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Article

Changing rate orders of race-gender heart disease death rates: An exploration of county-level race-gender disparities

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ABSTRACT

A holistic view of racial and gender disparities that simultaneously compares multiple groups can suggest associated underlying contextual factors. Therefore, to more comprehensively understand temporal changes in combined racial and gender disparities, we examine variations in the orders of county-level race-gender specific heart disease death rates by age group from 1973–2015. We estimated county-level heart disease death rates by race, gender, and age group (35–44, 45–54, 55–64, 65–74, 75–84, ≥ 85, and ≥ 35) from the National Vital Statistics System of the National Center for Health Statistics from 1973–2015. We then ordered these rates from lowest to highest for each county and year. The predominant national rate order (i.e., white women (WW) < black women (BW) < white men (WM) < black men (BM)) was most common in younger age groups. Inverted rates for black women and white men (WW < WM < BW < BM) was observed nationally only for ages 35–44, but was observed in at least some counties for all age groups < 75. From 1973 through 1979, national rates for black men aged ≥ 35 were lower than those for white men. This national observation was found in a minority of counties, primarily among ages 55–64 and 65–74. The observed rates orders and their differences over time and place suggest that social and economic forces may be driving trends in heart disease mortality. Learning more about the places and times that deviate from the predominant rate order can further inform our understanding of these macro-level drivers of heart disease mortality trends.

1. Introduction

Accounting for approximately 630,000 deaths per year in the United States, heart disease is the leading cause of death for the total population and across race and gender groups (Benjamin et al., 2017; Kochanek, Murphy, Xu, & Arias, 2017). Despite this relative importance, the absolute rates of heart disease mortality at the national level have varied markedly by race and gender since at least the 1960s (Benjamin et al., 2017; Kramer, Valderrama, & Casper, 2014). Since the 1980s, national rates have been higher among men relative to women and among blacks relative to whites (Kramer et al., 2014).

Conventionally, epidemiologic analyses of heart disease mortality summarize rate disparities by one dimension at a time, emphasizing racial differences in one analysis, and gender differences separately (Benjamin et al., 2017; Bosworth, 2018). The persistence of gender and racial differences may reinforce the notion that these gaps arise from essential biological difference, or at least that they demonstrate intractable differences. However, considering the intersection of race and gender reframes each as socially-constructed, and considering whether the race-gender patterns change illustrates the degree to which the conventional pattern is mutable (Green, Evans, & Subramanian, 2017; Hankivsky, 2012; Lawlor, Ebrahim, & Davey Smith, 2001; Lekan, 2009). For example, as recently as the late 1970s, national age-adjusted heart disease mortality was lower among black men than white men (Kramer et al., 2014; Vaughan, Kramer, & Casper, 2014). Likewise, although national rates for men have been consistently higher than

Abbreviations: BM, black men; BW, black women; CDC, Centers for Disease Control and Prevention; ICD, International Classification of Diseases; MCMC, Markov chain Monte Carlo; NCHS, National Center for Health Statistics; WM, white men; WW, white women

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rates for women, the gender gap has narrowed over time (Ford and Capewell, 2007; Ma, Ward, Siegel, & Jemal, 2015; Wilmot, O'Flaherty, Capewell, Ford, & Vaccarino, 2015). Additionally, racial disparities in heart disease mortality vary with age, such that younger black adults have substantially higher heart disease mortality than their white counterparts, while older black adults have lower rates than whites (Kramer et al., 2014; Van Dyke et al., 2018; Wilmot et al., 2015).

With this need to provide a multidimensional perspective of disparities, a method that simultaneously compares multiple groups (i.e. the cross-classification by gender and race) is required. In this paper, we accomplish this by examining variation in the rank ordering of heart disease death rates for race-gender groups over time. Although changes in the rate order mask increasing or decreasing disparities, they critically reveal the extreme case of a reversal in disparities and may reveal patterns not typically observed in surveillance data.

This description of ordered heart disease mortality rates is not a strictly academic exercise, but provides crucial information to allow the public health and medical communities to address disparities. By describing race-gender specific heart disease death rates over place and time, factors that contribute to the production of disparities, including the unequal diffusion of prevention and treatment that across race and gender, can be considered (Clouston, Rubin, Phelan, & Link, 2016; Phelan, Link, Diez-Roux, Kawachi, & Levin, 2004; Vaughan, Quick, Pathak, Kramer, & Casper, 2015b). By examining concurrent temporal changes in combined county-level racial and gender disparities, we may expand this understanding to find those places that foreshadow or notably deviate from national patterns. In this way, this work may inform effective individual and population level dissemination and adoption of heart disease prevention and health promotion activities. Therefore, in this paper, we examine variations in the orders of county-level race-gender specific heart disease death rates by age group from 1973–2015.

2. Materials and methods

2.1. Heart disease mortality data

For US residents ages 35 and older, we obtained county-level annual counts of heart disease deaths from 1973 through 2015 by race, gender, and age group (35–44, 45–54, 55–64, 65–74, 75–84, and 85+) from the National Vital Statistics System of the National Center for Health Statistics (NCHS). Use of this continuous time period ensures that data represent a census, rather than a sample, of deaths in the United States. The study population is restricted to individuals identified on a death certificate as either black or white, as these are the only racial groups for whom data are comparable and available for the entire study period. Hispanic ethnicity is not recorded on death certificates for the duration of the study period. Deaths from heart disease were defined as those for which the underlying cause of death was "diseases of the heart" according to the 8th, 9th, and 10th revisions of the International Classification of Diseases (ICD) (ICD–8: 390–398, 402, 404, 410–429; ICD–9: 390–398, 402, 404–429; ICD-10: I00–I09, I11, I13, I20–I51). This definition of ICD codes permits a consistent comparison across this 43 year period (Anderson, Miniño, Hoyert, & Rosenberg, 2001; Klebba & Scott, 1980). Annual population estimates (intercensal estimates from 1973–1999 and bridged-race intercensal estimates from 2000 through 2015) for each age-race-gender group were obtained from the National Center for Health Statistics.

2.2. Estimating race-gender death rates by age group, county, and year

To estimate heart disease death rates, we used a Bayesian multivariate space-time conditional autoregressive model extended to count data (Quick, Waller, & Casper, 2018; Quick, Waller, & Casper, 2017). This model is based on the popular Besag-York-Mollié conditional autoregressive model for spatially-referenced count data (Besag, York, & Mollié, 1991) and incorporates correlation across space, time, age group, race, and gender to obtain reliable rates even in the presence of small case counts (Quick et al., 2018). Details of this model have been previously published (Quick et al., 2018).

