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ORIGINAL RESEARCH

County-Level Factors Associated With Cardiovascular Mortality by Race/Ethnicity

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BACKGROUND: Persistent racial/ethnic disparities in cardiovascular disease (CVD) mortality are partially explained by healthcare access and socioeconomic, demographic, and behavioral factors. Little is known about the association between race/ethnicity-specific CVD mortality and county-level factors.

METHODS AND RESULTS: Using 2017 county-level data, we studied the association between race/ethnicity-specific CVD age-adjusted mortality rate (AAMR) and county-level factors (demographics, census region, socioeconomics, CVD risk factors, and healthcare access). Univariate and multivariable linear regressions were used to estimate the association between these factors; R^2 values were used to assess the factors that accounted for the greatest variation in CVD AAMR by race/ethnicity (non-Hispanic White, non-Hispanic Black, and Hispanic/Latinx individuals). There were 659 740 CVD deaths among non-Hispanic White individuals in 2698 counties; 100 475 deaths among non-Hispanic Black individuals in 717 counties; and 49 493 deaths among Hispanic/Latinx individuals across 267 counties. Non-Hispanic Black individuals had the highest mean CVD AAMR (320.04 deaths per 100 000 individuals), whereas Hispanic/Latinx individuals had the lowest (168.42 deaths per 100 000 individuals). The highest CVD AAMRs across all racial/ethnic groups were observed in the South. In unadjusted analyses, the greatest variation (R^2) in CVD AAMR was explained by physical inactivity for non-Hispanic White individuals (32.3%), median household income for non-Hispanic Black individuals (24.7%), and population size for Hispanic/Latinx individuals (28.4%). In multivariable regressions using county-level factor categories, the greatest variation in CVD AAMR was explained by CVD risk factors for non-Hispanic White individuals (35.3%), socioeconomic factors for non-Hispanic Black (25.8%), and demographic factors for Hispanic/Latinx individuals (34.9%).

CONCLUSIONS: The associations between race/ethnicity-specific age-adjusted CVD mortality and county-level factors differ significantly. Interventions to reduce disparities may benefit from being designed accordingly.

Key Words: cardiovascular disease mortality ■ disparities ■ race/ethnicity ■ social determinants

Cardiovascular disease (CVD) is the leading cause of death in the United States across all racial/ethnic groups.[1,2] Disparities in CVD outcomes for racial/ethnic minority groups have been documented extensively.[3] These disparities are complex, originating from a broad range of factors from patient behavior to community-level social determinants of health.[3] To narrow the gaps in outcomes, it is critical to develop an improved understanding of the drivers of variation in CVD outcomes among racial/ethnic populations.[4]

Historically, investigation of CVD outcome variation has focused on differences in patient-level behavior and health history. However, recent research has increasingly demonstrated the significant contribution of community-level risk factors to variation in CVD outcomes.[5–10] For example, just 10% of variation in CVD mortality across states is accounted for

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CLINICAL PERSPECTIVE

What Is New?

- We present the most thorough and detailed analysis to date of county-level predictors of cardiovascular mortality among non-Hispanic White, non-Hispanic Black, and Hispanic/Latinx individuals; we identify important variation in the most valuable factors for explaining cardiovascular mortality in different racial/ethnic groups.
- The greatest variation in cardiovascular disease mortality is explained by traditional cardiovascular disease risk factors for non-Hispanic White individuals, socioeconomic factors for non-Hispanic Black individuals, and demographic factors for Hispanic/Latinx individuals.
- The granularity of our analysis identifies factors, such as food insecurity, as important predictors across racial/ethnic groups and allows for nuanced understanding of the interaction of risk factors.

What Are the Clinical Implications?

- Understanding of the differential importance of risk factors across racial/ethnic groups is critical for targeting persistent disparities in cardiovascular disease mortality.
- Our analysis supports increased focus on social determinants of health across all racial/ethnic groups, but particularly for non-Hispanic Black individuals, for whom this was the strongest predictor in our analysis.
- Granular understanding of the variation in county-level risk factors across racial/ethnic groups can be leveraged to inform future investigation of interventions at the national and local levels.

Nonstandard Abbreviations and Acronyms

AAMR	age-adjusted mortality rate
CDC	Centers for Disease Control and Prevention
NHW	non-Hispanic White

by classic CVD risk factors, such as hyperlipidemia and diabetes mellitus, whereas almost three quarters of the variation in CVD mortality across US counties is explained by county-level risk factors, such as median household income and measures of healthcare access.[5,11] However, despite this growing evidence, most interventions to reduce health disparities take a disease-specific focus on individual or health system factors and often fail to account for social determinants of health.[12–14]

Most studies evaluating associations between community-level risk factors and CVD outcomes focus on just a few or a single risk factor. These make important contributions to the literature but may make it difficult to infer the relative importance of specific risk factors or subgroups of risk factor. Other studies have identified the importance of socioeconomic factors and CVD mortality differences between non-Hispanic White individuals (hereafter referred to as NHW individuals) and non-Hispanic Black individuals (hereafter referred to as Black individuals).[8] There have been no studies of the interplay between county-level factors and variation in race/ethnic-specific CVD mortality, including NHW individuals, Black individuals, and Hispanic/Latinx individuals, the largest and most rapidly growing minority group in the United States.

We examined the association between an extensive set of county-level risk factors and variation in contemporary CVD mortality among racial/ethnic groups, focusing on the counties where each relevant population resides.

METHODS

This article is reported following the Strengthening the Reporting of Observational Studies in Epidemiology guidelines for cross-sectional studies.[15] All data and materials used in this analysis are publicly available through the Centers for Disease Control and Prevention's (CDC's) Wide-Ranging Online Data for Epidemiologic Research database and the Robert Wood Johnson County Health Rankings database.

CVD Age-Adjusted Mortality Rates

County-level CVD age-adjusted mortality rates (AAMRs) were extracted from the publicly available CDC Wide-Ranging Online Data for Epidemiologic Research database for all age groups in 2017. CDC Wide-Ranging Online Data for Epidemiologic Research mortality rates are based on death certificate records collected by the National Center for Health Statistics.[16] County-level CVD mortality rates were defined as the number of deaths per 100 000 individuals that were attributed to diseases of the circulatory system (*International Classification of Diseases, Tenth Revision* [*ICD-10*] codes I05–I89) in a county. CVD mortality rates were calculated for counties with >20 deaths (Figure S1). The AAMRs were age adjusted by the CDC based on the 2000 US Census standard population. County-level race/ethnicity-specific AAMRs were extracted for self-identified NHW individuals, Black individuals, and Hispanic/Latinx individuals. CVD mortality data for self-identified American Indian or Alaska Native,

Native Hawaiian or other Pacific Islander, and Asian individuals were excluded from analysis because of limited reliable AAMRs.

County-Level Factors

County-level factors were derived from the 2017 Robert Wood Johnson Foundation County Health Rankings, an annual county-level data set based on a statistical compilation and interpolation of data from the Behavioral Risk Factor Surveillance System, Dartmouth Institute, American Community Survey, CDC Diabetes Interactive Atlas, CDC Wide-Ranging Online Data for Epidemiologic Research, Centers for Medicare & Medicaid Services National Provider Identification, US Census, and US Department of Agriculture.

