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Do US Black Women Experience Stress-Related Accelerated Biological Aging?:

A Novel Theory and First Population-Based Test of Black-White Differences in Telomere Length

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Abstract

We hypothesize that black women experience accelerated biological aging in response to repeated or prolonged adaptation to subjective and objective stressors. Drawing on stress physiology and ethnographic, social science, and public health literature, we lay out the rationale for this hypothesis. We also perform a first population-based test of its plausibility, focusing on telomere length, a biomeasure of aging that may be shortened by stressors. Analyzing data from the Study of Women's Health Across the Nation (SWAN), we estimate that at ages 49–55, black women are 7.5 years biologically “older” than white women. Indicators of perceived stress and poverty account for 27% of this difference. Data limitations preclude assessing objective stressors and also result in imprecise estimates, limiting our ability to draw firm inferences. Further investigation of black-white differences in telomere length using large-population-based samples of broad age range and with detailed measures of environmental stressors is merited.

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Keywords

Health disparities; Aging; Stress; Race/ethnicity; Weathering; Women's health; Poverty; Telomeres

Despite overall gains in active life expectancy and efforts to reduce health disparities in the United States, black-white and socioeconomic inequalities in life expectancy and the prevalence of chronic disease persist (Flegal et al. 2002; Geronimus et al. 1996; Levine et al. 2001; Mokdad et al. 2001; Wong et al. 2002). These health disadvantages are severe among African Americans. More troubling still, some evidence suggests that black health disadvantages worsened after the early 1990s, especially among women. In some high-poverty localities, excess mortality rates increased among black women residents between 1990 and 2000, largely due to deaths attributed to chronic disease (Geronimus et al. 2008). Yet another example, estimates using data from the National Health and Nutrition Examination Surveys III (1988–1991) and IV (1999–2002) show that hypertension prevalence rates grew in nonelderly black adults nationwide between the two survey waves, both absolutely and relative to whites (Geronimus et al. 2007). The entrenchment and, in some cases, worsening of black health disadvantages occurred across a wide range of health outcomes and during a period when the reduction or elimination of health disparities was identified as a high-priority national health objective. The clear failure to meet this objective suggests that future success may require new conceptual models and deepening understandings of the sources and mechanisms leading to health disparities.[1]

The age dimension of black-white health disadvantages may provide key insights. For example, in the case cited above, black women in young through middle adulthood experienced the steepest increase with age in the probability of being hypertensive, even net of excess obesity rates among US black relative to white women. More broadly, the most pronounced differences in health between US black and white women are seen in middle age, suggesting, at least metaphorically, an accelerated aging process (Geronimus 2001). Geronimus hypothesized that this age pattern of US black health disadvantage reflects a process of biological weathering (Geronimus 1992, 2001). That is, US blacks may be biologically older than whites of the same chronological age due to the cumulative impact of repeated exposure to and high-effort coping with stressors.

Stress physiology (Sapolsky 1998; Selye 1956), including the concept of allostatic load, or that overexposure to stress hormones can cause wear and tear on important body systems (McEwen and Seeman 1999; Seeman et al. 1997), lends biological plausibility to the weathering hypothesis. Our bodies are designed to respond to stressors through the cooperative effects of the primary stress response systems—the sympathetic nervous system (SNS) and hypothalamic-pituitary-adrenal (HPA) axis. An efficient response to an acute stressor involves activation of the SNS to direct resources to the “fight-or-flight” systems. Increases in cortisol from HPA activation may then serve to “reign in” the actions and damaging by-products of SNS activation (Sapolsky et al. 2000). However, with exposure to chronic stress and repeated activation of the stress response systems, these stress responses become inefficient, resulting in an allostatic load on the body's systems (McEwen 1998). For example, continued SNS

[1]Excessive prevalence of stress-related diseases of aging among nonelderly black women calls for better understanding and reversal, per se. In addition, life history theory suggests that local population health and life expectancy play a role in the development of life history traits such as reproductive strategies and risk-taking behavior (Chisholm 1993, 1999; Wilson and Daly 1997). Chisholm (1993, 1999) theorizes that the chronic risk and uncertainty suffered by adults of reproductive and working age who face chronic, multiple stressors could compromise their ability to invest in or buffer their children from risk through the development of secure attachments, with potentially lifelong implications. Stressful life experiences in childhood can also result in lifelong inefficiency in one's physiological adaptation to stressors or in a conditioned predisposition to overreact to challenges to homeostasis, with adverse health implications (McEwen 1998).

activation with chronic stress coupled with HPA dysfunction in the form of the loss of cortisol's anti-inflammatory effects would result in an increase in inflammation and oxidative stress. In turn, inflammatory processes result in increased risk of cardiovascular, immune, and metabolic dysfunction (Khansari et al. 2009). Through such mechanisms, allostatic load may then take a toll throughout the body and contribute to the development or progression of a broad range of clinical and preclinical pathological processes, including cardiovascular disease, obesity, diabetes, susceptibility to infection, carcinogenesis, and accelerated aging.