We fit this model using a Bayesian statistical approach in the R programming language (R Core Team, R Foundation for Statistical Computing, Vienna, Austria). Specifically, we fit the model using a Markov chain Monte Carlo (MCMC) algorithm, resulting in samples from the posterior distribution for each estimated rate. Consequently, for each combination of county, year, race, gender, and age, we obtained a posterior distribution for the corresponding heart disease mortality rate. These posterior distributions served as the basis for all inferences that follow.

Estimated race-gender specific heart disease death rates for each year and age group were aggregated across counties to calculate national rates and across age groups to calculate rates for ages 35 and older. Rates for ages 35 and older were age standardized to the 2000 standard US population (Klein & Schoenborn, 2001).

2.3. Ordering race-gender heart disease death rates within age group, county, and year

For each combination of age group, county, and year, we then calculated the orders of race-gender specific heart disease death rates from lowest to highest, which we call the "rate order." Rather than simply ordering the estimated rates, we used the following process to generate robust estimates of the rate orders that incorporated the precision of the underlying rates. For each sample from the Bayesian posterior distributions of the four race-gender rates for each combination of year, county and age group (35–44 through 85+, plus the combined ages 35+), the four race-gender rates were ordered from lowest to highest. By ordering the death rates for each sample, we obtained a distribution of rate orders for each combination of age group, county, and year, from which we calculated the posterior probability (i.e. the proportion of samples) associated with each possible rate order. We then assigned the rate order with the highest posterior probability (i.e. most common rate order across the samples) as the best estimate of the rate order. If the posterior probability was high, the rate order was relatively stable across samples from the posterior distributions and the credible intervals for rates were somewhat distinct. Conversely, rate orders with a low posterior probability represent less stable sequences of rates, implying indistinct and overlapping credible intervals for rates. We also used this process to determine the national orders of race-gender rates by age group and year.

As an example of this process, suppose that for a given county and year, we sampled the rate posterior distributions and the samples of the rates for white women (WW), black women (BW), white men (WM), and black men (BM), were 50, 75, 100, and 125 deaths per 100,000 population. This rate order, from lowest to highest, would then be WW < BW < WM < BM. After calculating this rate order for each of the samples from the posterior distributions for this county, we calculated the probability of this rate order (WW < BW < WM < BM) occurring across the samples. If this order occurred with a probability higher than any other rate order, the rate order assigned for this county and year would be WW < BW < WM < BM.

2.4. Inclusion criteria

Counties included in this analysis were required to have reliable rates for all four race-gender groups for at least 39 years (i.e. 90% of years in the study period) within each age group. We define a "reliable" rate as one whose posterior median is greater than the width of its 95% credible interval. This requirement is effectively a Bayesian analogue of the definition used by the Centers for Disease Control and Prevention (CDC) when reporting cancer statistics (Centers for Disease Control and Prevention, 2014). Furthermore, following CDC guidance, we also required that rates be based on a minimum of 10 deaths, thereby

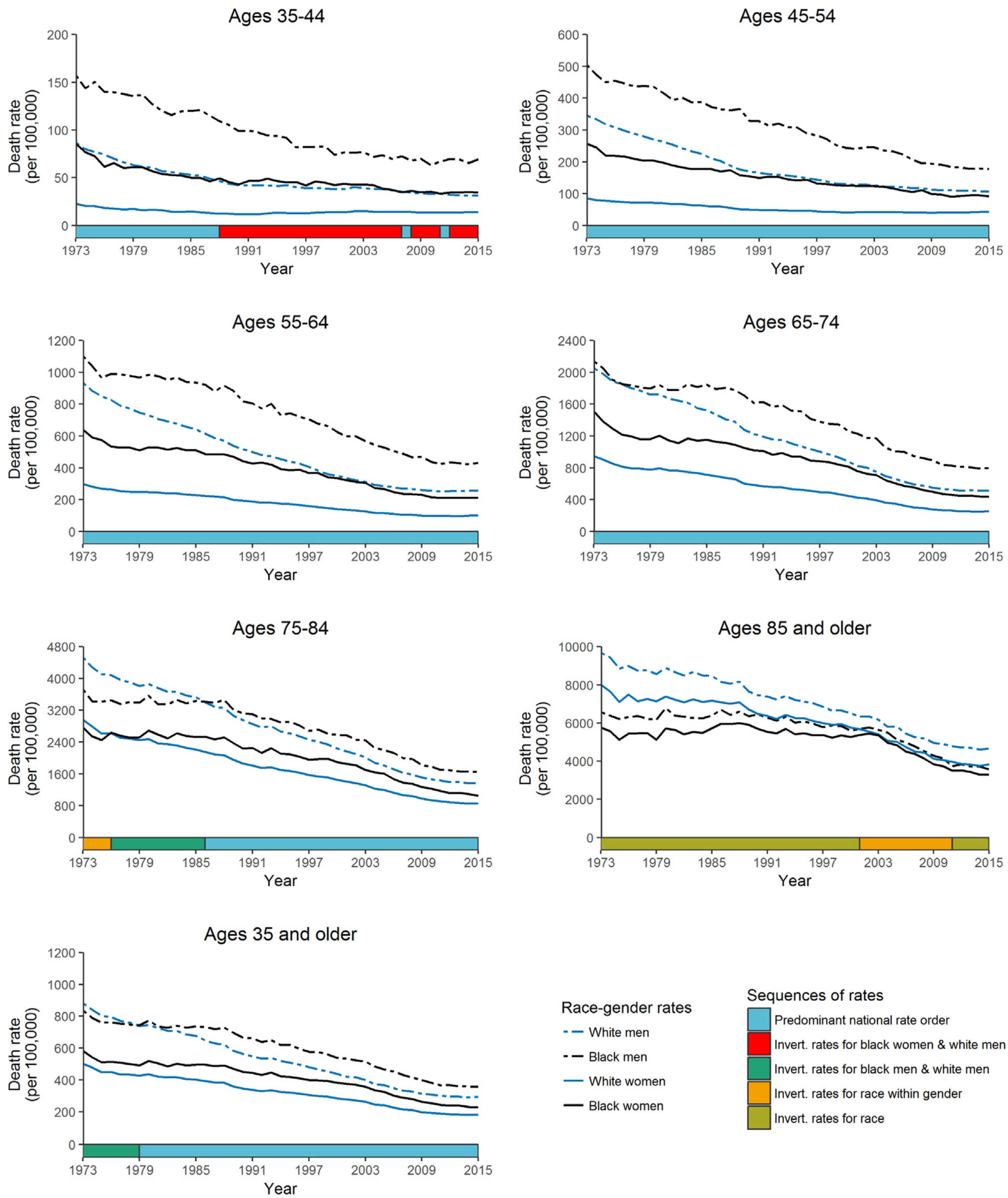

Fig. 1. Heart disease death rates by race, gender, and age group, United States, 1973–2015. Bars on the x-axes indicate the rate order for each year. Rates for ages 35 and older are age-standardized to the 2000 standard US population.

excluding counties with small numbers of deaths or populations for any race-gender group (Centers for Disease Control and Prevention, 2005).