Five categories of county-level factors were hypothesized a priori to explain variation in CVD AAMR based on previous work: demographic factors, census region, socioeconomic factors, CVD risk factors, and healthcare factors. For each pair of county-level factors that had a pairwise linear correlation of ≥0.8, the one with the weaker association with CVD mortality by univariate regression was excluded. After exclusions, the categories included the following: (1) demographic factors (population size, percentage rural, percentage women, percentage Black individuals, percentage Asian individuals, and percentage Hispanic individuals); (2) census region (Northeast, Midwest, South, and West); (3) socioeconomic factors (percentage some college, percentage unemployed, percentage food insecure, and median household income); (4) CVD risk factors (percentage smokers, percentage physically inactive, percentage diabetic individuals, and percentage obese individuals); and (5) healthcare factors (primary care provider rate and percentage uninsured adults) (see Table S1 for variable definitions and data sources). County-level population and median household income were log normalized and, in addition to primary care provider rate, were scaled to have a maximum value of 100 to facilitate comparison across covariates that are otherwise percentages.

Statistical Analysis

Univariate linear regression models were developed to determine the association between each county-level factor and CVD AAMR for NHW individuals, Black individuals, and Hispanic/Latinx individuals. We then developed a set of multivariable linear regression models for each of the 3 outcome variables (AAMR among NHW, Black, and Hispanic/Latinx individuals). Each set of multivariable linear regression models included an individual model for each of our 5 categories of county-level factors and a sixth model including all county-level factors. Because of the potential for variation in community factors over time and the unknown time to effect of community factors on CVD outcomes, we performed a sensitivity analysis using 2014 county-level factors (2014 was the first year Robert Wood Johnson Foundation County Health Rankings data included all the current set of variables) (Table S2). R^2 values were used to assess the factors that accounted for the greatest variation in CVD AAMR.

Spatial Analysis

We hypothesized that correlation of spatially associated observations (ie, nearby counties are more likely to have similar CVD AAMR) would be explained by the county-level risk factors for CVD mortality adjusted for in our models. To test this hypothesis, we estimated the average autocorrelation of model residuals using the Moran I statistic, a measure of correlation of observations with nearby observations. This analysis was performed for our 3 models using all county-level factors for NHW, Black, and Hispanic/Latinx populations. If there was significant spatial autocorrelation of the regression residuals, then we would perform additional analyses to account for spatial autocorrelation in our models. We would build 3 models using all county-level factors for NHW, Black, and Hispanic/Latinx populations, but using the R function *lagsarlm* to include spatial weights defined by the *queen* criterion (assigned 1 for shared boundary and 0 for no shared boundary).[17] We then would evaluate whether accounting for spatial autocorrelation affected our models.

All statistical analyses were performed using R 3.5.2 software (The R Foundation). This analysis of publicly available data was reviewed by a Stanford University institutional review board, which determined it was exempt from review, and need for consent was waived.

RESULTS

In 2017, there were 659 740 CVD deaths among NHW individuals (in 2624 counties); 100 475 CVD deaths among Black individuals (in 717 counties); and 49 493 CVD deaths among Hispanic/Latinx individuals (in 267 counties) (Figure S1). Black individuals had the highest mean CVD AAMR (320.04 deaths per 100 000 individuals) nationwide, which was 29% higher than NHW individuals (248.69 deaths per 100 000 individuals). On the other hand, Hispanic/Latinx individuals had the lowest mean CVD AAMR (168.42 deaths per 100 000 person-years) nationwide (Table 1). There were geographic differences in CVD AAMR by racial/ethnic subgroup (Figure 1 and Table 1). The South had the highest mean CVD AAMR for all racial/ethnic groups. For NHW individuals, the lowest CVD AAMR was seen in the West (211.95 deaths per 100 000 individuals), whereas the lowest mean CVD AAMRs for Black and Hispanic/Latinx individuals were in the Northeast

Table 1. Summary Statistics for County-Level Factors by Race/Ethnicity-Specific County Cohorts

Variable	Summary Statistics, Mean (SD)		
	NHW CVD AAMR	Black CVD AAMR	Hispanic/Latinx CVD AAMR
No. of Counties*	2624	717	267
AAMR	248.69 (61.29)	320.04 (88.07)	168.42 (55.10)
Demographic factors			
Population	121 271 (357 163)	317 176 (634 184.2)	653 444 (927 873)
Rural, %	53.05 (29.46)	34.82 (28.92)	13.39 (14.47)
Women, %	50.14 (1.90)	51.01 (1.58)	50.45 (1.71)
Black, %†	9.26 (13.48)	25.19 (17.79)	9.68 (10.34)
Asian, %†	1.57 (2.79)	2.87 (4.31)	5.25 (6.16)
Hispanic/Latinx, %†	8.29 (11.53)	9.70 (10.82)	30.06 (21.75)
Census region, mean (SE) AAMR			
Northeast	216.91 (34.50)	258.80 (63.37)	143.64 (36.05)
Midwest	237.00 (49.07)	312.15 (63.66)	167.03 (54.34)
South	271.57 (66.12)	331.46 (91.16)	176.70 (67.63)
West	211.95 (48.32)	281.27 (65.70)	171.42 (42.65)
Sociodemographic factors			
Some college, %	56.93 (11.05)	57.88 (11.50)	61.12 (10.92)
Unemployed, %	5.59 (1.79)	6.14 (1.72)	5.83 (2.47)
Food insecure, %	14.74 (3.85)	17.26 (5.17)	14.10 (3.42)
Median household income, $	49 008 (12 434)	49 649 (15 759)	57 136 (16 057)
CVD risk factors			
Smokers, %	17.94 (3.30)	18.17 (3.38)	15.21 (2.76)
Physically inactive, %	25.01 (5.32)	26.37 (5.49)	21.60 (4.36)
Diabetic, %	11.32 (2.42)	12.06 (2.82)	9.46 (1.81)
Obese, %	31.15 (4.42)	31.92 (5.47)	26.96 (4.45)
Healthcare factors			
PCP rate	56.63 (32.18)	63.14 (32.22)	72.47 (28.82)
Uninsured, %	16.59 (5.84)	18.52 (5.48)	18.88 (7.28)

Summary statistics are shown for race/ethnicity-specific county cohorts. AAMR indicates age-adjusted mortality rate (number of deaths per 100 000 individuals); CVD, cardiovascular disease; NHW, non-Hispanic White; and PCP rate, primary care physician rate (PCPs per 100 000 population).

*Number of counties with available and reliable CVD AAMR.

†Refers to the average percentage of the county population of the specified racial/ethnic group.

(258.80 deaths per 100 000 individuals and 143.64 deaths per 100 000 individuals, respectively). Overall, CVD deaths among Black and Hispanic/Latinx individuals were concentrated. Most represented counties for Black individuals were in the South, and most for Hispanic/Latinx individuals were in the West.