Large literatures in sociology, economics, anthropology, and public health document that US blacks are more likely to experience stressful situations, such as material hardship (Charles and Guryan 2008; Mayer and Jencks 1988), interpersonal discrimination (Barnes et al. 2004; Taylor and Turner 2002), structural discrimination in housing and employment (Charles and Hurst 2002; Darity and Mason 1998; Holzer et al. 2005; Ondrich et al. 2003; Yinger 1998), and multiple caregiving roles (Dilworth-Anderson et al. 2002; Hicks-Bartlett 2000; Lum 2005) than whites. Ambient stressors in residential or work environments—such as noise, crowding, decaying housing, danger, or extremes of temperature; regular disruption of diurnal rhythms; hunger; infection; or sustained cognitive or emotional engagement with stressful life experiences—are further examples of stressors that can pose significant physiological challenge and to which US blacks are disproportionately exposed, not only with greater frequency but, plausibly, also with greater duration or intensity than whites (Almeida et al. 2005; Gee and Payne-Sturges 2004; Morello-Frosch and Lopez 2006; Oths et al. 2001; Steptoe and Marmot 2006).

Indeed, researchers report black-white differences in the hypothesized stress-mediated pathways to poor health, whereby black adults exhibit a blunted diurnal cortisol rhythm and higher levels of general inflammation compared with white adults (Cohen et al. 2006; Kalinowski et al. 2004; Khera et al. 2005). Geronimus et al. (2007) report that blacks have higher mean allostatic load scores, a summary biological measure of stress-mediated wear and tear on the body, than do whites at all ages, and the differential in scores increases with age. Moreover, by age 30, black women exhibit greater risk of having high allostatic load scores than black men or than white men or women. This risk gap increases through midlife and is most severe among black women who are poor.

Stress-mediated health impacts may be felt especially by black women in poverty because they often bear central responsibility for the social and economic survival of their families and communities,[2] and thus, perhaps, the wear and tear on biological systems of repeated adaptation to related stressors (Burton and Whitfield 2003; Dilworth-Anderson and Rhoden 2000; Geronimus et al. 2006; Jarrett and Burton 1999; Lancaster 1989; Mullings and Wali 2001; Stack 1974; Stack and Burton 1993; Warren-Findlow 2006). For example, in their urban ethnographic study on welfare, children, and families, Burton and Whitfield (2006) found that most of the primary caregivers in their study led “highly challenging” lives and “could never get a break.” Such unremitting stress can wear away at health. Recruited to the study as primary caregivers of children, many were also the primary caregivers of their ailing or disabled mothers. A significant number of their mothers died prematurely—by age 55—and of cardiovascular disease, strokes, or cancer. This source of distress for adult daughters was also a window into their own future. Among the primary caregivers in Burton and Whitfield's study, 60% suffered multiple morbidities, even though 83% of these women were younger than 39

[2]In the most recent decades, gendered aspects of US public sentiment on race may have severely limited black men's role in providing social and economic security for their families, while raising expectations of black women, especially in high poverty populations. For example, young, less-educated black men have experienced a long secular decline in employment rates, continuing even through the labor market expansion of the 1990s (Holzer et al. 2005). At the same time, incarceration rates of young, less-educated black men soared (Western 2006), dramatically disrupting their potential to contribute to family support, while “welfare to work” requirements heightened the demands on black women (Geronimus and Thompson 2004; Jarrett and Burton 1999).

years of age.[3] As Burton and Whitfield observe of their study participants, those suffering from multiple health problems often found just getting through each day a challenge.

Prolonged psychosocial or physical challenge to metabolic homeostasis contributes to poor health outcomes and may also accelerate aging (McEwen and Seeman 1999; Sapolsky et al. 2000). Thus, the concept of weathering, related empirical findings showing the steepest age-gradient increase in the probability of chronic disease onset to be among black women, and ethnographic findings providing thick description of why this may be so raise the question of whether US black women may experience accelerated biological aging.

Telomeres, Age, and Health

The possibility that black women weather to the degree that they experience accelerated biological aging sets an ambitious research agenda requiring the identification of a measure of biological aging and, ultimately, a well-specified set of measurable environmental, material, and psychosocial stressors that have the potential to impact it, and can be studied across populations of blacks and whites. In this paper we take a modest empirical first step toward this end by considering a leading candidate biomeasure of aging—telomere length in a subset of leukocytes called peripheral blood mononuclear cells (PBMC)—as a potentially appropriate outcome variable for continued study.

Telomeres, the stabilizing caps on chromosomes, shorten with cell division until a certain point, at which the chromosomes are no longer stable and the cell either dies or enters senescence (Allsopp et al. 1992; Chan and Blackburn 2004). Research also indicates that, because breaks in the DNA structure due to oxidative stress are not easily repaired in telomeres, oxidative stress is an important mechanism by which telomeres are shortened (von Zglinicki 2002; von Zglinicki et al. 2000).

Since oxidative stress is an important mechanism linking aging, psychosocial stress, biological stress activation, inflammation, and disease development, PBMC telomeres may serve as a powerful marker of overall biological, versus chronological, age (Bauer et al. 2009; Demissie et al. 2006; Harrison et al. 2003; Khansari et al. 2009; Valdes et al. 2005). We propose that the excess morbidity and mortality experienced by black relative to white adults stems fundamentally from the persistent and multifactorial stressors—subjective and objective—experienced by black adults. This stress leads to greater activation of the biological stress processes, which in turn leads to a greater allostatic load and greater levels of inflammation and oxidative stress. Early inflammatory processes and oxidative stress then contribute to the black-white disparities in the development and progression of disease and subsequent mortality, with PBMC telomere length marking this process. Because the wear and tear of stress on the body accumulates over the lifespan, telomeres shorten with age and serve as an indicator of the resultant aging- and stress-related increase in inflammation and oxidative stress over the lifespan.

