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Article

Systolic Blood Pressure and Socioeconomic Status in a large multi-study population

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ABSTRACT

The present study used harmonized data from eight studies (N = 28,891) to examine the association between socioeconomic status (SES) and resting systolic blood pressure (SBP). The study replicates and extends our prior work on this topic by examining potential moderation of this association by race and gender. We also examined the extent to which body mass index (BMI), waist circumference (WC), and smoking might explain the association between SES and SBP. Data were available from six race/gender groups: 9200 Black women; 2337 Black men; 7248 White women; 6519 White men; 2950 Hispanic women; and 637 Hispanic men. Multivariable regression models showed that greater annual household income was associated with lower SBP in all groups except Hispanic men. The magnitude and form of this negative association differed across groups, with White women showing the strongest linear negative association. Among Black men and Hispanic women, the association was curvilinear: relatively flat among lower income levels, but then negative among higher income ranges. Education also was independently, negatively related to SBP, though evidence was weaker for race and gender differences in the strength of the association. Higher BMI and WC were associated with higher SBP, and current smoking with lower SBP. Inclusion of these risk factors resulted in only a modest change in the magnitude of the SBP and SES relation, accounting on average about 0.4 mmHg of the effect of income and 0.2 mmHg of the effect of education—effects unlikely to be clinically significant. Further understanding of mechanisms underlying the association between SBP and SES may improve risk stratification in clinical settings and potentially inform interventions aimed at reductions in social disparities in health.

Introduction

Although management of blood pressure through medication and other therapeutic modalities has progressed considerably in recent years, high blood pressure remains prevalent in the United States, conferring increased morbidity and mortality, as well as significant economic burden on the health care system (Kirkland et al., 2018). Prior work indicates that lower socioeconomic status (SES) is related to higher SBP (SBP) (Brummett et al., 2011; Chaix et al., 2010; Manuck, Phillips, Gianaros, Flory, & Muldoon, 2010; Metcalf et al., 2008). Individuals lacking in higher education are more likely to have hypertension, along with uncontrolled blood pressure values (Matei et al., 2018). Related work also shows that neighborhood socioeconomic status is related to systolic blood pressure among older individuals (Wagner, Boing, Subramanian, Hofelmann, & D'Orsi, 2016). Specifically, systolic blood pressure was significantly higher among individuals residing in census tracts with lower levels of education. Furthermore, longitudinal findings have demonstrated neighborhood level socioeconomic deprivation is related to incident hypertension (Claudel et al., 2018). Finally, more broadly, life-course socio-economic status has been related to hypertension, as well as the prevalence of other cardio-metabolic risk factors (Ogunsina, Dibaba, & Akinyemiju, 2018).

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A more refined understanding of how SES and SBP are related within race and gender groups offers the potential to further shape policy and guide interventions that are better tailored toward those specific groups. In the present study we attempted to replicate and extend our own prior work (Brummett et al., 2011), as well as that of others (Chaix et al., 2010; Manuck et al., 2010; Metcalf et al., 2008) by 1) examining the association of education and household income with SBP; 2) assessing the role of race and gender as moderators of these associations; and 3) studying body mass index (BMI), waist circumference (WC), and tobacco smoking as potential mediators of the SES-SBP association. The data used were from eight datasets that had been assembled and harmonized to serve a large program project on stress, genes, and cardiovascular risk factors (Brummett et al., 2018).

Methods

Study populations

We used eight datasets in this study, including six large public-access datasets available upon request to the database of genotypes and phenotypes (dbGaP/database of Genotypes and Phenotypes/National Center for Biotechnology Information, National Library of Medicine (NCBI/NLM)/https://www.ncbi.nlm.nih.gov/gap), and two datasets residing at Duke University Medical Center (DUMC). As noted in the Introduction, these specific datasets were chosen as part of an existing program project, which required both phenotypic and genotypic data related to behavioral risk factors for cardiovascular disease (Brummett et al., 2018). The six publicly-available datasets were obtained from the data repository dbGaP/database of Genotypes and Phenotypes/National Center for Biotechnology Information, National Library of Medicine (NCBI/NLM)/https://www.ncbi.nlm.nih.gov/gap(Mailman et al., 2007) through an authorized access. Below is a brief description of all the contributing studies. *All subjects, in each study, gave* written informed consent *in accordance with the Declaration of Helsinki.*

The Women's Health Initiative (WHI)

WHI is a long-term national health study dedicated to developing prevention strategies for heart disease, breast and colorectal cancer, and osteoporotic fractures in postmenopausal women (The WHI Study Group, 1998). The original study enrolled 161,808 postmenopausal women between the years 1993–1998. Minority women were well represented, and ages ranged between 50 to 79 years. The study was designed to be as inclusive as possible while retaining the goal of gathering data on postmenopausal women.

Atherosclerosis Risk in Communities Study (ARIC)

ARIC is a prospective epidemiologic study focused to investigate the etiology and natural history of atherosclerosis and demographic variation in cardiovascular risk factors, medical care, and disease (The ARIC Study Group, 1989). ARIC includes two parts: the Cohort Component and the Community Surveillance Component. The present study used the Cohort Component that began in 1987. Each ARIC field center randomly selected and recruited the cohort sample that consisted of approximately 4000 individuals aged 45–64.

The Coronary Artery Risk Development in Young Adults Study (CARDIA)

CARDIA was designed to study the etiology and natural history of cardiovascular disease beginning in young adulthood (Friedman et al., 1988). Between 1985 and 1986 a cohort of 5115 healthy black and white males and females between the ages of 18–30 years were recruited. The study CARDIA made efforts to recruit substantial numbers of subjects in all of the age, sex, racial and educational subgroups, yet it is it recognized that those who volunteered for the study were likely to be of higher socioeconomic status.

Framingham Offspring Cohort (FOS)

In 1948, the researchers for the original Framingham study recruited 5209 men and women between the ages of 30 and 62 from the town of Framingham, Massachusetts. In 1971 a second-generation (FOS) cohort were. The second examination of the Offspring cohort occurred eight years after the first examination. Due to the availability of psychosocial measurements and genetic data, we used the Generation 2 (or Offspring) dataset from the Framingham Heart Study Cohort for this work (Feinleib, Kannel, Garrison, McNamara, & Castelli, 1975). The second-generation cohort included adult children and their spouses of the original participants. In order to avoid violating the assumption of independent observations, we included only the index participant (the person with the lowest identification number) from any given family cluster. According to Kannel et al. (Kannel, Feinleib, McNamara, Garrison, & Castelli, 1979), families seemed to be similar in size and age for families with parents born in the late 19th or early 20th century, and there is little evidence that the presence of coronary heart disease, as well as factors for disease, differ in parents of those who volunteered for the study as compared to those who did not.