County-level factors (demographics, census region, socioeconomics, CVD risk, and healthcare factors) differed across the groups of counties for which CVD AAMRs were available for each racial/ethnic group (Table 1). These differences were most pronounced for the counties with reliable Hispanic/Latinx mortality data, which had the largest population, highest education levels, highest median income, lowest physical inactivity, lowest percentage diabetic, highest primary care provider rate, but also the highest uninsured rate. Conversely, counties with reliable mortality data for Black individuals had the highest unemployment, greatest food insecurity, highest percentage smokers, highest physical inactivity, highest percentage diabetic, and highest percentage obese.

In univariate analysis, the county-level factors that had the greatest positive association with CVD AAMR were percentage diabetic (ß coefficient=12.3) for NHW individuals, percentage unemployment (ß coefficient=19.5) for Black individuals, and percentage smokers (ß coefficient=6.20) for Hispanic/Latinx individuals (Table 2). The individual county-level factors that had the strongest negative association with CVD AAMR were median household income for NHW and Black individuals (ß coefficients=−15.9 and −17.6, respectively) and percentage women (ß coefficient=−14.6) for Hispanic/Latinx individuals. County-level factors that explained the greatest proportion of variance in CVD

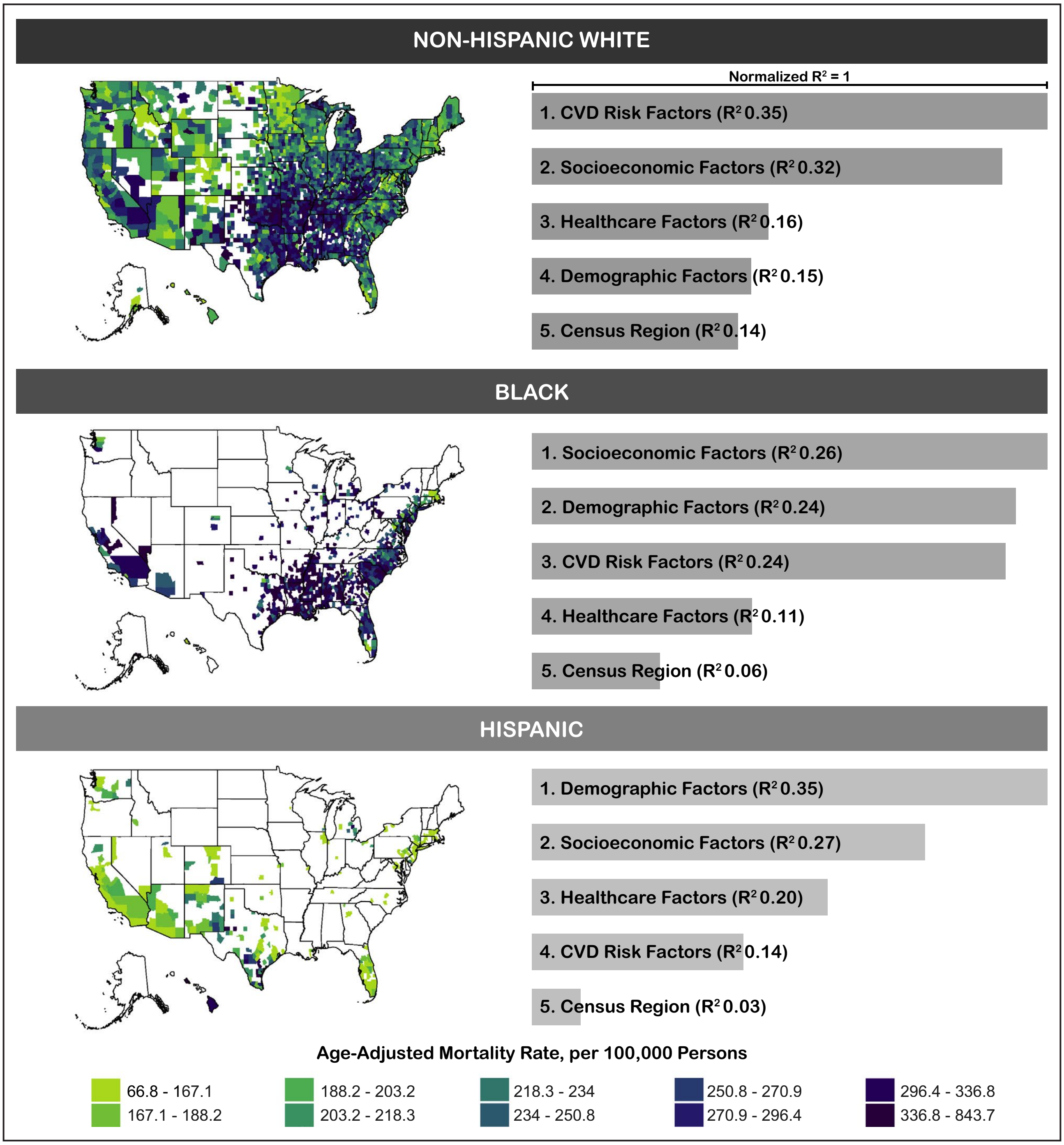

Figure 1. Differences across racial/ethnic groups in the county-level factors most strongly associated with age-adjusted cardiovascular disease (CVD) mortality.

Maps show variation in county-level age-adjusted cardiovascular mortality rate across the United States. There were 698 overlapping counties between non-Hispanic White (NHW) and Black county cohorts, 258 between NHW and Hispanic/Latinx county cohorts, and 179 between Black and Hispanic/Latinx county cohorts. Categories of factors that were included in multivariable analysis are shown ranked by the amount of variance in age-adjusted cardiovascular mortality rate that they explain (R^2). The width of the colored boxes is the R^2 relative to a reference of the maximum R^2 for each race/ethnicity. Factor categories and included county-level factors: demographic factors (population size, percentage rural, percentage women, percentage Black individuals, percentage Asian individuals, and percentage Hispanic individuals); census region (Northeast, Midwest, South, and West); socioeconomic factors (percentage some college, percentage unemployed, percentage food insecure, and median household income); CVD risk factors (percentage smokers, percentage physically inactive, percentage diabetic individuals, and percentage obese individuals); and healthcare factors (primary care provider rate and percentage uninsured adults).