Research using samples of white adults provide support for our proposed mechanism linking black-white disparities in stress, disease, and PBMC telomere length (Houben et al. 2008; Sapolsky 2004). Telomere length is inversely related to age (Benetos et al. 2001; Iwama et al. 1998; Lindsey et al. 1991)—with growing research indicating that it is also inversely related

[3]For example, 30-year-old Francine was the primary caregiver of both her 6-year-old severely asthmatic son and her mother, who, during the course of the ethnography, suffered a stroke, a heart attack, and underwent tumor surgery. Francine herself developed stomach cancer. Yet, Burton and Whitfield note, “like many of the mothers in the ethnography, Francine endured tremendous physical pain, going to the doctor only when the pain was unbearable and when she ‘didn't have other folks to take care of’” (2003:17). Another example was Barbara, who at age 37 suffered from multiple chronic health problems, including diabetes, back injury, kidney problems, migraines, hernias, depression, and anxiety. She was not unusual among the study participants.

to stressful situations that have documented black-white disparities, such as high-demand caregiving and low socioeconomic status (Cherkas et al. 2006; Epel et al. 2004). Furthermore, research suggests that telomere length is also inversely related to stress biomarkers, including cortisol, epinephrine, and norepinephrine (Epel et al. 2006). Finally, shorter telomeres have been associated with many chronic diseases known to have marked black-white disparities (Taylor 2001), such as hypertension (Aviv 2002; Demissie et al. 2006), atherosclerosis (Edo and Andres 2005; Matthews et al. 2006), cirrhosis (Wiemann et al. 2002), and diabetes (Adaikalakoteswari et al. 2005; Sampson et al. 2006), as well as mortality (Cawthon et al. 2003; Martin-Ruiz et al. 2006).

Researchers have reported no racial differences in telomere length at birth (Okuda et al. 2002). Although individual variation in telomere length has a strong genetic component (Graakjaer et al. 2003), evidence that heritability of telomere length decreases with age in adults, and findings of substantial telomere length differences between twins in the population-based Swedish twin registry and from a study of British twins discordant on adult socioeconomic position, suggest that social or environmental factors also can be important contributors to adult telomere length (Bakaysa et al. 2007; Cherkas et al. 2006).

If PBMC telomere length marks the increase in oxidative stress due to biological stress activation, and if weathering is produced by persistent high-effort coping with and physiologic adaptation to stressors, then black adults would experience a faster rate of PBMC telomere shortening through the lifespan, since they experience a greater accumulation of allostatic load. Thus, we hypothesize that by middle age, black women have shorter average telomere length than white women owing to a lifetime of repeated adaptation to material, psychosocial, and environmental stressors posing significant challenge to homeostasis.

We note that we are forwarding a fundamentally different understanding and more unified theory of black-white health disparities than more common ones that explain them by socioeconomic differences alone, or interpret racial differences in health as expressions of behavioral or genetic difference, or that focus on the epidemiology of a single disease outcome. An enduring puzzle in social epidemiology is that race coefficients remain sizeable and statistically significant, even after socioeconomic indicators are controlled (Schoendorf et al. 1992; Williams 1999). Indeed, while weathering appears marked for African Americans in poverty, it is evident to varying degrees at all socioeconomic levels (Geronimus 2001). Since US blacks across the socioeconomic spectrum engage with some degree of race-related stress (Colen et al. 2006; Geronimus and Thompson 2004; Pearson 2008), we see our focus on stress physiology as one way to explain these residual black-white differences, as well as suggestive of possible mechanisms for that portion of the difference that is attributable to socioeconomic characteristics.

Although unhealthy behaviors are more prevalent among the socioeconomically disadvantaged (black or white), they do not fully explain disparities that persist net of socioeconomic characteristics (Lantz et al. 1998). To the extent that unhealthy behaviors contribute to health disparities, they can sometimes be coping responses to psychosocial or environmental stressors (Bennett et al. 2005; Gil et al. 2004; Guthrie et al. 2002; Yen et al. 1999). Moreover, some unhealthy behaviors may themselves reflect neuroendocrine effects (Brunner et al. 2007; Dallman et al. 2003). For example, chronically high levels of glucocorticoids are thought to increase compulsive activities and the appeal of drugs, sugar, and fats. Based on such action of chronic stress hormone exposure, Dallman et al. (2003) propose that people facing chronic stressors may compulsively turn to high-fat and sugar-laden or “comfort” foods in an attempt to reduce anxiety and chronic stress-response activity. This may contribute to obesity, central adiposity, and related diseases in populations facing chronic stress.[4]

The argument that genetic difference accounts for the vast and growing disparities in health between the socially constructed populations of “black” and “white” is difficult to sustain (Cooper et al. 2003). Most would agree that environmental contributions are important (Wallace 2001). Still, biological mechanisms must link social and environmental forces to population health. Focusing on stress physiology and how, in a race-conscious society, it may mediate the relationship between differential life experience of racial/ethnic groups and health disparities may be a fruitful way to explicate key biological mechanisms that underlie racial inequality in health and are socially structured.