3. Results

3.1. National rate orders

Nationally, from 1973 through 2015, heart disease death rates decreased for each age-race-gender group (Fig. 1). In this context of decreasing mortality, the order of national race-gender specific rates varied by calendar year for ages 35–44, 75–84, and 85 +, and remained constant for ages 45–54, 55–64, and 65–74 (Fig. 1). Of 24 possible rate orders, we observed five rate orders in the national rates (Fig. 2). We refer to the most common rate order as the Predominant national rate order (white women (WW) < black women (BW) < white men (WM) < black men (BM)). The other four mutually exclusive rate orders are named according to how they differ relative to the predominant national rate order. They are: Inverted rates for black women and white men (WW < WM < BW < BM), Inverted rates for black men and white men (WW < BW < BM < WM), Inverted rates for race within gender (BW < WW < BM < WM), and Inverted rates for race (BW < BM < WW < WM).

3.2. County rate orders

Of 3,115 total counties, the number of counties meeting inclusion

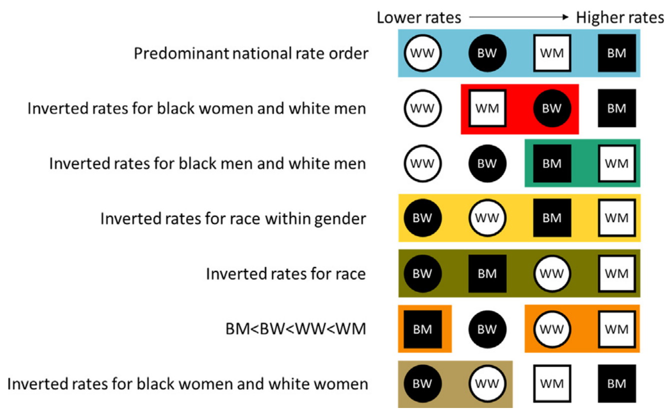

Fig. 2. Observed rate orders of heart disease death rates by race and gender. BM: black men; WM: white men; BW: black women; WW: white women. Colored bars represent differences compared to the predominant national rate order.

criteria were 196, 980, 1,380, 1,350, 1,203, and 702, for ages 35–44, 45–54, 55–64, 65–74, 75–84, and 85 + , respectively (Supplemental Fig. A.2). For ages 35 + , 1,864 counties were included. 1,251 counties did not meet inclusion criteria for any age group, primarily due to small black populations. Across all age groups at the county level, we observed 21 different rate orders (Supplemental Tables B). The five rate orders identified at the national level accounted for 95.0% of all county-level rate orders (Supplemental Tables B). Two additional rate orders (BM < BW < WW < WM and Inverted rates for black women and white women (BW < WW < WM < BM)) accounted for an additional 1.7% and 2.1% of all observed county-level rate orders, respectively (Table 1). These seven mutually exclusive rate orders were then retained for further analysis (Fig. 2). The 14 remaining observed county-level rate orders accounted for 1.2% of all observed county-level rate orders and were grouped as “Other” (Supplemental Tables B).

For all age groups (except the oldest), posterior probabilities were large, indicating a high degree of certainty in the assigned category of rate order (Supplemental Fig. A.1). For ages 85 and older, the posterior probabilities for the assigned categories were substantially lower, indicating greater uncertainty in the assignment of rate orders for the oldest age group.

3.2.1. *Predominant national rate order (WW < BW < WM < BM)*

Of the seven rate orders, the predominant national rate order (i.e., WW < BW < WM < BM) was most common in the younger age groups, with an average prevalence over the study period of 60.0%, 80.1%, 80.7%, and 71.0% of counties for ages 35–44, 45–54, 55–64, and 65–74, respectively (Table 1, blue band in Fig. 3). In the oldest age groups, only 40.1% and 2.9% of the counties experienced the predominant national rate order for age groups 74–84 and 85 and older, respectively.

3.2.2. *Inverted rates for black women and white men (WW < WM < BW < BM)*

This rate order, characterized by black women having higher rates than white men, was observed nationally only for ages 35–44, but at the county level was observed in at least some counties for all age groups younger than 75 (red band in Fig. 3). In the 35–44 year age group, the percentage of counties with this rate order steadily increased over time, almost doubling from an average of 24.1% of eligible counties before 1988 to an average of 44.8% after 1988. In a striking inversion from the predominant national rate order for ages 35–44, almost half of counties exhibited higher rates of heart disease mortality among black women than among white men. By the end of the study period, black women experienced higher rates than white men in roughly 1 in 7 counties for ages 45–54 and 55–64.

3.2.3. *Inverted rates for black men and white men (WW < BW < BM < WM)*

From 1973 through 1979, national rates for black men aged 35 and older were lower than those for white men, but were higher after 1979 (Fig. 1). This national observation is reflected in a minority of counties, primarily among age groups 55–64 and 65–74 (green band in Fig. 3). Prior to 1988, black men had lower rates than white men in 19.8% and 42.3% of counties, on average, in ages 55–64 and 65–74, respectively (Table 1). After 1988, very few counties exhibited lower rates for black men than white men (an average of 2.9% and 3.8% for ages 55–64 and 7.9% and 5.5% for 65–74 in 1988–2001 and 2002–2015, respectively) (Table 1, Fig. 3).

3.2.4. *Inverted rates for race within gender (BW < WW < BM < WM)*

This rate order was observed at both the national (Fig. 1) and county levels (Fig. 3), primarily in the two oldest age groups. Prior to 1988, among those aged 75–84, the expected gender order was maintained (i.e. men had greater rates than women), but the racial order was inverted within each gender (i.e., BW < WW < BM < WM) (an average of 47.1% of counties). However, by the end of the study period, the proportion of counties experiencing this rate order was substantially reduced (prevalence of 11.3%) (Table 1, Fig. 3). In the oldest age group, this order accounted for a consistently small percentage of counties (< 20%).

3.2.5. *Inverted rates for race (BW < BM < WW < WM), BM < BW < WW < WM, and Inverted rates for black women and white women (BW < WW < WM < BM)*

These three rate orders were observed almost exclusively in the 85 and older age group. Although the distribution of these rate orders in the 85 + age group changed over time, the precision of the assignment of these rate orders was much lower than for other age groups (Supplemental Tables B).