Table 2. Univariate Regression Results for Race/Ethnicity-Specific CVD AAMR

Variable	NHW CVD AAMR		Black CVD AAMR		Hispanic/Latinx CVD AAMR	
	ß (SE)	R^2	ß (SE)	R^2	ß (SE)	R^2
No. of Counties*	2624		717		267	
Demographic factors						
Population†	−2.21 (0.15)‡	0.080	−4.84 (0.33)‡	0.229	−3.76 (0.37)‡	0.284
Rural, %	0.48 (0.04)‡	0.053	1.11 (0.11)‡	0.133	1.62 (0.21)‡	0.182
Women, %	−0.36 (0.63)	0.0001	0.92 (2.09)	0.0003	−14.6 (1.76)‡	0.205
Black, %§	0.91 (0.09)‡	0.040	1.28 (0.18)‡	0.067	−1.26 (0.32)‡	0.056
Asian, %§	−5.33 (0.42)‡	0.059	−6.75 (0.72)‡	0.109	−1.79 (0.54)‡	0.040
Hispanic/Latinx, %§	−0.36 (0.10)‡	0.005	−1.72 (0.30)‡	0.045	1.06 (0.14)‡	0.175
Census region‖						
Northeast	NA		NA		NA	
Midwest	NA		NA		NA	
South	NA		NA		NA	
West	NA		NA		NA	
Sociodemographic factors						
Some college, %	−2.73 (0.09)‡	0.243	−3.32 (0.26)‡	0.188	−2.36 (0.27)‡	0.218
Unemployed, %	11.6 (0.63)‡	0.115	19.5 (1.77)‡	0.145	2.80 (1.36)	0.016
Food insecure %	6.94 (0.28)‡	0.190	7.53 (0.57)‡	0.195	1.08 (0.99)	0.004
Median household income†	−15.9 (0.51)‡	0.269	−17.6 (1.15)‡	0.247	−10.3 (1.32)‡	0.186
CVD risk factors						
Smokers, %	9.60 (0.31)‡	0.267	11.7 (0.87)‡	0.202	6.20 (1.17)‡	0.096
Physically inactive, %	6.54 (0.19)‡	0.323	7.66 (0.53)‡	0.228	3.74 (0.74)‡	0.087
Diabetic, %	12.3 (0.43)‡	0.237	12.8 (1.07)‡	0.168	3.25 (1.86)	0.011
Obese, %	6.27 (0.24)‡	0.205	7.06 (0.54)‡	0.192	3.56 (0.73)‡	0.083
Healthcare factors						
PCP rate¶	−1.84 (0.12)‡	0.089	−2.24 (0.34)‡	0.056	−3.44 (0.42)‡	0.206
Uninsured, %	3.54 (0.19)‡	0.114	5.04 (0.57)‡	0.098	2.12 (0.45)‡	0.078

ß, SE, and R^2 values are shown from univariate regression models for each individual county-level factor variable. ß indicates ß coefficient; AAMR, age-adjusted mortality rate (defined as the number of deaths per 100 000 individuals); CVD, cardiovascular disease; NA, not applicable; NHW, non-Hispanic White; and PCP, primary care physician.

*Number of counties with available and reliable CVD AAMR.

†Variables were log normalized and scaled to have a maximum value of 100.

‡*P*<0.01.

§Refers to the average percentage of the county population of the specified racial/ethnic group.

‖Categorical variables were excluded from univariate analysis.

¶Variable was scaled to have a maximum value of 100.

AAMR were percentage physically inactive (32.3%) for NHW individuals, median household income (24.7%) for Black individuals, and county population size (28.4%) for Hispanic/Latinx individuals. Notably, higher percentage of Hispanic/Latinx individuals in a county was associated with lower CVD AAMR among NHW and Black individuals, but higher CVD AAMR among Hispanic/Latinx individuals.

Multivariable models using the categories of pre-specified county-level factors (demographics, census region, socioeconomics, CVD risk, and healthcare factors) and combined models using all factors revealed important patterns in explanation of CVD AAMR variance by race/ethnicity (Figures 1 and 2 and Table 3). For example, in the multivariable regression socioeconomic factors model, the percentage of individuals with some college education was significantly inversely associated with CVD mortality for all groups. This inverse relationship was attenuated for all groups after adjusting for all other factors in the combined model, and only remained significant for the NHW population. In addition, in the demographic factor– specific model, percentage rural in a county was significantly positively associated with CVD mortality for NHW individuals, but in the combined model, the significant association reversed to a negative association. Figure 2 displays the

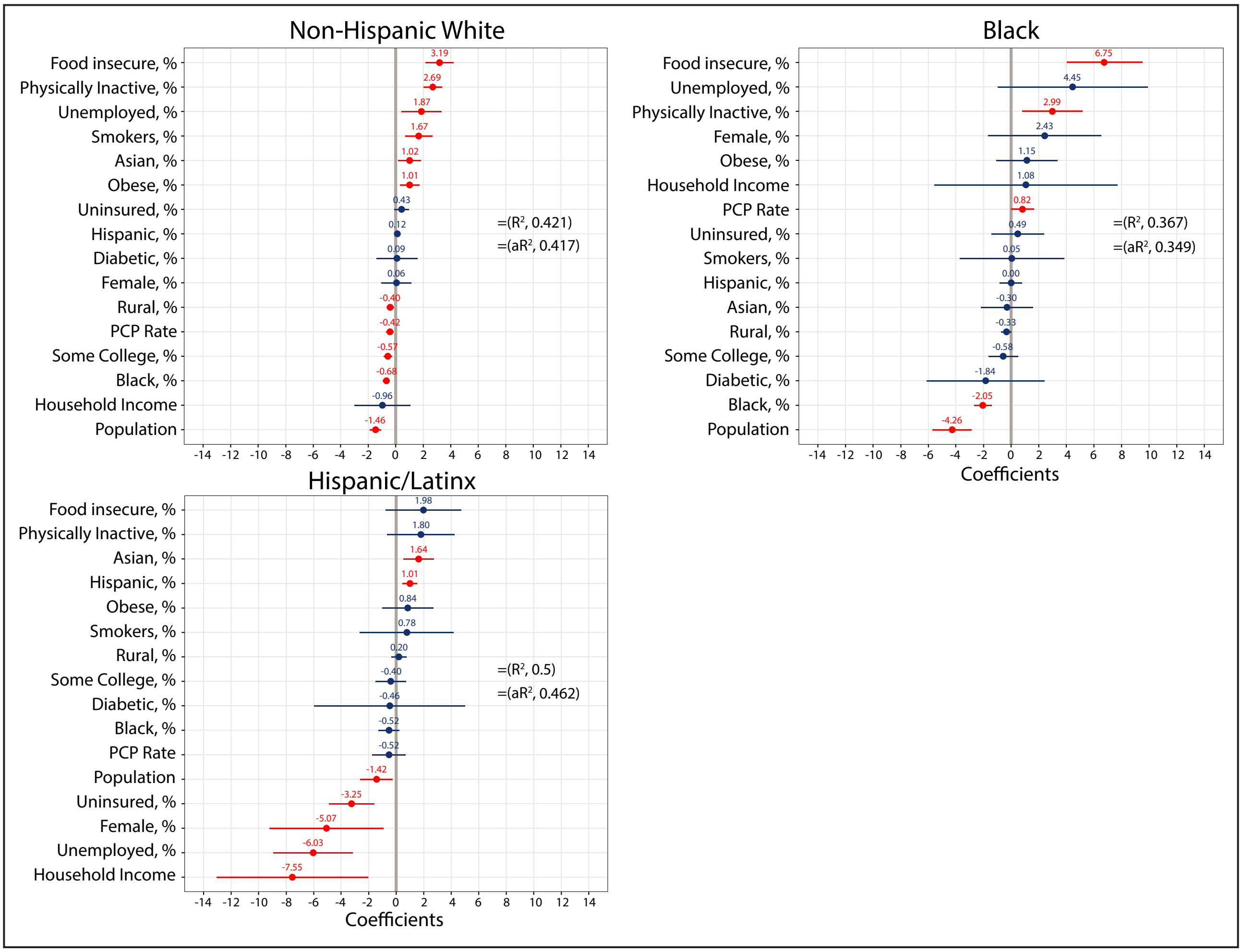

Figure 2. Multivariable regression model results for race/ethnicity-specific cardiovascular disease (CVD) age-adjusted mortality rate (AAMR).