Methods

Sample

For this initial test of the plausibility of our broader hypothesis and of the viability of telomere length as a candidate outcome measure for further study, we report on black-white differences in telomere length in a population-based sample of middle-aged women from the Study of Women's Health Across the Nation (SWAN). SWAN is a multi-site, multi-ethnic, population-based, observational cohort study designed to examine the health of women during their middle years. Recruitment procedures and the study design have been described elsewhere (Sowers et al. 2000). Briefly, at baseline (1996–1997), women were screened from defined sampling frames at seven US sites. Women between 42 and 52 years of age at baseline, who reported having had a menstrual period and no use of hormone therapy in the three months prior to recruitment, were invited to participate in a longitudinal study of natural menopause. The cohort participated in a baseline clinical examination and annual follow-up examinations. Participants also completed an annual questionnaire that included select demographic, economic, and psychometric characteristics. DNA samples from PBMCs were collected in year 7, when the youngest sample members were 49 years of age, and immortalized for storage in the SWAN specimen repository, applying an approach which maintains the integrity of the genetic structure (Neitzel 1986; Wall et al. 1995). Retention at year 7 (2003–2004) was 77% for blacks and 76% for whites.

We analyzed DNA samples on a randomly selected subsample of SWAN respondents who were recruited from sites that included both blacks and whites. We also drew on data associated with these samples, including race, age, study site, estradiol, perceived stress, income category, smoking status, and waist-to-hip ratio (WHR).

Initially, our sample included 115 whites and 117 blacks aged 49 through 55 at year 7. After excluding women who had missing information for key variables, our final sample size was 215 (105 white and 110 black). Chi-square and *t*-test analyses comparing differences between the 215 women included and women omitted indicated that there were no statistically significant differences in the distribution of perceived stress, income, or WHR variables. Black, but not white, omitted women were more likely to ever have smoked than their included counterparts, and those women who were omitted only because of missing estradiol information were younger than those included (mean = 50.76; SE=1.44 v. mean = 52.00; SE=1.91, respectively).

Variables

We measured telomere length by a ratio of telomere repeat copy number to a known single copy gene (36B4). Laboratory personnel conducting the telomere length measurements were

[4]Unhealthy behaviors can also be enabled or facilitated by environmental triggers, such as ethnically targeted cigarette advertising or the presence of many liquor stores and fast-food restaurants in central-city neighborhoods, whose residents also often lack spatial accessibility to healthy diets (LaViest and Wallace 2002; Stoddard et al. 1998; Zenk et al. 2005, 2006).

completely blinded to all known characteristics of the SWAN participants. We quantified DNA using the ABI Quantifiler Human DNA Quantification Kit followed by analysis on the ABI 7500 Real-Time PCR instrument according to the manufacturer's protocol (Green et al. 2005). We measured telomere length using real-time qPCR (Cawthon 2002) with the several modifications. The ratio of telomere repeat copy number to 36B4 was compared to samples whose telomere lengths were known, as measured by the traditional Southern Blot method (Cawthon 2002; Slagboom et al. 1994). Separate amplification reactions were prepared for analysis of the telomeric repeat units and the 36B4 gene; all samples were analyzed in triplicate. (See the Appendix for more complete details of our telomere length measurement process.)

The dependent variable used in this study is the median of the triplicate qPCR amplifications. Confirming the qPCR assay performed well and the DNA samples were high quality, the average coefficient of variation of the three measures was low, at 0.045, and the average correlation between them was high, at 0.93.

We report telomere length differences in terms of base pairs, calculated from the qPCR information (Cawthon 2002), because of our interest in interpreting them with reference to cellular aging. Others report an average annual loss of 41 base pairs for middle-aged and older women (Iwama et al. 1998). In line with this estimate, we find that telomeres shortened in our sample at a rate of approximately 49 base pairs per year. Thus, by estimating black-white differences in telomere length in base pairs we can offer a rough approximation of a “biological age” difference between black and white women by dividing the estimated difference by 49.[5]

We controlled for estradiol in all models to ensure that variation in telomere length is not simply due to individual variation in estradiol, as estrogen has been shown to lengthen telomeres through its actions on telomerase (Bayne et al. 2007). Furthermore, estradiol is a general antioxidant that is associated with decreased cardiovascular disease risk, evidenced by the increase in heart disease risk with menopause in women (Barrett-Connor and Bush 1991). Because our sample includes women of perimenopausal age range, we wanted to account for the possible explanation that black-white estrogen differences were responsible for telomere length differences (Lee et al. 2005).

Self-reported race was coded as black or white. Self-reported age was measured in single years. SWAN respondents were administered the PSS-4, an abbreviated version of the Perceived Stress Scale deemed to have good predictive validity, although it has been found to suffer a loss in reliability compared with the full PSS-10 (Cohen and Williamson 1988; Gallagher-Thompson et al. 2006; Leon et al. 2007; Sharp et al. 2007). The four questions ask about how often in the previous two weeks the participant has felt “unable to control important things in your life,” “confident about your ability to handle your personal problems,” “that things were going your way,” and “difficulties were piling so high that you could not overcome them.” The response choices were on a Likert-like scale: (1) “never,” (2) “almost never,” (3) “sometimes,” (4) “fairly often,” and (5) “very often.” To approximate variation across the sample in chronic stress over a number of years, we summed each respondent's responses each year and then averaged the variable for each respondent over the available years from baseline to DNA collection.

We coded poverty status from baseline year reports of SWAN income category into <$20,000 or ≥$20,000 in accordance with 1996–1997 average poverty thresholds (the SWAN baseline year). Smoking is associated with telomere length (Valdes et al. 2005) and can be a behavioral mediator of stress. Smoking status was measured as two dummy variables, one indicating

[5]Telomere length in women around this age range is about 7,000 base pairs; thus, crudely, there is a loss of about 6–7% of telomere length per year in midlife.

whether or not the respondent was a current smoker at the time of DNA data collection, and the other indicating whether or not the respondent ever smoked.