Multi-Ethnic Study of Atherosclerosis (MESA)

MESA was designed to study the CVD risk factors that predict progression of the clinically observable or subclinical cardiovascular disease; (Bild et al., 2002). Eligible participants were persons who lived within defined geographic boundaries for each field center who were between the ages of 45–84. MESA enrolled African-American, Chinese-American, Caucasian, or Hispanic and race/ethnic groups were selected to maximize efficiency to detect race/ethnic differences.

Jackson Heart Study (JHS)

The JHS is a large, community-based, observational study exploring the reasons for the high prevalence of cardiovascular disease among African Americans (Sempos, Bild, & Manolio, 1999). The participants were recruited from urban and rural areas from three counties that comprise the Jackson metropolitan statistical area. The cohort of 5306 participants included roughly 7 percent of all African Americans from the recruitment areas. They were between the ages of 35 and 84.

Duke Caregiver Study (DCS)

This was a DUMC study of family caregivers of individuals with Alzheimer's disease or other dementia and non-caregiving controls (Siegler, Dilworth-Anderson, Brummett, Haney, & Williams, 2010). The study examined the interaction of stress and genetic markers as predictors of cardiovascular disease. Participants were recruited using flyers, ads in the local media, and community outreach efforts. Non-caregivers were recruited by asking caregivers to nominate two to five friends who live in their neighborhood and are similar with respect to demographic factors (i.e., gender, age, and race).

Duke Family Heart Study (DFHS)

This DUMC study examined the effects of genetic variation on the relationship between psychosocial and cardiovascular risk factors (Brummett et al., 2010). Sibling pairs were recruited using community based ads. Participants who were the first family member to volunteer were then giving a phone interview battery to rank their level of hostility. Individuals who were high or low on hostility (according to predefined criteria) were then recruited to participate in the study. Finally, participants were asked to contact their brother(s) and/or sister(s) who might also qualify for and be interested in the study.

As with the Framingham study data we included only the index participant from a given family cluster.

Measures

Systolic Blood Pressure (SBP): For the DCS study SBP was the mean of the last 5 min of a 10-min resting blood pressure assessment. For the

DFHS study, SBP was a single resting blood pressure assessment. In all dbGaP datasets, SBP was an average of two resting SBP readings. The pre-computed average measurements were provided in datasets for MESA, ARIC, CARDIA, and JHS. For FOS and WHI we computed the average using the two available readings.

BMI and WC were available in all studies. BMI was calculated as kg/m^2. WC was measured to the nearest 0.5 cm at the superior border of the iliac crest for all respondents capable of standing unassisted. For descriptive purposes, obesity categories were defined using World Health Organization criteria: BMI <25 = normal weight; 25–29.9 = overweight; 30–34.5 = obese class I; 35–39.5 = obese class II; ≥ 40 = morbidly obese (WHO, 2000).

Self-report measures of education, income, and smoking were available in all studies. Education was assessed as total number of years. In some studies, household income was recorded as a specific monetary value, while in others, income was determined from endorsement of pre-specified bins representing a given income range. When data were binned, we used the median point of the bin range as the income value. Income was adjusted for inflation based on the year during which the assessments were made. Smoking was represented by a binary variable indicating whether or not the participant was currently a daily tobacco smoker.

Statistical analysis

Descriptive statistics were calculated using median and interquartile ranges for continuous variables and frequency counts and percentages for categorical variables. The primary analysis was performed using the least squares multiple regression routine available the rms package in R (http://cran-r.org). This model was:

SBP = Age + Study + Race + Gender + Income + Education + (Race x Income) + (Race x Gender) + (Gender x Income) + (Education x Income) + (Race x Education) + (Gender x Education) + (Race x Gender x Income) + (Race x Gender x Education)

where terms in parentheses represent product interaction terms. The effect of study source was modeled using seven dummy variables, with the ARIC study as the reference. Age, education, and income were modeled as continuous variables. Possible nonlinearity in the effect of income was modeled using a restricted cubic spline function with 3 knots at the default locations. Preliminary analysis with splines suggested a linear relationship between years of education and SBP. Following Harrell (Harrell, 2015) (pp. 31–33) a series of global or pooled Wald tests were performed in order to prevent overfitting. Unlike conventional multiple regression approaches in which each term is tested separately, the pooled approach considers sets of terms simultaneously. For example, the pooled test for income considers whether income is related to SBP in any fashion specified in the model, in this case as a main effect or as part of an interaction. Similar pooled tests are carried out for any term involved in a higher order term. In addition, there are pooled tests for all interaction terms and all nonlinear terms. A given pooled test should be rejected before interpreting its separate constituent terms. A p-value of 0.05 was used to aid decisions regarding interpretation of all model terms.

For continuous predictors, we scaled the regression coefficients in a manner that would provide a substantively meaningful interpretation. This was achieved by calculating the expected difference in SBP given two select values of a given predictor. We scaled years of education to a four-year difference, allowing, for example, a comparison of predicted SBP for someone with a four-year college degree versus the SBP for someone with a high school diploma. For income, we scaled to a $60,000 dollar difference, allowing a comparison of, say, a $60,000 versus $120,000 annual household income. Age was scaled such that the regression coefficient represented the expected difference in SBP for every ten-year increase in age.

In a second phase of analysis, we included the potential mediators of BMI, WC, and current tobacco smoking status (binary) as adjustment covariates in the primary model. BMI and WC were scaled to their approximate interquartile range: 7 units for BMI, 20 cm for WC. BMI and WC were modeled allowing for possible nonlinearity using restricted cubic splines.