Multivariable regression models including all county-level factors (percentage food insecure, percentage physically inactive, percentage smokers, percentage women, percentage obese, percentage unemployed, percentage Asian individuals, percentage diabetic, percentage uninsured, percentage Hispanic individuals, percentage Black individuals, primary care provider (PCP) rate, percentage rural, percentage some college, median household income, and population) for each of the county cohorts: non-Hispanic White, Black, and Hispanic/Latinx individuals. Point estimates are ß coefficients, and error bars indicate CIs. Blue signifies covariates with significant associations with CVD AAMR (P<0.01), whereas red signifies nonsignificant associations. aR^2 indicates adjusted R^2.

regression coefficients for our combined multivariable models for each racial/ethnic group, demonstrating the variability in importance of different factors for explaining variation in CVD AAMR in these populations. For example, although percentage of the population with food insecurity has the highest point estimate for positive effect on CVD AAMR across all groups, median household income was the greatest negative predictor for Hispanic/Latinx individuals but was not predictive for Black individuals (Figure 2).

All county-level factors in multivariable regression explained 41.7% of the variation in CVD AAMR among NHW individuals, 34.9% of the variation in CVD AAMR among Black individuals, and 46.2% of the variation in CVD AAMR among Hispanic/Latinx individuals (Table 3). CVD risk factors explained the greatest variation (35.3%) in CVD AAMR among NHW individuals, socioeconomic factors explained the greatest variation (25.8%) in CVD AAMR among Black individuals, and demographic factors explained the greatest variation (34.9%) in CVD AAMR among Hispanic/Latinx individuals. Socioeconomic factors were a close second for both NHW individuals and Hispanic/Latinx individuals (32.2% and 26.6%, respectively) in explaining the greatest variation in CVD mortality, whereas CVD risk factors (24.2%) and demographic factors (23.7%) were a close second and third, respectively, for Black individuals (Table 3). A sensitivity analysis evaluating the association between county-level factors from 2014 and CVD mortality produced similar results (Table S2).

Spatial analysis using the Moran I statistic demonstrated that after adjustment for the county-level factors

Table 3. Predictors of Race/Ethnicity-Specific CVD AAMRs in Multivariable Regression Models of Categories of County-Level Factors and All Factors Combined

Variable	NHW CVD AAMR	Black CVD AAMR	Hispanic/Latinx CVD AAMR	NHW CVD AAMR	Black CVD AAMR	Hispanic/Latinx CVD AAMR
	(n=2624)	(n=717)	(n=267)	(n=2624)	(n=717)	(n=267)
	Factor Category Models			Combined Models*		
				R^2: 0.42 aR^2: 0.42	R^2: 0.37 aR^2: 0.35	R^2: 0.50 aR^2: 0.46
Demographic factors[†]	R^2: 0.15 aR^2: 0.15	R^2: 0.24 aR^2: 0.24	R^2: 0.36 aR^2: 0.35			
Population[‡]	−1.81 (0.23)[§]	−5.89 (0.72)[§]	−1.99 (0.63)[§]	−1.47 (0.21)[§]	−4.26 (0.72)[§]	−1.42 (0.59)[‖]
Rural, %	0.13 (0.06)[‖]	−0.32 (0.18)	0.50 (0.29)	−0.40 (0.06)[§]	−0.33 (0.19)	0.20 (0.28)
Women, %	1.14 (0.61)	2.70 (1.93)	−7.40 (1.9)[§]	0.060 (0.56)	2.43 (2.09)	−5.07 (2.11)[‖]
Black, %	1.09 (0.08)[§]	−0.19 (0.21)	0.34 (0.31)	−0.68 (0.11)[§]	−2.05 (0.32)[§]	−0.52 (0.38)
Asian, %	−2.47 (0.48)[§]	−1.72 (0.83)[‖]	0.39 (0.52)	1.015 (0.42)[§]	−0.30 (0.96)	0.16 (0.57)[§]
Hispanic/Latinx, %	0.36 (0.11)[§]	0.64 (0.33)[‖]	0.47 (0.15)[§]	0.12 (0.12)	0.003 (0.41)	1.01 (0.27)[§]
Census region[¶]	R^2: 0.14 aR^2: 0.14	R^2: 0.068 aR^2: 0.064	R^2: 0.044 aR^2: 0.033			
Northeast	−20.1 (4.35)[§]	−53.3 (14.3)[§]	−23.4 (13.5)	4.70 (3.97)	−22.8 (13.3)	−17.25 (11.4)
South	34.6 (2.52)[§]	19.3 (10.4)	9.68 (12.0)	7.95 (2.87)[§]	−18.4 (11.3)	−3.69 (11.79)
West	−25.0 (3.76)[§]	−30.9 (16.9)	4.39 (12.2)	−12.86 (3.99)[§]	7.39 (18.2)	−11.55 (12.4)
SES factors[#]	R^2: 0.32 aR^2: 0.32	R^2: 0.26 aR^2: 0.26	R^2: 0.28 aR^2: 0.27			
Some college, %	−1.57 (0.12)[§]	−1.34 (0.39)[§]	−1.63 (0.40)[§]	−0.58 (0.16)[§]	−0.58 (0.54)	−0.40 (0.56)
Unemployed, %	−0.61 (0.71)	−0.17 (2.53)	−4.30 (1.40)[‖]	1.87 (0.75)[‖]	4.46 (2.77)	−6.03 (1.46)[§]
Food insecure, %	2.62 (0.38)[§]	2.23 (1.11)	−1.61 (1.07)	3.19 (0.53)[§]	6.75 (1.40)[§]	1.98 (1.36)
Median household income[‡]	−6.97 (0.85)[§]	−9.24 (2.68)[§]	−8.67 (2.19)[§]	−0.96 (1.037)	1.08 (3.38)	−7.55 (2.80)[§]
CVD risk factors**	R^2: 0.35 aR^2: 0.35	R^2: 0.25 aR^2: 0.24	R^2: 0.16 aR^2: 0.14			
Smokers, %	4.13 (0.42)[§]	4.77 (1.53)[‖]	3.92 (1.52)	1.67 (0.51)[§]	0.05 (1.92)	0.78 (1.74)
Physically inactive, %	4.11 (0.33)[§]	4.65 (1.02)[§]	3.36 (1.20)[‖]	2.69 (0.35)[§]	2.99 (1.11)[§]	1.80 (1.25)
Diabetic, %	1.67 (0.66)	0.76 (1.85)	−8.75 (2.57)[§]	0.089 (0.76)	−1.84 (2.17)	−0.46 (2.78)
Obese, %	0.14 (0.34)	0.56 (1.12)	2.01 (1.08)	1.007 (0.36)[§]	1.15 (1.14)	0.84 (0.94)
Healthcare factors[§]	R^2: 0.16 aR^2: 0.16	R^2: 0.11 aR^2: 0.11	R^2: 0.21 aR^2: 0.20			