WHR measures central adiposity and was calculated from waist and hip circumference measurements in centimeters. Given volatility of single-year weight measures, we averaged all available measurements for each respondent. We chose to use a measure of central adiposity (WHR) rather than of obesity (BMI) because research suggests that stress is more closely linked to central fat distribution (Epel et al. 2000). Some have hypothesized a link between stress and central adiposity through hypothalamic dysregulation (Bjorntorp 1997) and inflammatory processes associated with chronic diseases showing marked black-white disparities (e.g., diabetes, cardiovascular disease; Akbartabartoori et al. 2005; Ljung et al. 2000; Moyer et al. 1994; Panagiotakos et al. 2005).

Statistical Analysis

Using ordinary least squares regression, median telomere length was regressed on race, perceived stress, poverty, smoking, and WHR in a series of models that all include the control variables of age at year 7, estradiol at year 7, SWAN study site, and qPCR batch.[6]

To test our primary hypothesis that black SWAN respondents experience accelerated cellular aging relative to their white counterparts, we regress telomere length on race and the control variables only. Our theoretical model predicts that we will find that, on average, black respondents have shorter telomere length (a smaller number of base pairs) than white respondents. We further hypothesize that this difference is mediated by experience with stressors. Thus, our theory predicts that the magnitude of the estimated black-white difference in base pairs will be reduced when the remaining study variables are controlled. Based on our theoretical model, we first consider whether the size of the race coefficient is sensitive to the inclusion of our indicators of stressful life experiences: PSS and poverty. Finally we also include smoking and WHR in our models because they may be responses to stressors and serve as indicators of the biobehavioral pathways through which life stressors may impact health and telomere length.

All analyses were performed using STATA/SE 9.2 SE.

Results

Table 1 provides correlations among the study variables. Each explanatory variable is associated with telomere length in the predicted direction—in other words, perceived stress, poverty, smoking, and WHR are each negatively associated with telomere length. The strength of these associations ranges only from weak to moderate. Stronger associations between the explanatory variables and race are evident. Black respondents are worse off on all measures except ever smoking. In addition, perceived stress is positively associated with poverty, smoking, and WHR.

In Table 2, we report estimated coefficients for race with associated *p*-values and upper bounds for one-tailed tests appropriate to the hypothesis that black women have shorter telomere length than white women. All regression models include controls for the respondent's age and estradiol level in year 7 when DNA was collected, as well as controls for SWAN site and qPCR batch. In addition to these control variables, Model 1 includes only the race variable. On average, black women have shorter telomeres than white women by an estimated 371 base pairs ($p<0.07$). Perceived stress, inversely related to telomere length and higher in black women, accounts for some of this difference ($p<0.10$), reducing the estimated racial difference in

[6]As a robustness test, we also estimated models using the mean of the triplicate qPCR amplifications and obtained similar results.

telomere length to 338 base pairs (Model 2). Model 3 adds a control for poverty and the estimated difference drops to 272 base pairs, a 27% reduction from the unadjusted estimate, and an estimate that is not statistically significantly different from zero ($p<0.16$).

Models 4, 5, and 6 estimate whether smoking or WHR may account for some of the relation between telomere length and measures of perceived stress and economic well-being. When only current smoking is controlled, the estimated racial difference appears to be reduced by 20 base pairs. However, taking account of ever smoking, as well, leads to a small increase in the racial disparity. WHR is estimated to reduce the difference by an additional 77 base pairs. The remaining base pair differences are not statistically significantly different from zero ($p<0.23$).

Discussion

In this first population-based investigation of black-white differences in telomere length, we find evidence to suggest that by middle age, black women have shorter telomeres than white women. In line with previous findings on telomere attrition (Iwama et al. 1998), telomeres shortened in our sample at an average rate of 49 base pairs per year. Applying this estimate as a rough metric suggests that black women in the study sample experienced an accelerated biological aging of approximately 7.5 years compared with white women of the same chronological age. This finding is of similar magnitude to that of Cherkas et al. (2006), who estimated an average difference of about seven years of biological age between sample members of higher compared with lower social class of the same chronological age in their British study of social class differences in telomere length among white women.

We found evidence that stressors associated with perceived stress, poverty, and WHR contributed to black-white differences in telomere length. Differences by race in the probability of being poor or of having a higher WHR were strongly correlated with each other as well as accounting for the largest shares of the racial difference in telomere length in terms of base pairs. The finding that WHR may be an important pathway through which race and poverty impact telomere length is consistent with stress physiology. In their 19-year prospective study of job strain and obesity in 35- to 55-year-old members of the British Whitehall cohort, Brunner et al. (2007) found a dose-response relationship between work stress and central obesity, after adjustment for age, sex, social position, baseline obesity, smoking, diet, alcohol consumption, and physical activity. They interpret their findings as supportive of involvement of direct neuroendocrine effects of chronic stress on abdominal obesity. Chronic stress alters adrenocortical activity, leading to characteristic features of metabolic syndrome including insulin resistance and abdominal obesity. Whitehall participants were largely white Europeans, with some South Asian participants. No similar prospective, well-controlled study has been implemented in US populations. A recent cross-sectional study found an association between higher levels of daily stress and increased WHR in black women (Vines et al. 2007).