Results

Table 1 shows the characteristics of the sample. Black women represented the largest race/gender group. The median age of the sample was 55 years. The median SBP was 121 mmHg and the median BMI was 27.4 kg/m^2. Over 51% of the participants had SBP >120 mmHg and over 17% with SBP >140. Over 37% were classified as at least overweight (BMI 25–29.9); whereas, 19% were in the obese class I category (BMI 30–34.5); 8% in the obese class II category (BMI 35–39.9); and 6% were in the obese class III range (BMI ≥ 40). The correlation between income and education in the present sample was r = 0.46.

Predictors of SBP

The tests of the model terms are displayed in Table 2. Broadly speaking, although correlated, both income and education had independent associations with SBP, and these associations tended to differ across race and gender groups. We observed a race by gender by income interaction, suggesting that the association of income with SBP varied across race and gender. Fig. 1 displays the regression slopes for each group for income predicting SBP. In general, higher income was associated with lower SBP (Fig. 1), with the strongest effect observed for White women. A White woman with an annual household income of $120,000 would be expected to have a 2.0 (95%CI: 1.1, 3.0) mmHg SBP lower than a White women with a $60,000 annual income. The expected SBP difference for the same income difference was 0.9 mmHg (95%CI: 0.4, 1.5) lower for Black women and 1.6 mmHg (95%CI: 0.7, 2.6) lower for Hispanic women. Among Black men, the association was relatively flat at lower income levels; but, this became strong and negative after an annual income of about $100,000. Again comparing incomes of $120,000 to $60,000, the expected difference was 3.4 (95%CI: 1.8, 5.0) mmHg less for Black men, 1.0 (95%CI: 0.07, 1.9) mmHg for White men, but 0.1 (95%CI: 4.0, 3.7) greater for Hispanic men, reflecting the essentially flat slope for this latter group.

There was less evidence for a race by gender by education interaction. For all groups SBP was lower, in a linear fashion, as education increased (Fig. 2). This SBP-education association was strongest among Hispanic men, followed by Hispanic women. Comparing a person with a four-year college degree to a high school graduate, SBP was expected to be 2.2 (95%CI: 1.7, 2.8) mmHg lower among White women; 1.4 (95%CI: 0.9, 1.9) mmHg less for Black women; and 2.5 (95%CI: 1.7, 3.3) mmHg lower for Hispanic women. For men, SBP was expected to be 0.4 (−0.07, 0.9) mmHg lower for White men; 0.6 (95%CI: 0.2, 1.4) mmHg lower for Black men; and 1.8 (95%CI: 0.23, 3.4) mmHg lower for Hispanic men. Given the three-way interaction test for race by gender by education did not meet a conventional significance level, however, we cannot rule out that these apparent difference are specific to this sample. However, because the null hypothesis tests for the race by education and gender by education terms were rejected, we can conclude that there were differences in the education slope between genders, and across races.

As expected SBP was strongly related to age, with a 10-year increase in age associated with a 6.0 (95%CI: 5.8, 6.4) mmHg increase in SBP. Among women, African Americans had the highest BP regardless of income or education level. Among men, African Americans again had the highest SBP, but this difference diminished at higher levels of income.

Table 1
Sample characteristics.

	White Men	Black Men	Hispanic Men	White Women	Black Women	Hispanic Women	Combined
	(N = 6519)	(N = 2337)	(N = 637)	(N = 7248)	(N = 9200)	(N = 2950)	(N = 28891)
ARIC	65% (4237)	39% (910)	0% (0)	64% (4669)	16% (1480)	0% (0)	39% (11296)
CARDIA	10% (645)	14% (335)	0% (2)	10% (708)	5% (462)	0% (1)	7% (2153)
DCS	1% (60)	1% (16)	0% (0)	2% (159)	1% (66)	0% (0)	1% (301)
FOS	5% (317)	0% (0)	2% (11)	5% (331)	0% (0)	1% (17)	2% (676)
JHS	0% (0)	16% (378)	0% (0)	0% (0)	5% (496)	0% (0)	3% (874)
MESA	17% (1138)	28% (656)	98% (624)	17% (1232)	8% (746)	20% (600)	17% (4996)
DFHS	2% (122)	2% (42)	0% (0)	2% (149)	1% (95)	0% (0)	1% (408)
WHI	0% (0)	0% (0)	0% (0)	0% (0)	64% (5855)	79% (2332)	28% (8187)
Smoking: Yes	21%(1393)	28%(643)	16%(101)	23%(1635)	15%(1345)	8%(221)	19% (5338)
Age [Years]	48/**54**/60	45/**52**/60	52/**61**/69	47/**53**/60	52/**58**/64	54/**60**/66	50/**56**/62
Education	12/**14**/16	12/**13**/16	8/**12**/13	12/**13**/14	12/**14**/16	12/**13**/14	12/**13**/16
Income	63.0/**89.2**/105.0	29.4/**58.6**/89.4	20.0/**39.3**/64.3	43.0/**64.3**/105.0	27.4/**50.3**/89.4	27.4/**50.3**/77.8	36.1/**63.0**/105.0
Body Mass Index [Kg/m^2]	24.4/**26.7**/29.4	24.6/**27.7**/30.9	25.8/**28.2**/30.8	22.3/**25.1**/29.1	26.2/**29.8**/34.6	25.1/**28.1**/32.0	24.3/**27.5**/31.4
Waist Size [cm]	90.2/**97.5**/105.0	87.0/**96.0**/105.1	93.0/**99.5**/106.5	78.2/**89.0**/100.0	82.0/**92.0**/103.0	79.0/**87.4**/98.0	83.0/**93.0**/103.0
Systolic Blood Pressure [mmHg]	109/**119**/130	114/**124**/138	111/**124**/138	104/**114**/127	115/**128**/140	111/**123**/137	110/**121**/135

Values are %(N) categorical variables and 25th/**50**th/75th percentile for continuous variables. All values are unadjusted. ARIC = Atherosclerosis Risk in Communities Study; CARDIA=Coronary Artery Risk Development in Young Adults Study; DCS = Duke Caregiver Study; FOS=Framingham Offspring Cohort; JHS = Jackson Heart Study; MESA = Multi-Ethnic Study of Atherosclerosis; DFHS = Duke Family Heart Study; WHI= Women's Health Initiative.

Table 2
Multiple regression parameter tests.