(continues)

Table 3 Continued

Variable	NHW CVD AAMR	Black CVD AAMR	Hispanic/Latinx CVD AAMR	NHW CVD AAMR	Black CVD AAMR	Hispanic/Latinx CVD AAMR
	(n=2624)	(n=717)	(n=267)	(n=2624)	(n=717)	(n=267)
	Factor Category Models			Combined Models*		
PCP rate§	−1.41 (0.11)§	−1.24 (0.36)§	−0.29 (0.59)	−0.416 (0.117)§	0.82 (0.42)‖	−0.52 (0.61)
Uninsured, %	2.94 (0.19)§	4.18 (0.62)§	−2.30 (0.64)§	0.43 (0.28)	0.49 (0.97)	−3.25 (0.83)§

β coefficients (SEs), R^2 values, and multiple R^2 values are shown for multivariable regression models for each of the 5 county-level factor categories and a combined model including all covariates. These 6 models were analyzed for each of the county cohorts: NHW, Black, and Hispanic/Latinx individuals. AAMR indicates age-adjusted mortality rate; aR^2, adjusted R^2; CVD, cardiovascular disease; NHW, non-Hispanic White; PCP, primary care provider; and SES, socioeconomic status.

*Overall models adjusted for all studied variables.

†Model 1 (demographic factors): population, percentage rural, percentage women, percentage Black individuals, percentage Asian individuals, and percentage Hispanic/Latinx individuals.

‡Variables were log normalized and scaled to have a maximum value of 100.

§P<0.01.

‖P<0.05.

¶Model 2 (census region): Northeast, South, and West.

#Model 3 (socioeconomic factors): percentage some college, percentage unemployed, percentage food insecure, and median household income.

**Model 4 (CVD risk factors): percentage smokers, percentage physically inactive, percentage diabetic, and percentage obese.

††Model 5 (healthcare factors): PCP rate and percentage uninsured.

‡‡Variable was scaled to have a maximum value of 100.

included in our NHW, Black, and Hispanic/Latinx models, there was no spatial autocorrelation of the model residuals and, therefore, no further adjustment for spatial autocorrelation was indicated in our models. The Moran I statistics were 0.0091 (P=0.23), −0.017 (P=0.69), and 0.0011 (P=0.46) for the NHW, Black, and Hispanic/Latinx models, respectively.

DISCUSSION

Using contemporary national CVD mortality data, we found that the associations between county-level factors (demographics, census region, socioeconomics, CVD risk factors, and healthcare factors) and age-adjusted CVD mortality differ across racial/ethnic groups, and more important, that these factors have differential effects in explaining county-level differences in mortality within each racial/ethnic group. The greatest variation in CVD age-adjusted mortality was explained by traditional CVD risk factors for NHW individuals, socioeconomic factors for Black individuals, and demographic factors for Hispanic/Latinx individuals. We documented persistent disparities in CVD mortality by race/ethnicity, with Black individuals experiencing 29% higher mortality compared with NHW individuals.

Our analysis is complementary to prior literature that has documented ongoing racial/ethnic and geographic differences in CVD mortality.[18] Similar to prior studies, we found that Black individuals continue to experience the highest CVD mortality and that Hispanic/Latinx individuals experience the lowest CVD mortality.[19–21] The persistence of CVD mortality disparities for Black individuals, despite increasing recognition of CVD disparities over the past decade, indicates the root causes of CVD disparities, particularly for Black individuals, remain insufficiently addressed. Conversely, it is likely that counties where Hispanic/Latinx individuals live are generally healthier as observed in our data; counties with reliable estimates for CVD mortality among Hispanic/Latinx individuals tended to be larger, more educated, wealthier, and located in urban areas. These positive county-level factors may in part influence improved CVD outcomes among Hispanic/Latinx individuals relative to other racial/ethnic groups. Our finding that Hispanic/Latinx individuals have the lowest CVD mortality rates when compared with other groups supports the previously described "Hispanic paradox" (ie, Hispanic/Latinx individuals have better-than-expected health outcomes when compared with NHW individuals, despite generally having increased risk factors and lower socioeconomic status).[19,20]

We showed that CVD mortality remained largely geographically concentrated for Black and Hispanic/Latinx individuals, and that the South census region had the highest CVD mortality rates across all groups.[5,8,13] This concentration of CVD mortality in Black and Hispanic/Latinx individuals relates to the fact that these populations tend to live in certain areas in the United States.[22] However, although the Hispanic/Latinx population is concentrated in what appears to be healthier counties, we have also demonstrated, consistent with past literature, that a higher percentage of Hispanic/Latinx individuals in a county is predictive of higher CVD AAMR among Hispanic/Latinx individuals.[23] The cause of this association is incompletely understood, but may relate to the ecological fallacy, which indicates that associations found at the county level do not necessarily apply to subareas or individuals in that county. It is likely that there are adverse community factors that are not completely captured in risk adjustment at the county level, as Hispanic/Latinx individuals often live in poor and resource-poor neighborhoods.[23]

Counties are complex environments with variable diversity and distribution of community-level risk factors for CVD mortality. As a result, the development of efficient and effective interventions depends on an understanding of the relative importance of risk factors across racial/ethnic subgroups. A foundational study evaluating the association of county quartile rank in 4 broad groups of county-level risk factors (health behaviors, clinical care, social and economic factors, and physical environment) with CVD mortality between 2006 and 2010 demonstrated that, for NHW and Black individuals, the social and economic factor quartiles had the strongest association with county-level CVD death rates.[8] However, Hispanic/Latinx individuals were not separately examined nor was the relative importance of individual risk factors, a gap in the applicability of those findings to policy development. Our work fills that gap.

Through multivariable adjustment using our extensive set of county-level factors, we found that traditional CVD risk factors explained the greatest variation in CVD mortality among NHW individuals, by accounting for a little over a third of this variation. Among CVD risk factors, those with the strongest relationship with CVD mortality among NHW individuals are the percentage of the population who are physically inactive and who smoke. We further found that socioeconomic factors explained over a third of the variation seen in CVD mortality among NHW individuals, and in a multivariable model including all county-level factors, percentage food insecurity actually had the greatest adjusted effect on CVD AAMR. Although socioeconomic factors are increasingly being recognized as important predictors of CVD outcomes among minority populations, our analysis demonstrates the importance of broad consideration of social determinants of health for CVD outcome interventions.

