91, 1.40
High-high	1.00	Referent	1.00	Referent	1.00	Referent	1.00	Referent	1.00	Referent	1.00	Referent
P for interaction (SES × sex)					0.04						0.79	
P for interaction (SES × race/ethnicity)							0.91					

Abbreviations: CI, confidence interval; HR, hazard ratio; SES, socioeconomic status.

[a] Results were adjusted for age (years; continuous), sex (male or female), marital status (married, widowed, divorced, separated, or never married), education (less than high school, high school or vocational school, or college or higher), annual household income (<\$25,000, \$25,000–\$49,999, \$50,000–\$74,999, or ≥\$75,000), and study center (Washington County, Maryland; Forsyth County, North Carolina; Jackson, Mississippi; or the suburbs of Minneapolis, Minnesota).

[b] Older adulthood: baseline (median age, 62 years); middle adulthood: age 40–50 years; young adulthood: age 30 years; childhood: age 10 years. Average life-course neighborhood SES was calculated as the mean of neighborhood SES at each life stage, weighted by the duration of each stage.

[c] *P* value for the interaction term between neighborhood SES variables and sex in each racial/ethnic group.

[d] *P* value for the interaction term between neighborhood SES variables and race/ethnicity in the overall sample.

study conducted in Finland, Kivimäki et al. (40) reported that childhood neighborhood disadvantage was associated with multiple cardiometabolic risk factors, including obesity, hypertension, and diabetes, by middle age.

The lack of association between childhood neighborhood SES and CVD risk in older adulthood in our study may be explained by several factors. First, recalled childhood neighborhood SES may not be accurate. Unlike adulthood neighborhood SES, which was measured at the census-tract level, childhood neighborhood SES was measured at the county level. Misclassification of neighborhood SES is thus possible, as this larger geographic unit does not reflect neighborhood exposures. Moreover, it is challenging to recall early-life residential locations precisely, which may also lead to errors in the assignment of census data (32). Taken together, these issues suggest that our measure of childhood neighborhood SES may have been subject to exposure misclassification. Second, it has been proposed that childhood neighborhood SES may influence CVD risk by shaping socioeconomic trajectories later in life (41), and thus may not be an independent risk factor for CVD. However, we found no evidence suggesting an association between childhood neighborhood SES and CVD risk even without adjusting for adulthood education and income, implying that the null findings cannot be explained by this reason alone. Third, it has been proposed that children in low-SES neighborhoods, particularly Black girls, may avoid spending time in their home neighborhood because of safety concerns (42), and therefore neighborhood measurement based on home addresses may not accurately reflect actual neighborhood exposure. Finally, it is also possible that family SES plays a more important role than neighborhood SES in childhood development and has a larger impact on health trajectories in adulthood. Given that there is currently very limited research on childhood neighborhood SES and CVD, we encourage investigators in future studies to examine whether and how neighborhood conditions in childhood may influence cardiovascular health.

In race/ethnicity- and sex-specific analysis, we found that the association between neighborhood SES in older and middle adulthood and CVD risk was particularly strong among Black women. This finding is consistent with results from the Jackson Heart Study, a cohort study of over 4,000 African Americans, in which Barber et al. (13) also reported a sex difference in the association between neighborhood SES and total CVD risk: Each standard-deviation increase in neighborhood socioeconomic disadvantage was associated with a 25% increase in CVD incidence in women (HR = 1.25, 95% CI: 1.05, 1.45) but not in men (HR = 1.08, 95% CI: 0.82, 1.41). In the Black Women's Health Study, the lowest quartile of neighborhood SES was associated with a 40% increase in CVD mortality (12), and the effect estimate was higher than in predominantly White cohorts. These results, together with ours, suggest that neighborhood conditions in older and middle adulthood may be a particularly strong predictor of cardiovascular health outcomes among Black women. It has been proposed that individual characteristics may play an important role in modifying the association between neighborhood environment and health outcomes, because of differences in exposure patterns, relative socioeconomic standing in communities, perception about neighborhood conditions, and resources and abilities to take advantage of services in high-SES neighborhoods and/or cope with challenging environments (43, 44). For CVD, although there have been few studies examining its association with neighborhood SES according to both race/ethnicity and sex, it has been reported that the association may be particularly strong among low-SES individuals (45). Our findings extend current evidence and highlight the importance of considering individual-level factors as modulators of the association between neighborhood SES and health.

Our analysis focusing on life-course patterns of neighborhood SES found that chronic exposure to low neighborhood SES was a consistent predictor of high risk of CVD. In contrast, the association between changes in neighborhood SES (e.g., the low-high and high-low groups) and CVD was weaker and less consistent. In a previous analysis in the NIH-AARP Diet and Health Study, we found that declining neighborhood SES was associated with a higher risk of CVD, while improving neighborhood SES was associated with a lower risk (46). However, the study also found that such associations were only apparent for relatively large changes in neighborhood SES (i.e., a reduction or increase in neighborhood SES ranking by 20 percentile points or more). In the current analysis, we were not able to examine larger changes in neighborhood conditions because of a limited sample size. Studies with larger sample sizes, more dynamic neighborhood exposures, and longer follow-up periods are needed to further clarify the relationship between change in neighborhood SES and CVD risk.

Our study had several strengths. First, we assessed neighborhood SES during 4 life stages, from childhood to older adulthood, which allowed us to assess the 4 stages' distinctive relationships with CVD and to examine the associations for cumulative neighborhood SES exposures and changes in neighborhood SES across different life stages. Second, the large sample size and long follow-up enabled us to examine potential differences in the associations for each race-sex group and for different CVD subtypes. Our study also had several limitations. Neighborhood SES in middle and young adulthood and childhood was assessed on the basis of recall of address information, which may be subject to recall bias and open to exposure misclassification. As noted above, information on neighborhood SES in childhood could be assessed only at the county level, and lack of more granular measures may have contributed to the null findings for childhood SES. Moreover, for administrative reasons, follow-up for CVD outcomes at the Jackson, Mississippi, study site was paused in 2017, and we were not able to include more recent CVD events in the analysis as was done for other study sites. In addition, Black participants were clustered within study sites, with the majority of Black cohort members recruited from Jackson, Mississippi. Thus, the racial/ethnic differences we observed in this study may have been partially driven by regional differences. Studies using widely representative samples are needed to further examine race/ethnicity-specific associations between neighborhood SES and CVD. In addition, our study sample was not representative of the entire Black and White population of the United States, and the findings may not be generalizable to populations that differ from the study sample. Finally, we focused only on neighborhood SES measures and did not have information on other neighborhood factors, such as geographic racial discrimination and disparities in neighborhood health environment, that may have contributed to the observed associations between neighborhood SES and CVD, as well as potential differences among race-sex groups. In future studies, researchers should systematically investigate specific neighborhood attributes and pathways underlying the potential health effects of neighborhood environment in Black and White populations.

In summary, our findings from this large biracial cohort add to the growing literature supporting a role of neighborhood SES in various stages of adulthood and cardiovascular health. Our study also suggests that older Black women living in low-SES neighborhoods may be at especially high risk for developing cardiovascular events, such as heart failure and stroke. In future studies aimed at improving neighborhood conditions to reduce health disparities, investigators should consider the impact of such programs on individuals with different sociodemographic characteristics.

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Information about access to ARIC data can be found on the study's website (https://sites.cscc.unc.edu/aric/).

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