Limitations

Our point estimates of the black-white difference in telomere length are of meaningful size, but they are imprecisely estimated. Focusing on the *p*-values alone would indicate that our findings of black-white differences in telomere length are marginally significant and that they are fully accounted for by perceived stress and income poverty. In contrast, focusing on the magnitude of the point estimates, instead, would suggest that half or more of the black-white difference remains unexplained, net of the variables we were able to control.

A full reading of our findings in light of data limitations leads us to conclude that further research is needed before a role of a more complete set of measures of subjective and objective stressors is ruled out as contributing to black-white differences in telomere length. We come to this conclusion for several reasons. First, given limitations of our stress measures, residual

confounding (Kaufman et al. 1997) is likely, implying that part or all of the remaining black-white difference in telomere length is due to a more complete list of social, economic, or environmental stressors. The PSS does not account for chronic stressors or for objective stressors in the physical or social environment that can activate the biological stress process. Household income measures are prone to measurement error, can be volatile, and are incomplete measures of economic resources (Haider and Solon 2006; Mayer and Jencks 1988). For example, they do not include wealth, access to credit, or purchasing power, which are known to vary dramatically between blacks and whites in the United States (Barsky et al. 2002; Morillas 2007).

Second, there is good reason to suspect that our failure to reject the null hypothesis of no difference, once perceived stress and poverty are controlled, is more likely to reflect imprecision in our estimates (Type II error) than a lack of a residual black-white difference in telomere length that might be explained by additional stressors. Using a community-based sample such as SWAN would introduce greater random error (between-women variability in telomere length) than existed in earlier studies of stress and telomere length that were more homogeneous. For example, Epel et al. (2004) analyzed a homogenous sample of white women who were carefully chosen and matched on important factors to reduce confounds and variance. Random error was also likely introduced by SWAN's immortalization process, which, while preserving DNA integrity, may have added telomeric subunits in random repeat lengths to telomere ends (Wall et al. 1995). Random error would reduce the efficiency (statistical power) of our sample (Wooldridge 2002).

In addition, the youngest SWAN participants were 49 years of age when DNA was collected. By ages 49–55, several factors may dilute evidence of differential cellular aging between blacks and whites, including: (1) a greater proportion of black than white women will have already died, disproportionately from diseases associated with shorter telomere length (Geronimus et al. 1999; Wong et al. 2002); (2) age-related chronic disease prevalence increases across demographic groups at this age (Crimmins and Saito 2001; Geronimus et al. 2001, 2006, 2007; Hayward and Heron 1999); (3) telomere length may begin to shorten rapidly across the board in the fifties (Frenck et al. 1998); and (4) random error caused by variation in progress along the menopausal transition among women in this age group. We note that Epel et al.'s (2004) research had a younger sample (mean age = 38 years). Had we been able to focus on women in their thirties and early forties, we might have had a stronger test of our hypothesis.

In theory, the most complete test of our hypothesis would be to follow cohorts of black and white women from birth through middle age to study influences on telomere attrition over the life-course. Of course, the data for this ideal test do not exist, and it would take decades to produce them. Because there are few scientific reasons to collect genetic material at multiple time points, SWAN, like other population-based data sets, collected DNA information only once, ruling out a comparison of telomere length at two or more points over a shorter time period.[7] Thus, we analyzed cross-sectional data to test for differences in average telomere length between the black and white populations at the given chronological age when DNA samples were collected, with the understanding that average telomere length reflects differences that have accumulated over the full lifetime to that age. Such a cross-sectional study can inform and motivate the considerable investment needed for future long-term, longitudinal data collection efforts by contributing to the assessment of the merit of making such a major investment.

[7]In fact, depending on the length of interval between DNA sample collections, this short-term longitudinal approach would not always provide a reliable test of our hypothesis, which concerns the accumulated impact of stressors over a span of 30 or more years.

Our findings are supportive of our primary hypothesis that, by middle age, black women's average telomere length is shorter than white women's and this difference is associated with exposure to stressors. Findings on the contribution of the measured stressors are most judiciously viewed as suggestive. Although all of the relationships estimated were in the hypothesized direction, data limitations resulted in imprecise estimates in some cases, limiting our ability to draw firm inferences. Our theory and empirical findings based on our limited test suggest that further investigation of black-white differences in telomere length using large-population-based samples of broad age range and with more detailed measures of subjective and objective stressors would be a promising approach. Such investigation could deepen understanding of the biological mechanisms through which social structural processes exert their impact on morbidity and mortality to produce racial health inequality.

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Appendix

Telomere Length Measurement

The telomere amplification reaction for each sample included 35 ng of sample DNA, 25 (μl of Power SYBR® Green PCR Master Mix (Applied Biosystems, Foster City, CA), 40 ng of E. Coli DNA, and the telomere primers, which have been specifically designed to prevent the formation of primer dimmers (Cawthon 2002). Final reaction volume was 50 μl. Telomere primer sequences were tel 1b 5′-CGGTTTGTTTGGGTTTGGGTTTGGGTTTGGGTTTGGGTT-3′ (final concentration of 100 nM) and tel 2b 5′-GGCTTGCCTTACCCTTACCCTTACCCTTACCCTTACCCT-3′ (final concentration of 900 nM) (Gil and Coetzer 2004). The single copy gene amplification reaction for each sample included 35 ng of sample DNA, 25 μl of Power SYBR® Green PCR Master Mix, 36B4 primers, and deionized, distilled water to a final volume of 50 μl. The 36B4 primer sequences are 36B4u 5′-CAGCAAGTGGGAAGGTGTAATCC-3′ (final concentration of 300 nM) and 36B4d 5′- CCCATTCTATCATCAACGGGTACAA-3′ (final concentration of 500 nM). All amplification runs were prepared in MicroAmp Optical 96-well reaction plates (Applied Biosystems, Foster City, CA). For each amplification run, known standards from a single DNA reference sample were also amplified (as described above) to ensure that the amplification was functioning as expected. Following the addition of all sample or standard DNA and reagents, the plates were sealed with a MicroAmp Optical Adhesive film (Applied Biosystems, Foster City, CA) and centrifuged at 3,000 rpm for approximately 20 s.