Among Black individuals, socioeconomic factors explained the largest proportion of the variation seen in CVD mortality, whereas CVD risk factors explained the second largest proportion. In our socioeconomic factor–specific model, county median household income had the strongest association, an inverse association, with CVD mortality among Black individuals, despite adjustment for other indicators of socioeconomic disadvantage. Notably, however, in our multivariable models including all factors, food insecurity had the greatest adjusted effect on CVD AAMR for Black individuals as well. Our findings strongly support food insecurity as an important CVD mortality risk factor, which warrants further study as we demonstrate herein its important association with outcomes across racial/ethnic subgroups. For Black individuals, a broad approach to CVD risk mitigation, addressing social determinants of health as well as CVD risk factors, will likely yield the highest benefit. Our findings are in line with prior research that shows the deleterious effects of adverse socioeconomic position and suggests that their impact on the health of minority groups may be stronger than previously appreciated.[10,13,22,24] Furthermore, these findings are at odds with suggestions that behavioral risk factors, rather than factors of structural inequity, play the largest role in minority health outcomes. National and local interventions to reduce CVD mortality should consider these the importance of these county-level factors, especially as knowledge of such risk factors has successfully informed CVD risk reduction programs at the community and county level in the past, leading to significant reductions in CVD morbidity and mortality.[25,26]

In counties reporting CVD mortality among Hispanic/Latinx individuals, demographic factors were the most important risk factor group for explaining variation in CVD mortality. Although demographic factors are not typically amenable to county-level intervention, the knowledge that larger populations and increased percentage women are protective for Hispanic/Latinx communities, whereas higher percentage Hispanic/Latinx individuals in a county is deleterious, is important for assisting in identifying communities at risk, likely identifying areas of higher disadvantage.[23] In addition, these findings are important hypothesis-generating insights that should promote further investigation of elements of the social structure of Hispanic/Latinx communities that might be protective against CVD mortality, especially as the paradigm of Hispanic/Latinx cultural enclaves being protective against CVD mortality is not supported by these findings. Our analysis also demonstrates that, similar to NHW and Black communities, socioeconomic risk factors, especially education and median household income, are important for explaining variation in CVD mortality among Hispanic/Latinx individuals. However, although CVD risk factor profiles are often reported to be worse among Hispanic/Latinx individuals compared with NHW individuals, we found that CVD risk factors explained much less variation in CVD mortality among Hispanic/Latinx individuals than either NHW or Black individuals, which may be attributed in part to ecological fallacy.

Our study has several important implications. Studies based solely on the aggregated mortality rates likely fail to fully capture reasons for CVD disparities. This is supported by the observed geographic differences in CVD mortality; differences in county-level factors across counties; and the differences in the county-level factors that explain variation in aggregated and disaggregated analyses of CVD mortality. As shown in our study, racial/ethnic minority groups live and die in certain parts of the United States and thereby interventions to reduce disparities should be tailored based on detailed understanding of the characteristics of those counties. In addition, extensive adjustment for a diverse set of community factors allowed for critically important assessment of the relationship between factors, and the inclusion of spatial analysis strengthens the validity of our findings. For racial/ethnic minority groups, interventions that focus on the social determinants of health may prove more effective than narrowly focused interventions that solely address traditional CVD risk factors.

Our study was subject to several limitations. The misclassification or lack of classification of race and ethnicity on death records may potentially lead to the underrepresentation of certain groups.[27] As with all observational studies, our associations may have been affected by unknown confounders, especially given the geographic scale of our mortality and risk factor data, which would not capture neighborhood- and individual-level factors that may affect outcomes. In addition, we are limited by the fact that time to effect of county-level factors is largely unknown, but we attempted to address this through sensitivity analysis using 2014 county-level factors. It is also important that ecological fallacy be considered in interpretation of our results as this is a county-level analysis. Finally, data censoring for counties with <20 CVD deaths will bias the analysis toward larger, more population-dense counties, which should be considered in extrapolation of results.

CONCLUSIONS

Disparities in CVD outcomes are persistent with Black individuals experiencing far higher CVD AAMR than NHW individuals. County-level factors that are most important for explaining county-level heterogeneity in CVD AAMR differ by race/ethnicity. The greatest variation in CVD AAMR was explained by traditional CVD risk factors for NHW individuals, socioeconomic factors for Black individuals, and demographic factors for Hispanic/Latinx individuals.

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Disclosures

None.

Supplementary Material

Tables S1–S2
Figure S1

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Supplemental Material

Table S1. Definition of Variables.

Variables	Description	Sources of Data	Year	Category
Outcome				
Age-Adjusted Mortality Rates	Number of deaths per 100,000 persons that were attributed to Diseases of the Circulatory System (coded to the *tenth revision of the International Statistical Classification of Diseases and Related Health problems,* ICD-10 codes I05 - I89).	CDC WONDER	2017	Outcome
Covariates				
Population	Number of persons.	Census Population Estimates	2016	Demographics
% Rural	Urban areas are defined as having 50,000 or more people. Rural encompasses all population, housing, and territory not included within an urban area.	Census Population Estimates	2010	Demographics
% Females	Percentage of population that are females.	Census Population Estimates	2016	Demographics
% Black	Percentage of population self-identifying as non-Hispanic black/African-American.	Census Population Estimates	2016	Demographics
% Asian	Percentage of population self-identifying as Asian.	Census Population Estimates	2016	Demographics
% Hispanic	Percentage of population self-identifying as Hispanic.	Census Population Estimates	2016	Demographics
Census Region	Groupings of states and the District of Columbia that subdivide the United States for the presentation of census data. The Census Bureau defines four census regions - Northeast, Midwest, South, and West.	US Census	2017	Demographics
% Some college	Percentage of adults ages 25-44 with some post-secondary education.	American Community Survey, 5-year estimates	2012-2017	Socioeconomic
% Unemployed	Percentage of population ages 16 and older unemployed but seeking work.	Bureau of Labor Statistics	2017	Socioeconomic
% Food Insecure	Percentage of the population who did not have access to a reliable source of food during the past year.	Map the Meal Gap	2015	Socioeconomic
Median household income	Income in a county at which half of households in a county earn more and half of households earn less.	Small Area Income and Poverty Estimates	2016	Socioeconomic

% Smokers	Percentage of adults that reported currently smoking.	Behavioral Risk Factor Surveillance System	2016	Behavioral
% Physically inactive	Percentage of adults age 20 and over reporting no leisure-time physical activity.	CDC Diabetes Interactive Atlas	2014	Behavioral
% Diabetic	Percentage of adults who have diabetes.	CDC Diabetes Interactive Atlas	2015	Behavioral
% Obese	Percentage of adults that report BMI >= 30.	CDC Diabetes Interactive Atlas	2014	Behavioral
Primary care physician rate	Ratio of primary care physicians to population size.	Area Health Resource File/American Medical Association	2017	Healthcare
% Uninsured	Percentage of population under age 65 without health insurance.	Small Area Health Insurance Estimates	2015	Healthcare

Census Regions	States Included
Northeast	Connecticut, Massachusetts, Maine, New Hampshire, New Jersey, New York, Pennsylvania, Rhode Island, Vermont
Midwest	Iowa, Illinois, Indiana, Kansas, Michigan, Minnesota, Missouri, North Dakota, Nebraska, Ohio, South Dakota, Wisconsin
South	Alabama, Arkansas, *District of Columbia,* Delaware, Florida, Georgia, Kentucky, Louisiana, Maryland, Mississippi, North Carolina, Oklahoma, South Carolina, Texas, Tennessee, Virginia, West Virginia
West	Alaska, Arizona, California, Colorado, Hawaii, Idaho, Montana, New Mexico, Nevada, Oregon, Utah, Washington, Wyoming

ICD, International Classification of Diseases; CDC WONDER, Centers for Disease Control and Prevention Wide Ranging Online Data for Epidemiologic Research; BMI, body mass index.