4. Discussion

In this study of county-level race-gender rates of heart disease mortality from 1973 through 2015, we used rate orders to examine changes in race and gender disparities over time and age group. The race-gender ordering that appears to be the ‘conventional’ U.S. pattern (WW < BW < WM < BM) was observed for roughly 75% of counties for combined ages 35 and older from 1979 to 2015, but this rate order was not the most common rate order for each 10-year age group and its prevalence changed over time. With this changing prevalence, we observed two notable alternative rate orders that represent a reversal in the established national disparity. First, the rate order with inverted rates for black men and white men (WW < BW < BM < WM) was most common at the beginning of the study period, especially in age groups younger than age 84. Second, the rate order with inverted rates for black women and white men (WW < WM < BW < BM) was most common in ages 35–44 and was also observed in age groups below age 74. While the frequent reporting of conventional gender and race differences may unintentionally reinforce these differences as biologically essential, identifying differences in the race-gender patterns across time and geography highlights the importance of social context in producing intersectional population experiences (Bauer, 2014; Wemrell, Mulinari, & Merlo, 2017). The rank-ordering of social group heart disease mortality rates across counties point to geographic and social contextual constructs (e.g. education, access to care, insurance coverage, and discrimination) as moderators of local race and gender disparities that are often considered to be driven by biological factors (Harper, Lynch, & Smith, 2011; Lewis, Williams, Tamene, & Clark, 2014; McWilliams, Meara, Zaslavsky, & Ayanian, 2009; Patel, Ali, Narayan, & Mehta, 2016; Wemrell et al., 2017).

Higher age-standardized heart disease death rates for white men compared to black men in the 1970s for ages 35 and older was

Table 1
Average percentages of counties for each rate order of race-gender heart disease death rates by age group and time period.

Age group/Rate order	Average percentage of counties by time period			Total
	1973–1987 (%)	1988–2001 (%)	2002–2015 (%)	1973–2015 (%)
Age 35 and older (n = 1864)				
Predominant national rate order	48.1	79.6	72.0	66.1
Inverted rates for black women and white men	0.8	4.3	3.7	2.9
Inverted rates for black men and white men	36.2	11.5	10.4	19.8
Inverted rates for race within gender	14.5	4.0	11.4	10.1
Inverted rates for race	0.1	0	0.1	0.1
BM < BW < WW < WM	0	0	0	0
Inverted rates for black women and white women	0.2	0.4	2.4	1.0
Other	0	0.1	0.1	0.1
Age 35–44 (n = 196)				
Predominant national rate order	74.9	52.2	52	60
Inverted rates for black women and white men	24.1	45.6	43.9	37.5
Inverted rates for black men and white men	0.9	1.3	2.1	1.4
Inverted rates for race within gender	0	0.1	1.1	0.4
Inverted rates for race	0	0	0.1	0
BM < BW < WW < WM	0	0	0	0
Inverted rates for black women and white women	0	0	0.7	0.2
Other	0	0.8	0.1	0.3
Age 45–54 (n = 980)				
Predominant national rate order	86.5	78.5	74.9	80.1
Inverted rates for black women and white men	6.7	19.5	14.4	13.4
Inverted rates for black men and white men	6.7	1.4	5.5	4.6
Inverted rates for race within gender	0.1	0	2.1	0.7
Inverted rates for race	0	0	0	0
BM < BW < WW < WM	0	0	0	0
Inverted rates for black women and white women	0	0	2	0.6
Other	0	0.6	1.1	0.6
Age 55–64 (n = 1380)				
Predominant national rate order	78.1	82.3	82.0	80.7
Inverted rates for black women and white men	1.9	14.3	12.4	9.4
Inverted rates for black men and white men	19.8	2.9	3.8	9.1
Inverted rates for race within gender	0	0.2	0.7	0.3
Inverted rates for race	0	0	0	0
BM < BW < WW < WM	0	0	0	0
Inverted rates for black women and white women	0	0.1	0.8	0.3
Other	0.1	0.3	0.3	0.2
Age 65–74 (n = 1350)				
Predominant national rate order	52.0	82.6	79.8	71.0
Inverted rates for black women and white men	1.6	8.2	12.1	7.2
Inverted rates for black men and white men	42.3	7.9	5.5	19.1
Inverted rates for race within gender	3.6	0.5	1.1	1.8
Inverted rates for race	0	0	0	0
BM < BW < WW < WM	0	0	0	0
Inverted rates for black women and white women	0.2	0.2	1.1	0.5
Other	0.3	0.6	0.4	0.5
Age 75–84 (n = 1203)				
Predominant national rate order	15.9	47.9	58.3	40.1
Inverted rates for black women and white men	0.5	2.7	3.9	2.3
Inverted rates for black men and white men	29.5	27.0	14.7	23.9
Inverted rates for race within gender	47.1	16.2	11.3	25.4
Inverted rates for race	4.0	0.3	0.5	1.7
BM < BW < WW < WM	0.1	0.1	0.2	0.1
Inverted rates for black women and white women	1.9	4.3	8.8	4.9
Other	1.1	1.5	2.3	1.6
Age 85 and older (n = 702)				
Predominant national rate order	1.7	2.5	4.5	2.9
Inverted rates for black women and white men	0.4	0.7	1.6	0.9
Inverted rates for black men and white men	0.8	0.7	2.0	1.2
Inverted rates for race within gender	13.7	13.6	16.9	14.7
Inverted rates for race	59.5	40.0	30.0	43.5
BM < BW < WW < WM	14.3	20.5	21.2	18.6
Inverted rates for black women and white women	5.9	12.5	11.2	9.8
Other	3.8	9.6	12.5	8.5

previously reported at the national level (Kramer et al., 2014; Vaughan et al., 2015b). However, our county level results reveal that the national reversal of rates for black men and white men was driven by a subset of counties in age groups from 55 to 84 and that, even in the early 1970s, a substantial number of counties already exhibited what has since become the predominant national rate order (i.e., black men having higher rates than white men). This dichotomy indicates that, from the mid-1970s through the late 1980s, conditions in a small proportion of counties were conducive to lower rates of heart disease mortality among white men. However, those conditions appear to have changed such that, by the end of the study period, white men had lower rates in almost all counties. This cross-over of rates could reflect the slower