Factor	F	d.f.	P
Age	966.16	2	<.0001
Nonlinear	1.71	1	0.1915
Study	43.91	7	<.0001
Race (Factor + Higher Order Factors)	58.56	16	<.0001
All Race Interactions	3.15	14	0.0001
Gender (Factor + Higher Order Factors)	20.85	12	<.0001
All Gender Interactions	7.01	11	<.0001
Education (Factor + Higher Order Factors)	20.80	6	<.0001
All Education Interactions	5.76	5	<.0001
Income (Factor + Higher Order Factors)	9.27	12	<.0001
All Income Interactions	2.99	10	0.0009
Nonlinear (Factor + Higher Order Factors)	3.30	6	0.0030
Race * Education (Factor + Higher Order Factors)	2.00	4	0.0919
Gender * Education (Factor + Higher Order Factors)	7.07	3	0.0001
Race * Gender (Factor + Higher Order Factors)	3.53	8	0.0004
Race * Income (Factor + Higher Order Factors)	3.13	8	0.0015
Nonlinear (Factor + Higher Order Factors)	3.89	4	0.0037
Nonlinear Interaction: f(A,B) vs. AB	4.08	2	0.0170
Gender * Income (Factor + Higher Order Factors)	3.34	6	0.0027
Nonlinear (Factor + Higher Order Factors)	4.07	3	0.0067
Nonlinear Interaction: f(A,B) vs. AB	11.89	1	0.0006
Race * Gender * Education (Factor + Higher Order Factors)	1.05	2	0.3512
Race * Gender * Income (Factor + Higher Order Factors)	3.37	4	0.0091
Nonlinear	3.89	2	0.0204
TOTAL NONLINEAR	3.08	7	0.0030
TOTAL INTERACTION	5.37	17	<.0001
TOTAL NONLINEAR + INTERACTION	5.12	19	<.0001
TOTAL	213.70	32	<.0001

Tests for Race, Gender, Education, and Income consider all terms in which those variables are included. For example, the pooled 16 d.f. test of Race includes the main effect of Race, 2-way interactions with Gender, non-linear Income, and Education, and three-way interactions with Gender and non-linear Income, and Gender and Education. Tests of nonlinearity are based on restricted cubic spline with 3 knots. Similarly, the pooled test of, say, Race by Income, consider that 2-way interaction, plus the 3-way Race by Gender by Income interaction.

Predictors of SBP accounting for potential mediators

Fig. 3 displays the unadjusted SBP values for each additional term in the model. When models included the three potential mediators, BMI, WC, and smoking, all were related to SBP with evidence of modest nonlinearity for BMI and WC (see Table 3). A 7-unit increase (75th vs 25th percentile) in BMI was associated with a 2.0 (95%CI: 1.4, 2.6) mmHg greater SBP, while a 20 cm increase in WC was associated with a 3.3 (95%CI: 2.7, 3.9) mmHg greater SBP. Smoking was associated with a 1.6 (95%CI: 1.1, 2.1) mmHg lower SBP. These three potential mediators, however, accounted for only a modest portion of the effects of education and income, the largest of these being 0.6 mmHg of the education effect and 0.7 mmHg of the income effect among White Women, and 0.6 mmHg of the income effect for Hispanic women. The scaled regression estimates for each race/gender subgroup with and without smoking, BMI, and WC are reported in Table 4.

Discussion

Using harmonized data from over 31,000 individuals, this study replicates our prior work that lower SES is associated with greater SBP. Here, we add evaluations of different associations across race and gender. Consistent with prior work greater income was generally associated with lower SBP, with the association strongest for White women, but essentially absent among Hispanic men. Consistent with at least some prior work, more years of education were associated with lower SBP, with strongest effects in Hispanic men. BMI and WC were each related to SBP in the expected direction. Current smokers had lower SBP than individuals not currently smoking, possibly because persons with high SBP were more likely to have quit. Finally, these variables explained only a modest amount of the association between SES and SBP.

In the present study, as well as our prior work (Brummett et al., 2011), the strongest negative association between SES and SBP was found among women, in particular among White women. A similar study in a Vietnamese population found that men with increased income were more likely to have hypertension, yet among women those with lower economic status were more likely to be hypertensive (Minh, Byass, Chuc, & Wall, 2006).The authors speculate that the increased risk of hypertension among wealthier men may be related to the adoption of Western risk factors such as a high-fat diet, smoking, and consuming excess alcohol. In contrast, the increased risk of hypertension among poor women may be related to differing risk factors such as early dietary habits, e.g. malnutrition. More broadly, an extensive review of the relations among SES and health (Anderson & Armstead, 1995) notes that race and gender differences are prevalent. For example the relation