All reactions were performed on the ABI 7500 Real-Time qPCR system. Both amplifications (telomere and 36B4) included a heat-activation step at 9°C for 10 min. For the telomere amplification, this was followed by 25 cycles of 95°C for 15 s and 54°C for 1 min. For the 36B4 amplification, this was followed by 30 cycles of 95°C for 15 s, 58°C for 1 min. Fluorescence data was collected during the annealing/extension steps of both reactions. The instrument was set to run in 9600 emulation mode with auto ramping. Resulting data was analyzed with ABI's SDS v1.2 software package using a manual C_t of 0.06 and the auto baseline

setting. Telomere: 36B4 C_t ratios and telomere length were calculated using Cawthon's (2002) formula.

References

Adaikalakoteswari A, Balasubramanyam M, Mohan V. Telomere shortening occurs in Asian Indian Type 2 diabetic patients. Diabetic Medicine 2005;22(9):1151–1156. [PubMed: 16108841]

Akbartabartoori M, Lean ME, Hankey CR. Relationships between cigarette smoking, body size and body shape. International Journal of Obesity (Lond) 2005;29(2):236–243.

Allsopp RC, Vaziri H, Patterson C, Goldstein S, Younglai EV, Futcher AB, et al. Telomere length predicts replicative capacity of human fibroblasts. Proceedings of the National Academy of Sciences of the United States of America 1992;89(21):10114–10118. [PubMed: 1438199]

Almeida DM, Neupert SD, Banks SR, Serido J. Do daily stress processes account for socioeconomic health disparities? Journal of Gerontology: Psychological Sciences and Social Sciences 2005;60(Spec No 2):34–39.

Aviv A. Chronology versus biology: Telomeres, essential hypertension, and vascular aging. Hypertension 2002;40(3):229–232. [PubMed: 12215458]

Bakaysa SL, Mucci LA, Slagboom PE, Boomsma DI, McClearn GE, Johansson B, et al. Telomere length predicts survival independent of genetic influences. Aging Cell 2007;6(6):769–774. [PubMed: 17925004]

Barnes LL, Mendes De Leon CF, Wilson RS, Bienias JL, Bennett DA, Evans DA. Racial differences in perceived discrimination in a community population of older blacks and whites. Journal of Aging and Health 2004;16(3):315–337. [PubMed: 15155065]

Barrett-Connor E, Bush TL. Estrogen and coronary heart disease in women. Journal of the American Medical Association 1991;265(14):1861–1867. [PubMed: 2005736]

Barsky R, Bound J, Charles KK, Lupton JP. Accounting for the black-white wealth gap:A nonparametric approach. Journal of the American Statistical Association 2002;97(459):663–673.

Bauer ME, Jeckel CM, Luz C. The role of stress factors during aging of the immune system. Annals of the New York Academy of Sciences 2009;1153:139–152. [PubMed: 19236337]

Bayne S, Jones ME, Li H, Liu JP. Potential roles for estrogen regulation of telomerase activity in aging. Annals of the New York Academy of Sciences 2007;1114:48–55. [PubMed: 17986576]

Benetos A, Okuda K, Lajemi M, Kimura M, Thomas F, Skurnick J, et al. Telomere length as an indicator of biological aging: The gender effect and relation with pulse pressure and pulse wave velocity. Hypertension 2001;37(2 Part 2):381–385.

Bennett GG, Wolin KY, Robinson EL, Fowler S, Edwards CL. Perceived racial/ethnic harassment and tobacco use among African American young adults. American Journal of Public Health 2005;95(2): 238–240. [PubMed: 15671457]

Bjorntorp P. Body fat distribution, insulin resistance, and metabolic diseases. Nutrition 1997;13(9):795–803. [PubMed: 9290093]

Brunner EJ, Chandola T, Marmot MG. Prospective effect of job strain on general and central obesity in the Whitehall II Study. American Journal of Epidemiology 2007;165(7):828–837. [PubMed: 17244635]

Burton LM, Whitfield KE. “Weathering” towards poorer health in later life: Co-morbidity in urban low-income families. Public Policy and Aging Report 2003;13(3):13–18.

Burton, LM.; Whitfield, KE. Health, aging, and America's poor: Ethnographic insights on family co-morbidity and cumulative disadvantage. In: Baars, J., editor. Aging, globalization, and inequality: The new critical gerontology. Amityville: Baywood Publishers; 2006. p. 215-230.

Cawthon RM. Telomere measurement by quantitative PCR. Nucleic Acids Research 2002;30(10):e47. [PubMed: 12000852]

Cawthon RM, Smith KR, O'Brien E, Sivatchenko A, Kerber RA. Association between telomere length in blood and mortality in people aged 60 years or older. Lancet 2003;361(9355):393–395. [PubMed: 12573379]

Chan SR, Blackburn EH. Telomeres and telomerase. *Philosophical Transactions of the Royal Society of London*. Biological Sciences 2004;359(1441):109–121. [PubMed: 15065663] B

Charles KK, Guryan J. Prejudice and wages: An empirical assessment of Becker's The Economics of Discrimination. Journal of Political Economy 2008;116(5):773–809.