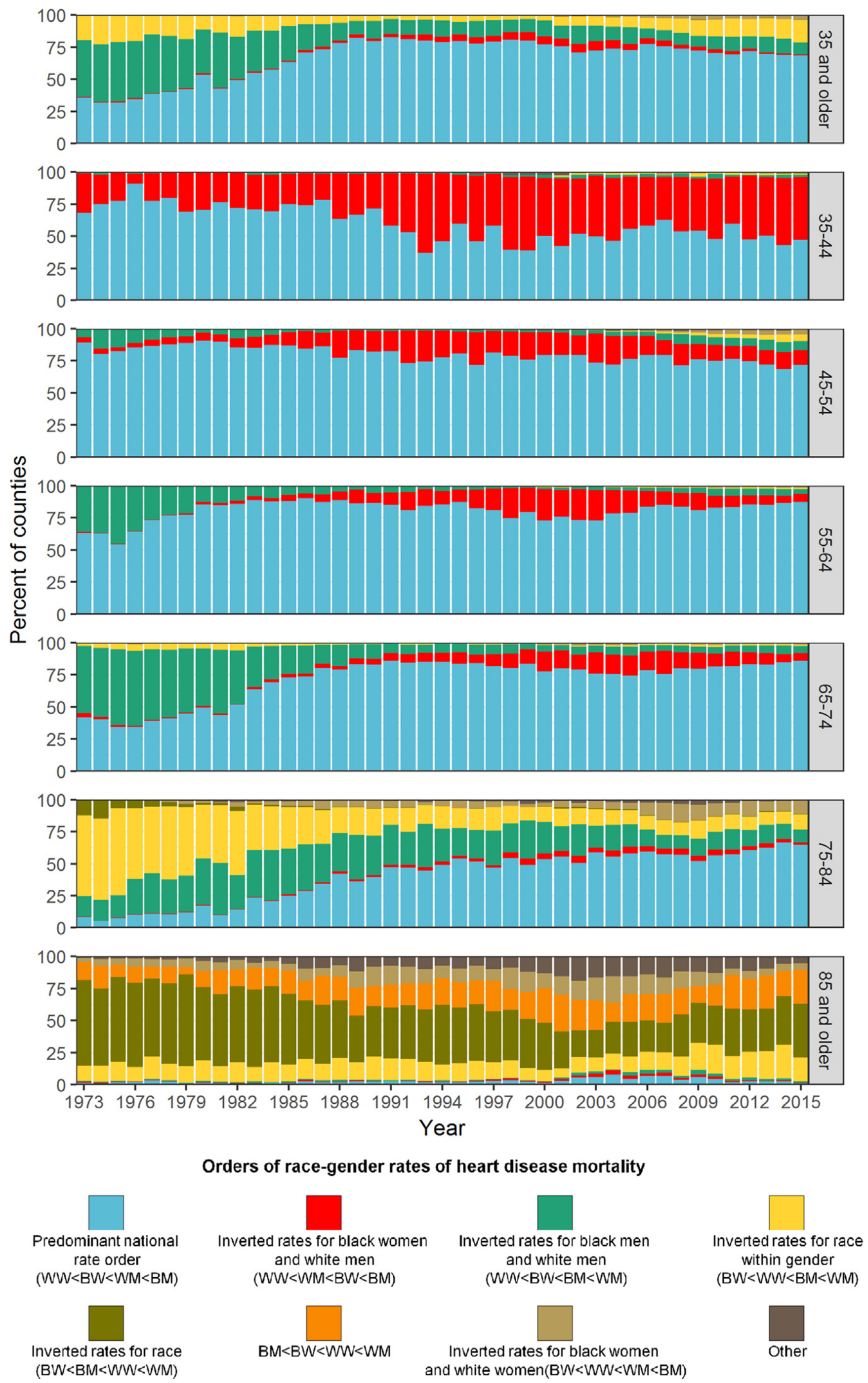

Fig. 3. Distribution of county-level orders of race-gender rates of heart disease mortality, by age group and year.

dissemination and adoption of heart disease prevention and health promotion activities among black men (Clouston et al., 2016; Phelan et al., 2004). Over such a long time period, competing risks could also explain lower rates of heart disease mortality among black men. Early in the study period, black men may have been dying from causes other than heart disease, especially given the large differential in life expectancy between black and white men in this time period (Xu, Kochanek, & Murphy, 2010).

Unlike the inversion of rates for black men and white men, the observed inversion of rates for black women and white men has not been observed nationally, but is particularly noteworthy for two reasons. First, heart disease death rates for women have historically been lower than for men; second, biologic protection (primarily estrogen) is thought to be the dominant reason for lower rates among women (Pérez-López, Larrad-Mur, Kallen, Chedraui, & Taylor, 2011; Villablanca, Jayachandran, & Banka, 2010). Therefore, a possible explanation for our findings is that exogenous factors, including social and environmental context in many counties, may be overriding the biological protectiveness for heart disease among black women in the younger age groups. Similar conclusions were drawn by Lawlor et al. in their study of gender disparities for heart disease mortality by time and country (Lawlor et al., 2001). Based upon their observations that gender disparity in heart disease mortality in six countries changed dramatically over several decades, and that the relative risk for heart disease mortality among men compared with women varied widely among 50 countries (from 1.4 in rural China and Cuba to 2.9 in Poland),