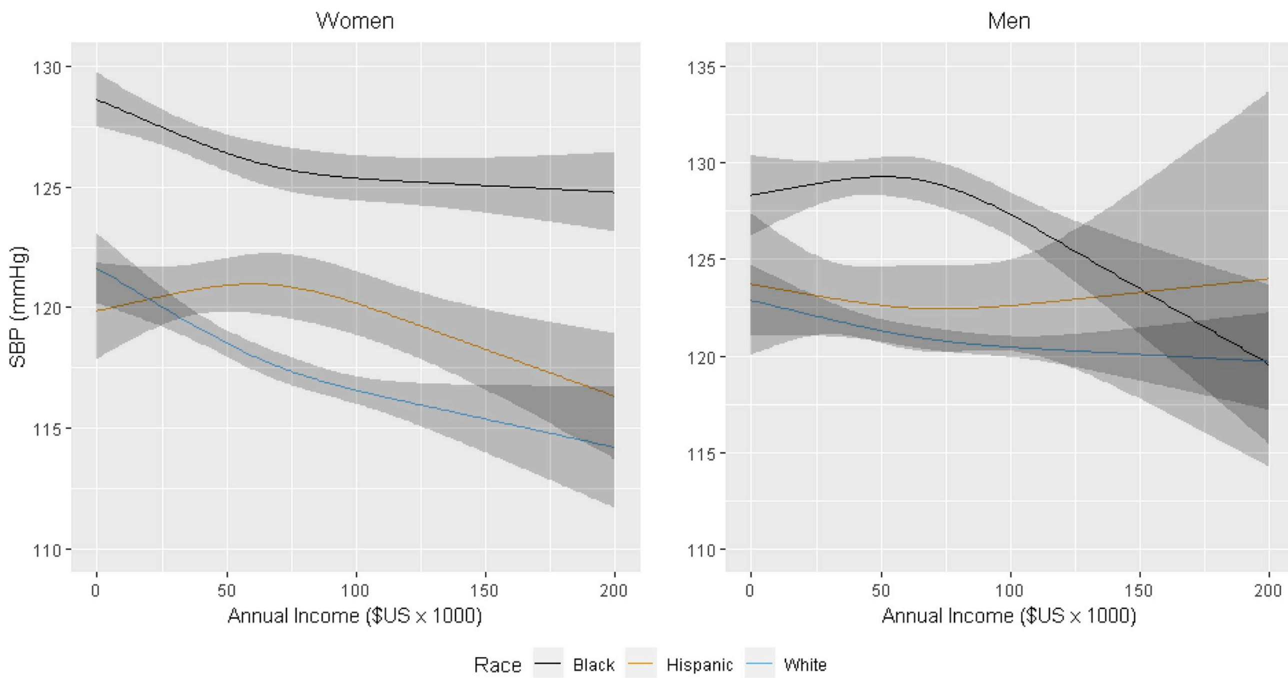

Fig. 1. Race by gender by Income interaction predicting SBP. Fitted regression lines for each race-gender group. Shaded areas represent 95% confidence bands.

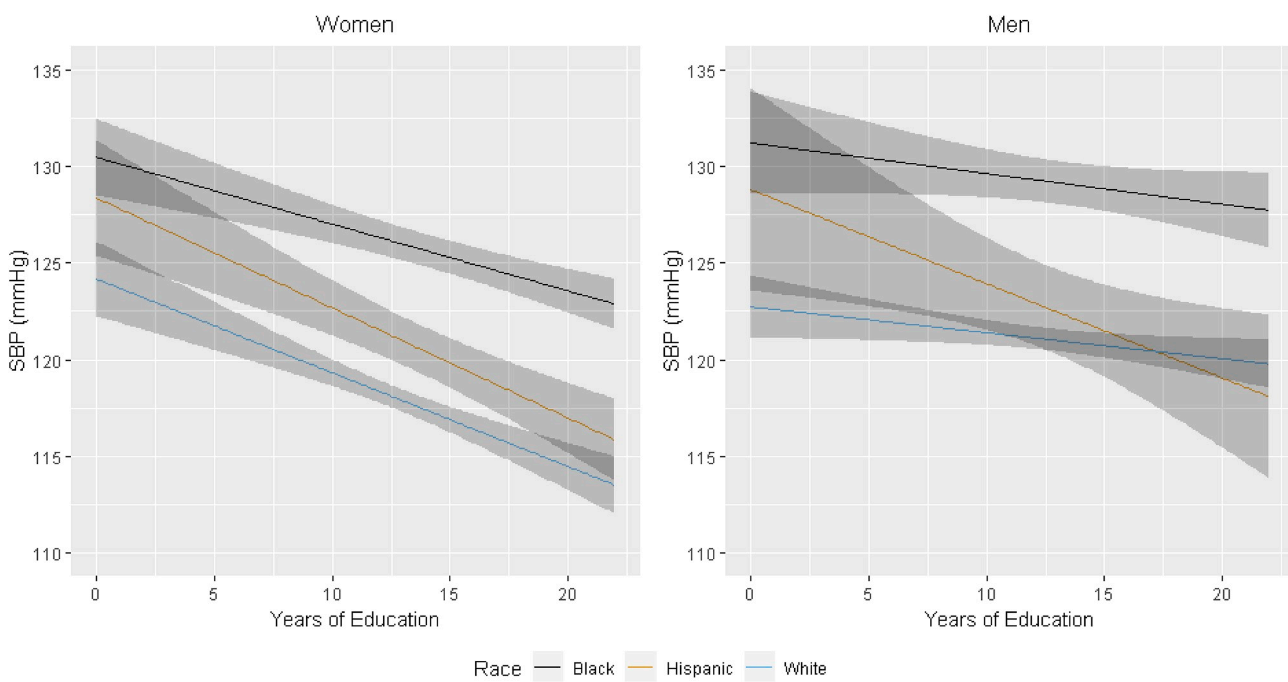

Fig. 2. Race by gender by Education interaction predicting SBP. Fitted regression lines for each race-gender group. Shaded areas represent 95% confidence bands.

between BMI and education is consistently inverse among White women, while an inverted-U shaped association exists among Black women and both Black and White men. In addition, women with high SES report the highest levels of physical activity when compared to other race and gender groups. Unfortunately we did not have a measure of physical activity that would allow us to explore this potential mediator among White women.

Despite the overall inverse associations for income and education with SBP, the magnitude and form of the association were somewhat different for Black men, and for Hispanic men and women. First, among Hispanic men the association between income and SBP was essentially absent. One possible explanation for the absence of an association among Hispanic men is the physical nature of the labor that is prevalent among Hispanic men. In 2014 the majority of occupations held by Hispanic men were in construction, grounds keeping, and forestry services (Bureau of Labor Statistics, 2014). Similar findings were reported by Sorlie (Sorlie et al., 2014), who reported no association between income and hypertension in a sample of Hispanic participants. The second exception to the overall trend was among Black men. In this group, income was inversely related to SBP in a nonlinear fashion: there was essentially no association when annual income was less than about $100,000, but a strong negative association among higher income