Table S2. Sensitivity Analysis: Multivariable Regression Model Results Using CHR Data From 2014 and CVD Mortality Data From 2017.

Variable	Demographic Factors*	Census Region†	Socioeconomic Factors‡	CVD Risk Factors§	Healthcare Factors‖	Combined Model#
NHW CVD AAMR Multivariable Regression Results						
Observations	*2,431*	*2,431*	*2,431*	*2,431*	*2,431*	*2,431*
R^2	0.154	0.145	0.343	0.396	0.184	0.449
Adjusted R^2	0.152	0.144	0.342	0.395	0.184	0.444
Black CVD AAMR Multivariable Regression Results						
Observations	*705*	*705*	*705*	*705*	*705*	*705*
R^2	0.233	0.067	0.276	0.262	0.132	0.378
Adjusted R^2	0.226	0.063	0.271	0.258	0.130	0.361
Hispanic/Latinx CVD AAMR Multivariable Regression Results						
Observations	*251*	*251*	*251*	*251*	*251*	*251*
R^2	0.186	0.053	0.222	0.199	0.090	0.435
Adjusted R^2	0.166	0.042	0.209	0.186	0.083	0.389

In sensitivity analysis, we repeated the multivariable models in our primary analysis with 2014 county-level factor data. The multivariable models included models for our five categories of county-level factors and a combined model with all factors. These six models were evaluated for each racial/ethnic cohort of counties and the aggregated cohort. The number of observations, R^2, and adjusted R^2 are presented for each of our 24 models.

CVD, cardiovascular disease; NHW, non-Hispanic whites; AAMR, age-adjusted cardiovascular mortality rate.

*Demographic factors: Population, percentage rural, percentage female, percentage black, percentage Asian, percentage Hispanic

†Census region: Northeast, South, West

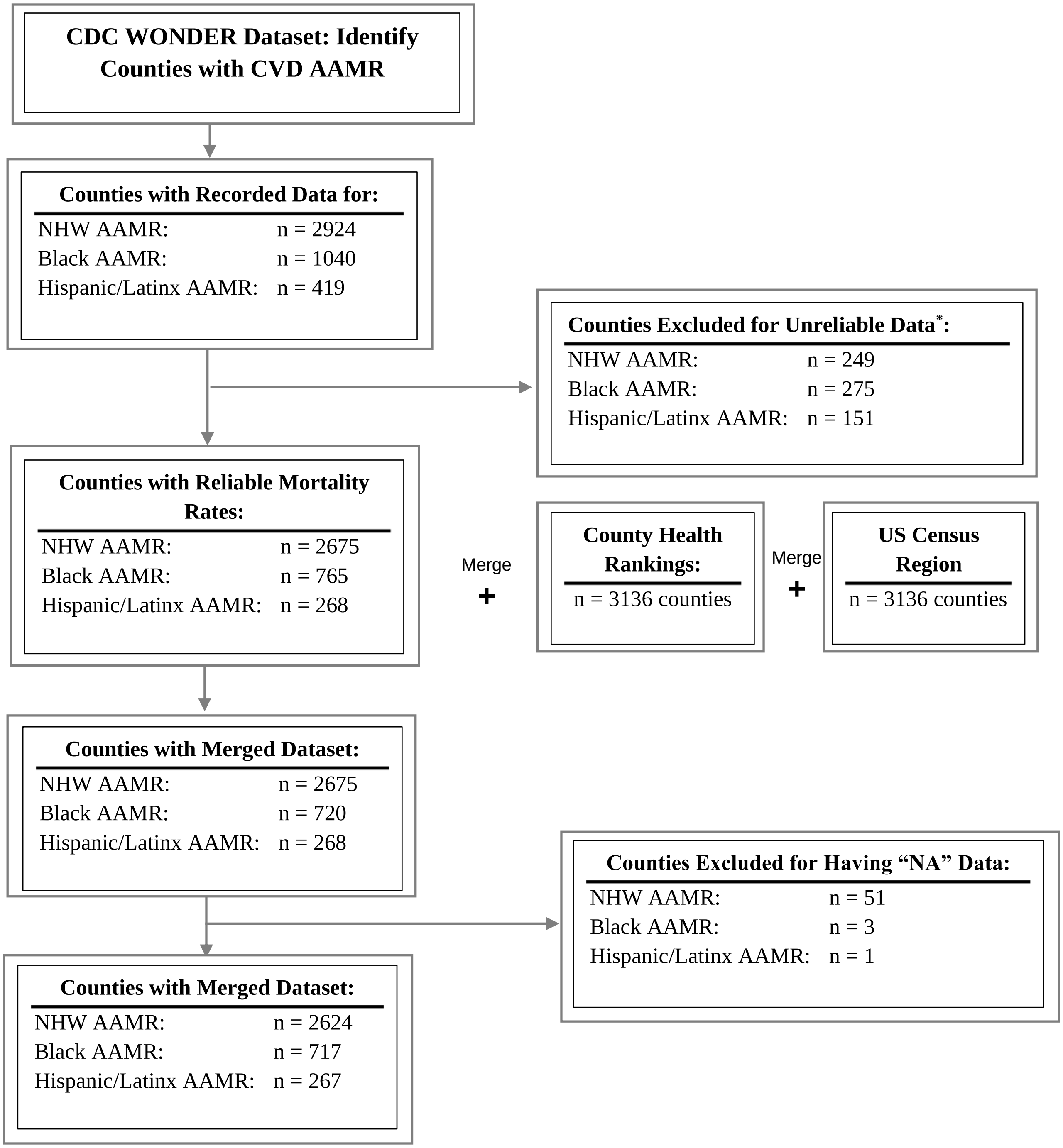
‡Socioeconomic factors: percentage some college, percentage unemployed, percentage food insecure, median household income

§CVD Risk factors: percentage smokers, percentage physically inactive, percentage diabetic, percentage obese

‖Healthcare factors: Primary Care Provider (PCP) Rate, percentage uninsured

#Combined includes all the above factor

Figure S1. Data Extraction Flow Chart.



*Counties Excluded for Unreliable Data had 20 or fewer deaths recorded

We identified all counties with CVD AAMR data available in the CDC WONDER database. Counties were excluded for having missing AAMR or unreliable AAMR. These datasets were merged with the Robert Wood Johnson Foundation County Health Rankings data and US Census region data.

CDC WONDER, Centers for Disease Control Wide-ranging Online Data for Epidemiologic Research; CVD AAMR, cardiovascular disease age-adjusted mortality rate.