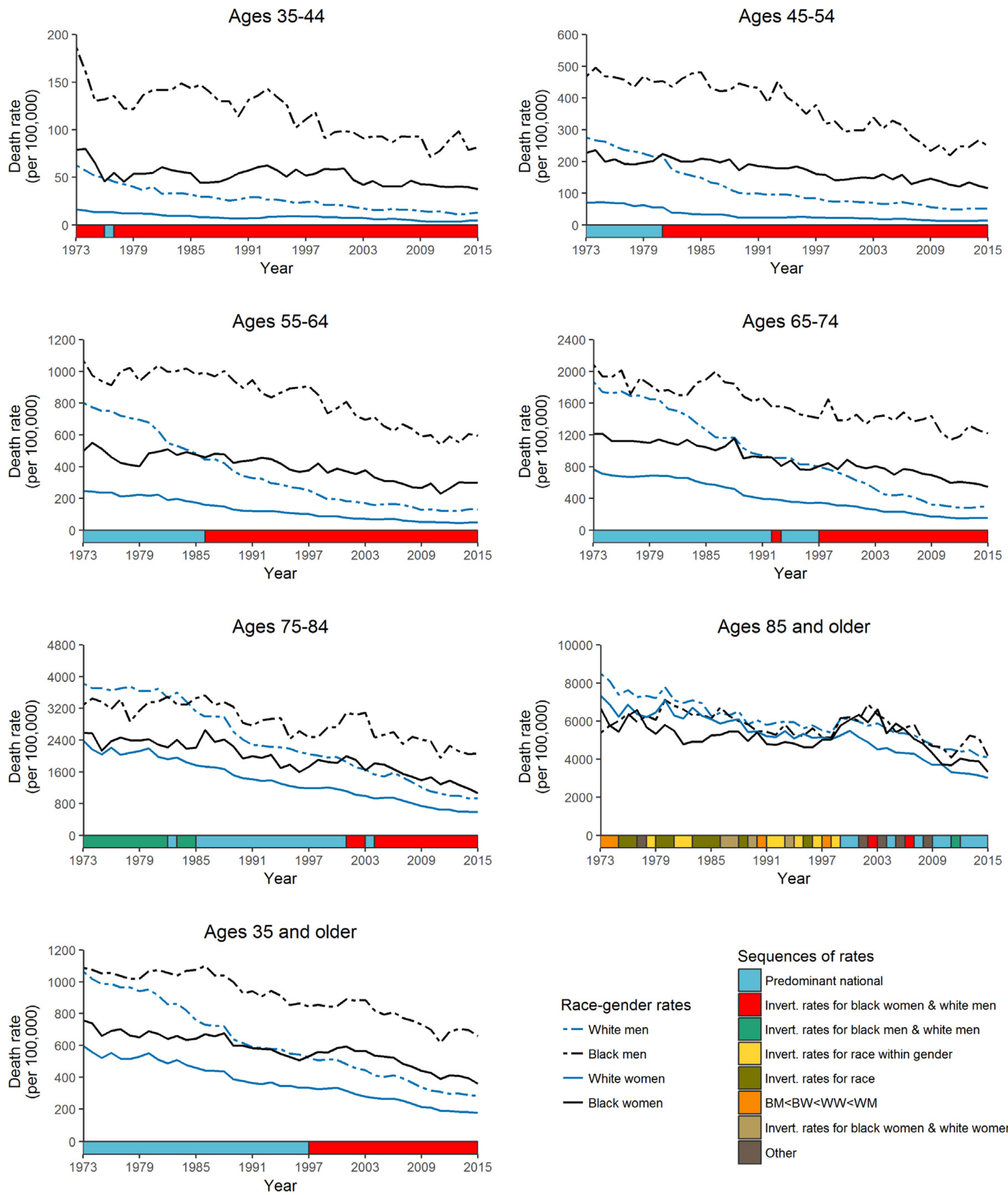

Fig. 4. Heart disease death rates by race, gender, and age group, 1973–2015, for Washington, DC. Bars on the x-axes indicate the rate orders for each year. Rates for ages 35 and older are age-standardized to the 2000 standard US population.

they concluded that "sex differences [in heart disease mortality] are largely the result of environmental factors and hence not inevitable."

The changing prevalence of counties with inverted rates for black women and white men by age group, time, and county (Fig. 2) provide additional information to possible drivers of this inversion in rates. The inverted rates are most prevalent in the younger age groups when female biological protectiveness is thought to be strongest (Pérez-López et al., 2011; Villablanca et al., 2010), thereby suggesting the strength of the non-biological factors. The prevalence of inverted rates increased over time for age groups 35–44 through 65–74, with some attenuation since the mid-2000s for all age groups except 35–44. Local trends of race-gender specific heart disease death rates, as shown in the example of trends for Washington, DC (Fig. 4), indicate that the increasing prevalence of inverted rates of heart disease deaths for black women and white men is a function of faster declines among white men and slower or stagnating declines among black women. While no studies have documented the effectiveness of heart disease prevention and treatment efforts by race-gender group over time, several studies have documented disproportionate gains in health and longevity among socio-demographic groups in the United States with black women often benefitting least from improvements in health status (Geronimus, 2001; Geronimus, Hicken, Keene, & Bound, 2006; Lekan, 2009; Oliver & Muntaner, 2005; Pappas, Queen, Hadden, & Fisher, 1993). One hypothesis for the lack of equal improvements in health among black women, the 'weathering process', may be relevant for understanding the inverted heart disease death rates for black women and white men because it manifests largely as high prevalence of chronic disease among young and middle aged black women (Geronimus, 2001; Geronimus et al., 2006). The weathering process posits that black women "experience early health deterioration as a consequence of the cumulative impact of repeated experience with social, economic, and political exclusion"(Geronimus, 2001) and the proposed physiological mechanism, allostatic load, has important implications for heart disease (Chyu & Upchurch, 2011; Clark, Bond, & Hecker, 2007; Geronimus, Bound, Waidmann, Colen, & Steffick, 2001; Lekan, 2009; Logan & Barksdale, 2008; McEwen, 2008). Persistent racial disparities in heart disease are well documented and further investigations are needed into race-related factors that could override the biological protectiveness for heart disease among black women, and how those factors have varied over time.

Future work may further explore the proposed explanations for our observed results. However, testing these hypotheses, especially using national vital statistics data over such a long time period, will be difficult. Consistent county-level data are not available for the entire duration of this study, and individual-level details in mortality data are limited. Therefore, furthering this work may need to be continued within long-term cohort studies or in places with more robust surveillance systems.

4.1. Strengths and limitations

The primary strength of this study is the ability to summarize over 1.3 million county-level heart disease death rates, allowing us to compare age-specific race-gender groups across time and place. We used national death records representing a census of deaths. Race is accurately recorded in these data (Arias, Heron, & Hakes, 2016). Additionally, our use of "all diseases of the heart" minimized misclassification and, due to high comparability ratios, allowed comparison of death rates over a long time period (Anderson et al., 2001; Ives, Samuel, Psaty, & Kuller, 2009; Klebba & Scott, 1980; Lloyd-Jones, Martin, Larson, & Levy, 1998). With these data, we estimated heart disease death rates using a Bayesian model which accounted for spatial, temporal, and between-group dependencies. This model estimates rates that are more robust and precise than other methods, even in the presence of small counts or populations (Vaughan et al., 2015a). The Bayesian approach also allowed calculation of rate orders to incorporate the precision of the rate estimates, giving a high degree of certainty in these results (except for ages 85 and older) and helping to ensure that changes in the rate order are due to sampling error.

Our analysis also has a few limitations. First, despite the strength of the Bayesian model, small population sizes and numbers of deaths limited the inclusion of many counties, especially for ages 35–44. As a result, counties with sufficiently high rates and large populations are overrepresented in this age group. Despite this limitation, our Bayesian model allowed us to include counties that would likely be excluded using other models (Vaughan et al., 2015a). Additionally, while focusing on the rate orders was efficient for summarizing the abundance of information, the cost of this efficiency was the loss of other county-specific information. For instance, this summary of rates is unable to match a county-specific race-gender-age rate order with the patterns of declining heart disease death rates in that county. Our analysis also did not incorporate Hispanic ethnicity, which has only been routinely recorded on US death records since 1999. Consequently, we could not separate race and Hispanic ethnicity over the study period. Hispanic whites have lower heart disease death rates than non-Hispanic whites, although national trends since 1999 are virtually identical (Kramer et al., 2014). Despite this limitation, analysis of data publicly available through CDC WONDER for Hispanics ages 35 and older from 1999 through 2015 found similar patterns of rate orders over time. Finally, uncertainty in rate *estimates* often coincided with uncertainty in the corresponding *rate orders*. Thus, just as we are more confident in our rate estimates for highly populated counties, we are also more confident in the rate orders for highly populated counties. However, the high values in the posterior probability in all but the oldest age group (Supplemental Fig. A.1) give us a high degree of certainty in our findings, even in small populations.