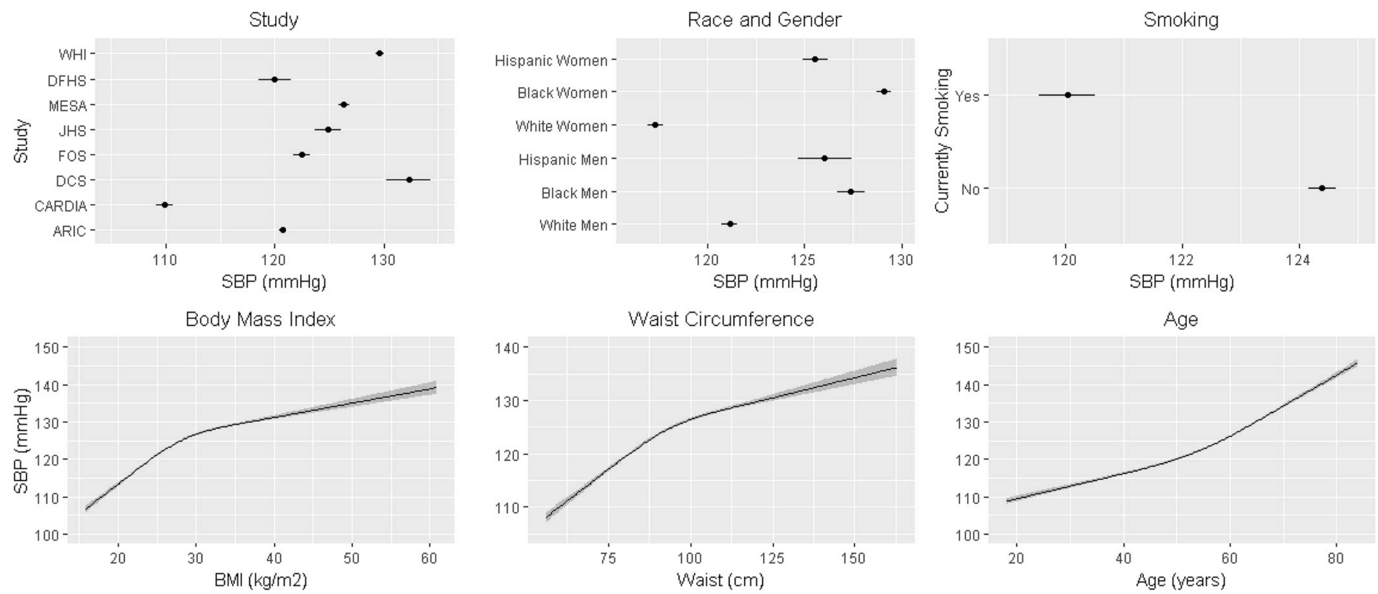

Fig. 3. Unadjusted associations between SBP and covariates used in model. Association of continuous variables are represented as the fitted regression line, with shaded area representing 95% confidence bands. For categorical variables, the center point is the predicted SBP value, with error bars representing 95% confidence limits.

Table 3
Multiple regression parameter tests with additional mediating variables included.

Factor	F	d.f.	P-value
Age	944.62	2	<.0001
Nonlinear	16.00	1	0.0001
Race (Factor + Higher Order Factors)	42.79	16	<.0001
All Race Interactions	2.78	14	0.0004
Gender (Factor + Higher Order Factors)	8.46	12	<.0001
All Gender Interactions	3.14	11	0.0003
Smoking	34.69	1	<.0001
Study	57.88	7	<.0001
Education (Factor + Higher Order Factors)	13.58	6	<.0001
All Education Interactions	3.56	5	0.0032
Income (Factor + Higher Order Factors)	6.30	12	<.0001
All Income Interactions	2.31	10	0.0104
Nonlinear (Factor + Higher Order Factors)	2.73	6	0.0119
BMI	22.67	2	<.0001
Nonlinear	6.54	1	0.0106
Waist	55.88	2	<.0001
Nonlinear	5.45	1	0.0195
Race * Education (Factor + Higher Order Factors)	2.54	4	0.0381
Gender * Education (Factor + Higher Order Factors)	3.02	3	0.0283
Race * Gender (Factor + Higher Order Factors)	3.06	8	0.0019
Race * Income (Factor + Higher Order Factors)	2.72	8	0.0054
Nonlinear (Factor + Higher Order Factors)	3.11	4	0.0143
Nonlinear Interaction: f(A,B) vs. AB	4.06	2	0.0173
Gender * Income (Factor + Higher Order Factors)	2.15	6	0.0444
Nonlinear (Factor + Higher Order Factors)	2.32	3	0.0732
Nonlinear Interaction: f(A,B) vs. AB	6.56	1	0.0104
Race * Gender * Education (Factor + Higher Order Factors)	1.26	2	0.2831
Race * Gender * Income (Factor + Higher Order Factors)	2.68	4	0.0300
Nonlinear	2.19	2	0.1119
TOTAL NONLINEAR	6.47	9	<.0001
TOTAL INTERACTION	2.88	17	0.0001
TOTAL NONLINEAR + INTERACTION	4.71	21	<.0001
TOTAL	223.02	37	<.0001

See note for Table 2 for explanation of tests.

ranges. One possible explanation for this threshold effect may have to do with the underlying higher prevalence of high blood pressure in Black men compared to the other race/gender groups. It may simply require greater socioeconomic resources to adequately influence higher levels of SBP. Finally, Hispanic women exhibited a nonlinear association similar in form to Black men. This finding is in contrast to Sorlie et al.(Sorlie et al., 2014), who reported a lack of association between income and hypertension among Hispanic women. One possible explanation for this discrepancy between studies is that Sorlie et al. used a dichotomous hypertension outcome while we modeled SBP as a continuous variable. Thus, our analyses may have been more sensitive to the presence of an association. Beyond this, there is a remarkable paucity of literature that might inform an explanation for this finding (Rodriguez Carlos et al., 2014). We hope to examine this issue further in datasets that provide additional explanatory variables.

In prior work (Brummett et al., 2011; Chaix et al., 2010), the association between education and SBP were partially explained by BMI and WC. This was also true in the present study, though it was a far more modest effect. This difference may be attributed to the present sample being significantly older than in the prior work (median of 56 years vs 29 years) where BMI and blood pressure relationships are weaker (Droyvold et al., 2005). In contrast to education, analyses for income and SBP were similar across our two studies, that is, household income remained associated with SBP even when controlling for BMI and WC.

The present study has a number of important limitations. First, the availability of additional potential confounders or mediators differed across study sources, obviating our ability to include them in the analyses. For example, we did not have access to potentially important covariates that affect SBP either by way of common cause or as a mechanism, such as medication, diet, alcohol use, health beliefs, and exercise habits. The available datasets did include BMI, waist circumference, and current smoking, and we found modest evidence that these variables explained some of the association between the SES variables and SBP. In addition, the reliability and validity of the measures under study very likely varied considerably across study sources. The SES variables, for example, were assessed by self-report, and the response options differed across studies. We also note that our adjustment for inflation was based on national-level data and did not account for regional differences in the cost of living. In addition, SBP was ascertained under varying conditions across the studies. The cross-sectional

Table 4
Scaled regression coefficients (b), with and without adjustment for potential mediators BMI, Waist Circumference, and Current Smoking.

		Factor	*b*	Lower 95% CL	Upper 95% CL
White Women	No Mediators	Education	−2.23	−2.79	−1.67
		Income	−2.04	−2.95	−1.13
	With Mediators	Education	−1.60	−2.15	−1.04
		Income	−1.31	−2.20	−0.41
White Men	No Mediators	Education	−0.42	−0.90	0.07
		Income	−1.00	−1.93	−0.07
	With Mediators	Education	−0.44	−0.92	0.03
		Income	−0.75	−1.66	0.17
Black Women	No Mediators	Education	−1.38	−1.88	−0.88
		Income	−0.93	−1.49	−0.37
	With Mediators	Education	−0.86	−1.35	−0.37
		Income	−0.56	−1.11	−0.01
Black Men	No Mediators	Education	−0.61	−1.36	0.15
		Income	−3.36	−4.97	−1.76
	With Mediators	Education	−0.70	−1.44	0.04
		Income	−3.23	−4.80	−1.65
Hispanic Women	No Mediators	Education	−2.47	−3.26	−1.67
		Income	−1.63	−2.59	−0.67
	With Mediators	Education	−2.11	−2.89	−1.33
		Income	−1.01	−1.95	−0.06
Hispanic Men	No Mediators	Education	−1.82	−3.41	−0.23
		Income	0.14	−3.68	3.96
	With Mediators	Education	−1.97	−3.52	−0.41
		Income	0.23	−3.51	3.98

Values in column labeled *b* are scaled regression coefficients. Education is scaled to 4 year increments, comparing, for example, the predicted SBP for a 16-year to that of someone with a 12-year education. Income is scaled to a $60,000 difference in annual household income, comparing, for example, a household income of $120,000 to $60,000. Estimates are generated from a model using all race/gender groups simultaneously.

nature of this study precludes conclusions regarding causality; as noted above unmeasured confounders may have biased the associations we observed. Finally, although selection bias is an ever-present concern, the studies that were included in these analyses tended to use sampling techniques that would limit bias. None of the studies selected participants based on SES or blood pressure, and, given the median sample age of 56 years, the threat of survivor bias is likely small. Moreover, one of the strengths of combining datasets is that missing substrata in a given a particular dataset can be offset by its availability in others. Finally, although we have no data available for formally evaluating the impact of the above limitations on our estimates, we are encouraged by the consistency of the findings with our prior work and other literature.

Finally, we note that our categorization of study participants by race is at best a crude and potentially illusory representation of a much fuller and richer set of characteristics, including the wide array of genetic ancestries and cultural practices and beliefs. Kaplan and Bennett (Kaplan & Bennett, 2003) proposed that when race is used in biomedical research "all conceptually relevant factors should be considered." In the ideal, the concept of race would not be used at all, but rather these richer set of factors. However, self-identified race continues to be a useful if imprecise tool for understanding socioeconomic status and related its consequences (see, for example https://www.apa.org/pi/ses/resources/publications). Thus, we acknowledge the limitations of using race categories and look forward to a day when large amounts of data are available using a richer set of descriptors. Nevertheless, we believe that, the present data does offer at least broad insight into how socioeconomic variables may behave given self-described race.

The findings of the present study have potentially important clinical implications. A large scale meta-analysis of data from 61 prospective studies found that for each 2 mm Hg increase in SBP there is a 10% increase in stroke mortality and a 7% increase in IHD mortality. In the present study, compared to an annual household income of $120,000, White women with annual household income of $60,000 had 2.0 mmHg higher SBP and in Black men this same income difference was associated with a 3.4 mmHg higher SBP. Regarding interventions with potential to reduce the impact of lower SES on blood pressure, both meditation and cognitive behavioral stress management approaches have been found to reduce blood pressure in clinical trials.

In summary, our findings further highlight the importance of race and gender in evaluating the role of SES with regard to health disparities. In the United States, approximately 39% of young Blacks and 33% percent of young Hispanics live in poverty, a rate that is double that for young Whites (American Psychological Association, 2019). With regard to education, Blacks and Hispanics are more likely to attend high-poverty schools as compared to Whites (National Center for Education Statistics, 2007), and at every level of income or education, Blacks have significantly poorer health outcomes compared to Whites. Thus, our findings add to the evidence that race and gender are important considerations when examining how SES influences health outcomes such as SBP (Williams & Mohammed, 2013). These findings further support the need for programs such as described by Carey et al. (Carey, Muntner, Bosworth, & Whelton, 2018), targeting more vulnerable sections of the population.

Ethics approval

All subjects, in each study, gave written informed consent *in accordance with the Declaration of Helsinki. In addition, this work was approved by the Institutional Review Board at Duke University Medical Center.*

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Appendix A. Supplementary data

Supplementary data related to this article can be found at https://doi.org/10.1016/j.ssmph.2019.100498.

References

American Psychological Association. (2019). *Ethnic and racial minorities & socioeconomic status*.
Anderson, N. B., & Armstead, C. A. (1995). Toward understanding the association of socioeconomic status and health: A new challenge for the biopsychosocial approach. *Psychosomatic Medicine, 57*, 213–225.
Bild, D. E., Bluemke, D. A., Burke, G. L., Detrano, R., Diez Roux, A. V., Folsom, A. R., et al. (2002). Multi-ethnic study of atherosclerosis: Objectives and design. *American Journal of Epidemiology, 156*, 871–881.
Brummett, B. H., Babyak, M. A., Siegler, I. C., Shanahan, M., Harris, K. M., Elder, G. H., et al. (2011). Systolic blood pressure, socioeconomic status, and biobehavioral risk factors in a nationally representative US young adult sample. *Hypertension, 58*, 161–166.
Brummett, B. H., Babyak, M. A., Singh, A., Hauser, E. R., Jiang, R., Huffman, K. M., et al. (2018). Lack of association of a functional polymorphism in the serotonin receptor