4.2. Conclusions

The temporal and spatial changes in the rate orders of heart disease mortality by race, gender, and age group suggest the need to recalibrate expectations about disparities in heart disease mortality and underscore that the current disparities are not inevitable. In particular, the inversion of heart disease death rates for black men and white men that occurred early in the study period suggests the strength of social and economic forces in driving trends in heart disease mortality. These forces may even overwhelm the presumed female biologic protection, as observed in the more recent inversion of rates for black women and white men. Learning more about the places and times that deviate from the predominant order of heart disease rates by race, gender and age can further inform our understanding of macro-level social and environmental drivers of heart disease mortality trends.

Conflicts of interest

The authors report no conflicts of interest.

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The findings and conclusions in this report are those of the authors and do not necessarily represent the official position of the Centers for Disease Control and Prevention.

Appendix A. Supplementary material

Supplementary data associated with this article can be found in the online version at doi:10.1016/j.ssmph.2018.100334.

References

Anderson, R. N., Miniño, A., Hoyert, D. L., & Rosenberg, H. M. (2001). Comparability of cause of death between ICD-9 and ICD-10: Preliminary estimates. *National Vital Statistics Reports, 49*, 1–32.

Arias, E., Heron, M., & Hakes, J. (2016). The validity of race and hispanic-origin reporting on death certificates in the United States: An update. *Vital and Health Statistics, 2*, 1–21.

Bauer, G. R. (2014). Incorporating intersectionality theory into population health research methodology: Challenges and the potential to advance health equity. *Social Science & Medicine, 110*, 10–17. https://doi.org/10.1016/j.socscimed.2014.03.022.

Benjamin, E., Blaha, M., Chiuve, S., Cushman, M., Das, S., Deo, R., ... Muntner, P. (2017). Heart disease and stroke statistics-2017 update: A report from the American Heart Association. *Circulation, 135*. https://doi.org/10.1161/CIR.0000000000000152.

Besag, J., York, J., & Mollié, A. (1991). Bayesian image restoration, with two applications in spatial statistics. *Annals of the Institute of Statistical Mathematics, 43*, 1–20.

Bosworth, B. (2018). Increasing disparities in mortality by socioeconomic status. *Annual Review of Public Health, 39*, 237–251.

Centers for Disease Control and Prevention (2005). CDC/ATSDR Policy on Releasing and Sharing Data. Atlanta, GA.

Centers for Disease Control and Prevention (2014). United States Cancer Statistics (USCS): Suppression of Rates and Counts [WWW Document]. URL 〈https://www.cdc.gov/cancer/npcr/uscs/technical_notes/stat_methods/suppression.htm〉 (Accessed 3 March 2017).

Chyu, L., & Upchurch, D. M. (2011). Racial and ethnic patterns of allostatic load among adult women in the United States: Findings from the National Health and Nutrition Examination Survey 1999–2004. *Journal of Women's Health, 20*, 575–583. https://doi.org/10.1089/jwh.2010.2170.

Clark, M. S., Bond, M. J., & Hecker, J. R. (2007). Environmental stress, psychological stress and allostatic load. *Psychology, Health & Medicine, 12*, 18–30. https://doi.org/10.1080/13548500500429338.

Clouston, S. A. P., Rubin, M. S., Phelan, J. C., & Link, B. G. (2016). A social history of disease: Contextualizing the rise and fall of social inequalities in cause-specific mortality. *Demography, 53*, 1631–1656. https://doi.org/10.1007/s13524-016-0495-5.

Ford, E. S., & Capewell, S. (2007). Coronary heart disease mortality among young adults in the U.S. from 1980 through 2002. Concealed leveling of mortality rates. *Journal of the American College of Cardiology, 50*, 2128–2132. https://doi.org/10.1016/j.jacc.2007.05.056.

Geronimus, A., Bound, J., Waidmann, T., Colen, C., & Steffick, D. (2001). Inequality in life expectancy, functional status, and active life expectancy across selected black and white populations in the United States. *Demography, 38*, 227–251. https://doi.org/10.1353/dem.2001.0015.

Geronimus, A. T. (2001). Understanding and eliminating racial inequalities in women's health in the United States: The role of the weathering conceptual framework. *Journal of the American Medical Women's Association, 56*(133–6), 149–150. https://doi.org/10.1080/19397030902947041.

Geronimus, A. T., Hicken, M., Keene, D., & Bound, J. (2006). "Weathering" and age patterns of allostatic load scores among blacks and whites in the United States. *American Journal of Public Health, 96*, 826–833. https://doi.org/10.2105/AJPH.2004.060749.

Green, M. A., Evans, C. R., & Subramanian, S. V. (2017). Can intersectionality theory enrich population health research? *Social Science & Medicine, 178*, 214–216. https://doi.org/10.1016/j.socscimed.2017.02.029.

Hankivsky, O. (2012). Women's health, men's health, and gender and health: Implications of intersectionality. *Social Science & Medicine, 74*, 1712–1720. https://doi.org/10.1016/j.socscimed.2011.11.029.

Harper, S., Lynch, J., & Smith, G. D. (2011). Social determinants and the decline of cardiovascular diseases: Understanding the links. *Annual Review of Public Health, 32*, 39–69. https://doi.org/10.1146/annurev-publhealth-031210-101234.

Ives, D. G., Samuel, P., Psaty, B. M., & Kuller, L. H. (2009). Agreement between nosologist and cardiovascular health study review of deaths: Implications of coding differences. *Journal of the American Geriatrics Society, 57*, 133–139. https://doi.org/10.1111/j.1532-5415.2008.02056.x.

Klebba, A. J., & Scott, J. (1980). Estimates of selected comparability ratios based on dual coding of 1976 death certificates by the eighth and ninth revisions of the international classification of diseases. *Monthly Vital Statistics Report, 28*, 1–19.

Klein, R.J., Schoenborn, C.A. (2001). Age adjustment using the 2000 projected U.S. population. *Heal. People 2010 Stat. notes 20*, 1–10.

Kochanek, K. D., Murphy, S. L., Xu, J., & Arias, E. (2017). Mortality in the United States, 2016. *NCHS Data Brief, 293*, 1–8. https://doi.org/10.1056/NEJM184002260220306.

Kramer, M. R., Valderrama, A. L., & Casper, M. L. (2014). Decomposing black-white disparities in heart disease mortality in the United States, 1973–2010: An age-period-cohort analysis. *American Journal of Epidemiology, 182*, 302–312. https://doi.org/10.1093/aje/kwv050.

Lawlor, D. A., Ebrahim, S., & Davey Smith, G. (2001). Sex matters: Secular and geographical trends in sex differences in coronary heart disease mortality. *BMJ, 323*, 541–545. https://doi.org/10.1136/bmj.323.7312.541.

Lekan, D. (2009). Sojourner syndrome and health disparities in African American women. *Advanced Nursing Science, 32*, 307–321.

Lewis, T. T., Williams, D. R., Tamene, M., & Clark, C. R. (2014). Self-reported experiences of discrimination and cardiovascular disease. *Current Cardiovascular Risk Reports, 8*, 1–15. https://doi.org/10.1007/s12170-013-0365-2.

Lloyd-Jones, D. M., Martin, D. O., Larson, M. G., & Levy, D. (1998). Accuracy of death certificates for coding coronary heart disease as the cause of death. *Annals of Internal Medicine, 129*, 1020–1026. https://doi.org/10.7326/0003-4819-129-12-199812150-00005.

Logan, J. G., & Barksdale, D. J. (2008). Allostasis and allostatic load: Expanding the discourse on stress and cardiovascular disease. *Journal of Clinical Nursing, 17*, 201–208. https://doi.org/10.1111/j.1365-2702.2008.02347.x.

Ma, J., Ward, E. M., Siegel, R. L., & Jemal, A. (2015). Temporal trends in mortality in the United States, 1969–2013. *JAMA, 314*, 1731–1739. https://doi.org/10.1001/jama.2015.12319.

McEwen, B. S. (2008). Central effects of stress hormones in health and disease: Understanding the protective and damaging effects of stress and stress mediators. *European Journal of Pharmacology, 583*, 174–185.

McWilliams, J. M., Meara, E., Zaslavsky, A. M., & Ayanian, J. Z. (2009). Differences in control of cardiovascular disease and diabetes by race, ethnicity, and education: U.S. Trends from 1999 to 2006 and effects of medicare coverage. *Annals of Internal Medicine, 150*, 505–516. https://doi.org/10.7326/0003-4819-150-8-200904210-00005.

Oliver, M. N., & Muntaner, C. (2005). Researching health inequities among African Americans: The imperative to understand social class. *International Journal of Health Services, 35*, 485–498. https://doi.org/10.2190/PPQX-47DY-KW0X-78Y8.

Pappas, G., Queen, S., Hadden, W., & Fisher, G. (1993). The increasing disparity in mortality between socioeconomic groups in the United States, 1960 and 1986. *The New England Journal of Medicine, 329*, 103–109.

Patel, S. A., Ali, M. K., Narayan, K. M. V., & Mehta, N. K. (2016). County-level variation in cardiovascular disease mortality in the United States in 2009–2013: Comparative assessment of contributing factors. *American Journal of Epidemiology, 184*, 933–942. https://doi.org/10.1093/aje/kww081.

Pérez-López, F., Larrad-Mur, L., Kallen, A., Chedraui, P., & Taylor, H. (2011). Gender differences in cardiovascular disease: Hormonal and biochemical influences. *Reproductive Sciences, 17*, 511–531. https://doi.org/10.1177/1933719110367829.Gender.

Phelan, J. C., Link, B. G., Diez-Roux, A., Kawachi, I., & Levin, B. (2004). "Fundamental causes" of social inequalities in mortality: A test of the theory. *Journal of Health and Social Behavior, 45*, 265–285.

Quick, H., Waller, L. A., & Casper, M. (2017). Multivariate spatiotemporal modeling of age-specific stroke mortality. *The Annals of Applied Statistics, 11*, 2165–2177.

Quick, H., Waller, L. A., & Casper, M. (2018). A multivariate space-time model for analysing county level heart disease death rates by race and sex. *The Journal of the Royal Statistical Society, Series C (Applied Statistics), 67*, 291–304. https://doi.org/10.1111/rssc.12215.

Van Dyke, M. E., Greer, S. A., Odom, E., Schieb, L. J., Vaughan, A. S., Kramer, M. R., & Casper, M. (2018). Heart disease death rates among blacks and whites aged ≥35 Years – United States, 1968–2015. *MMWR Surveillance Summaries, 67*, 1–11. https://doi.org/10.15585/mmwr.ss6705a1.

Vaughan, A. S., Kramer, M. R., & Casper, M. (2014). Geographic disparities in declining rates of heart disease mortality in the US South, 1973–2010. *Preventing Chronic Disease, 11*, E185. https://doi.org/10.5888/pcd11.140203.

Vaughan, A. S., Kramer, M. R., Waller, L. A., Schieb, L. J., Greer, S., & Casper, M. (2015a). Comparing methods of measuring geographic patterns in temporal trends: An application to county-level heart disease mortality in the United States, 1973 to 2010. *Annals of Epidemiology, 25*, 329–335. https://doi.org/10.1016/j.annepidem.2015.02.007.

Vaughan, A. S., Quick, H., Pathak, E. B., Kramer, M. R., & Casper, M. (2015b). Disparities in temporal and geographic patterns of declining heart disease mortality by race and sex in the United States, 1973–2010. *Journal of the American Heart Association, 4*, e002567. https://doi.org/10.1161/JAHA.115.002567.

Villablanca, A. C., Jayachandran, M., & Banka, C. (2010). Atherosclerosis and sex hormones: Current concepts. *Clinical Science, 119*, 493–513. https://doi.org/10.1042/CS20100248.

Wemrell, M., Mulinari, S., & Merlo, J. (2017). Intersectionality and risk for ischemic heart disease in Sweden: Categorical and anti-categorical approaches. *Social Science & Medicine, 177*, 213–222. https://doi.org/10.1016/j.socscimed.2017.01.050.

Wilmot, K. A., O'Flaherty, M., Capewell, S., Ford, E. S., & Vaccarino, V. (2015). Coronary heart disease mortality declines in the United States from 1979 through 2011: Evidence for stagnation in young adults, especially women. *Circulation, 132*, 997–1002. https://doi.org/10.1161/CIRCULATIONAHA.115.015293.

Xu, J., Kochanek, K. D., & Murphy, S. L. (2010). National vital statistics reports deaths: Final data for 2007. *Statistics, 58*, 135.