gene with body mass index and depressive symptoms in a large meta-analysis of population based studies. *Frontiers in Genetics, 9*, 423.
Brummett, B. H., Boyle, S. H., Ortel, T. L., Becker, R. C., Siegler, I. C., & Williams, R. B. (2010). Associations of depressive symptoms, trait hostility, and gender with C-reactive protein and interleukin-6 response after emotion recall. *Psychosomatic Medicine, 72*, 333–339.
Bureau of Labor Statistics, U.S.D.o.L. (2014). *The economics daily, Hispanics and latinos in industries and occupations*.
Carey, R. M., Muntner, P., Bosworth, H. B., & Whelton, P. K. (2018). Prevention and control of hypertension: JACC health promotion series. *Journal of the American College of Cardiology, 72*, 1278–1293.
Chaix, B., Bean, K., Leal, C., Thomas, F., Harvard, S., Evans, D., et al. (2010). Individual/neighborhood social factors and blood pressure in the RECORD Cohort Study: Which risk factors explain the associations? *Hypertension, 55*, 769–775.
Claudel, S. E., Adu-Brimpong, J., Banks, A., Ayers, C., Albert, M. A., Das, S. R., et al. (2018). Association between neighborhood-level socioeconomic deprivation and incident hypertension: A longitudinal analysis of data from the dallas heart study. *American Heart Journal, 204*, 109–118.
Droyvold, W. B., Midthjell, K., Nilsen, T. I., & Holmen, J. (2005). Change in body mass index and its impact on blood pressure: A prospective population study. *International Journal of Obesity, 29*, 650–655.
Feinleib, M., Kannel, W. B., Garrison, R. J., McNamara, P. M., & Castelli, W. P. (1975). The Framingham offspring study. Design and preliminary data. *Preventive Medicine, 4*, 518–525.
Friedman, G. D., Cutter, G. R., Donahue, R. P., Hughes, G. H., Hulley, S. B., Jacobs, D. R., Jr., et al. (1988). Cardia: Study design, recruitment, and some characteristics of the examined subjects. *Journal of Clinical Epidemiology, 41*, 1105–1116.
Harrell, F. E. (2015). *Regression modeling strategies: With applications to linear models, logistic regression, and survival analysis*. New York: Springer.
Kannel, W. B., Feinleib, M., McNamara, P. M., Garrison, R. J., & Castelli, W. P. (1979). An investigation of coronary heart disease in families. The Framingham offspring study. *American Journal of Epidemiology, 110*, 281–290.
Kaplan, J. B., & Bennett, T. (2003). Use of race and ethnicity in biomedical publication. *Jama, 289*, 2709–2716.
Kirkland, E. B., Heincelman, M., Bishu, K. G., Schumann, S. O., Schreiner, A., Axon, R. N., et al. (2018). Trends in healthcare expenditures among US adults with hypertension: National estimates, 2003-2014. *J Am Heart Assoc, 7*.
Mailman, M. D., Feolo, M., Jin, Y., Kimura, M., Tryka, K., Bagoutdinov, R., et al. (2007). The NCBI dbGaP database of genotypes and phenotypes. *Nature Genetics, 39*, 1181.
Manuck, S. B., Phillips, J. E., Gianaros, P. J., Flory, J. D., & Muldoon, M. F. (2010). Subjective socioeconomic status and presence of the metabolic syndrome in midlife community volunteers. *Psychosomatic Medicine, 72*, 35–45.
Matei, S., Cutler, S. J., Preda, M., Dorobantu, M., Ilinca, C., Gheorghe-Fronea, O., et al. (2018). The relationship between psychosocial status and hypertensive condition. *Current Hypertension Reports, 20*, 102.
Metcalf, P. A., Scragg, R. R., Schaaf, D., Dyall, L., Black, P. N., & Jackson, R. T. (2008). Comparison of different markers of socioeconomic status with cardiovascular disease and diabetes risk factors in the Diabetes, Heart and Health Survey. *N Z Med J, 121*, 45–56.
Minh, H. V., Byass, P., Chuc, N. T., & Wall, S. (2006). Gender differences in prevalence and socioeconomic determinants of hypertension: Findings from the WHO STEPs survey in a rural community of vietnam. *Journal of Human Hypertension, 20*, 109–115.
National Center for Education Statistics. (2007). *Status and trends in the education of racial and ethnic minorities*.
Ogunsina, K., Dibaba, D. T., & Akinyemiju, T. (2018). Association between life-course socio-economic status and prevalence of cardio-metabolic risk ractors in five middle-income countries. *J Glob Health, 8*, 020405.
Rodriguez Carlos, J., Allison, M., Daviglus Martha, L., Isasi Carmen, R., Keller, C., Leira Enrique, C., et al. (2014). Status of cardiovascular disease and stroke in hispanics/latinos in the United States. *Circulation, 130*, 593–625.
Sempos, C. T., Bild, D. E., & Manolio, T. A. (1999). Overview of the Jackson heart study: A study of cardiovascular diseases in african American men and women. *The American Journal of the Medical Sciences, 317*, 142–146.
Siegler, I. C., Dilworth-Anderson, P., Brummett, B. H., Haney, T. L., & Williams, R. B. (2010). Caregiving, residence, race, and depressive symptoms. *Aging & Mental Health, 72*, 771–778.
Sorlie, P. D., Allison, M. A., Aviles-Santa, M. L., Cai, J., Daviglus, M. L., Howard, A. G., et al. (2014). Prevalence of hypertension, awareness, treatment, and control in the hispanic community health study/study of latinos. *American Journal of Hypertension, 27*, 793–800.
The ARIC investigators. (1989). The atherosclerosis risk in Communities (ARIC) study: Design and objectives. The ARIC investigators. *American Journal of Epidemiology, 129*, 687–702.
The WHI Study Group. (1998). Design of the women's health initiative clinical trial and observational study. The women's health initiative study group. *Controlled Clinical Trials, 19*, 61–109.
Wagner, K. J., Boing, A. F., Subramanian, S. V., Hofelmann, D. A., & D'Orsi, E. (2016). Effects of neighborhood socioeconomic status on blood pressure in older adults. *Revista de Saúde Pública, 50*, 78.
WHO. (2000). *Technical report series 894. Obesity: Preventing and managing the global epidemic* (Geneva, Switzerland).
Williams, D. R., & Mohammed, S. A. (2013). Racism and health I: Pathways and scientific evidence. *American Behavioral Scientist, 57*, 1152–1173.