Charles KK, Hurst E. The transition to home ownership and the black-white wealth gap. Review of Economics and Statistics 2002;84(2):281–297.

Cherkas LF, Aviv A, Valdes AM, Hunkin JL, Gardner JP, Surdulescu GL, et al. The effects of social status on biological aging as measured by white-blood-cell telomere length. Aging Cell 2006;5(5): 361–365. [PubMed: 16856882]

Chisholm JS. Death, hope, and sex: Life-history theory and the development of reproductive strategies. Current Anthropology 1993;34:1–24.

Chisholm JS. Attachment and time preference: Relations between early stress and sexual behavior in a sample of American university women. Human Nature 1999;10:51–83.

Cohen, S.; Williamson, GM. Perceived stress in a probability sample of the United States. In: Spacapan, S.; Oskamp, S., editors. The social psychology of health. Newbury Park: Sage Publications; 1988. p. 31-67.

Cohen S, Schwartz JE, Epel E, Kirschbaum C, Sidney S, Seeman T. Socioeconomic status, race, and diurnal cortisol decline in the Coronary Artery Risk Development in Young Adults (CARDIA) Study. Psychosomatic Medicine 2006;68(1):41–50. [PubMed: 16449410]

Colen CG, Geronimus AT, Bound J, James SA. Maternal upward socioeconomic mobility and black-white disparities in infant birthweight. American Journal of Public Health 2006;96:2032–2039. [PubMed: 17018818]

Cooper RS, Kaufman JS, Ward R. Race and genomics. New England Journal of Medicine 2003;348(12): 1166–1170. [PubMed: 12646675]

Crimmins EM, Saito Y. Trends in healthy life expectancy in the United States, 1970-1990: Gender, racial, and educational differences. Social Science and Medicine 2001;52(11):1629–1641. [PubMed: 11327137]

Dallman MF, Pecoraro N, Akana SF, La Fleur SE, Gomez F, Houshyar H, et al. Chronic stress and obesity: A new view of “comfort food”. Proceedings of the National Academy of Sciences of the United States of America 2003;100(20):11696–11701. [PubMed: 12975524]

Darity WA, Mason PL. Evidence on discrimination in employment: Codes of color, codes of gender. Journal of Economic Perspectives 1998;12(2):63–90.

Demissie S, Levy D, Benjamin EJ, Cupples LA, Gardner JP, Herbert A, et al. Insulin resistance, oxidative stress, hypertension, and leukocyte telomere length in men from the Framingham Heart Study. Aging Cell 2006;5(4):325–330. [PubMed: 16913878]

Dilworth-Anderson, P.; Rhoden, L. Caregiving roles in older women. In: Burgess, NJ.; Brown, E., editors. African-American women: An ecological perspective. New York: Routledge; 2000. p. 83-98.

Dilworth-Anderson P, Williams IC, Gibson BE. Issues of race, ethnicity, and culture in caregiving research: A 20-year review (1980–2000). Gerontologist 2002;42(2):237–272. [PubMed: 11914467]

Edo MD, Andres V. Aging, telomeres, and atherosclerosis. Cardiovascular Research 2005;66(2):213–221. [PubMed: 15820190]

Epel ES, McEwen B, Seeman T, Matthews K, Castellazzo G, Brownell KD, et al. Stress and body shape: Stress-induced cortisol secretion is consistently greater among women with central fat. Psychosomatic Medicine 2000;62(5):623–632. [PubMed: 11020091]

Epel ES, Blackburn EH, Lin J, Dhabhar FS, Adler NE, Morrow JD, et al. Accelerated telomere shortening in response to life stress. Proceedings of the National Academy of Sciences of the United States of America 2004;101(49):17312–17315. [PubMed: 15574496]

Epel ES, Lin J, Wilhelm FH, Wolkowitz OM, Cawthon R, Adler NE, et al. Cell aging in relation to stress arousal and cardiovascular disease risk factors. Psychoneuroendocrinology 2006;31(3):277–287. [PubMed: 16298085]

Flegal KM, Carroll MD, Ogden CL, Johnson CL. Prevalence and trends in obesity among US adults, 1999–2000. Journal of the American Medical Association 2002;288(14):1723–1727. [PubMed: 12365955]

Frenck RW Jr, Blackburn EH, Shannon KM. The rate of telomere sequence loss in human leukocytes varies with age. Proceedings of the National Academy of Sciences of the United States of America 1998;95(10):5607–5610. [PubMed: 9576930]

Gallagher-Thompson D, Shurgot GR, Rider K, Gray HL, McKibbin CL, Kraemer HC, et al. Ethnicity, stress, and cortisol function in Hispanic and non-Hispanic white women: A preliminary study of family dementia caregivers and noncaregivers. American Journal of Geriatric Psychiatry 2006;14 (4):334–342. [PubMed: 16582042]

Gee GC, Payne-Sturges DC. Environmental health disparities: A framework integrating psychosocial and environmental concepts. Environmental Health Perspectives 2004;112(17):1645–1653. [PubMed: 15579407]

Geronimus AT. The weathering hypothesis and the health of African-American women and infants: Evidence and speculations. Ethnicity and Disease 1992;2(3):207–221. [PubMed: 1467758]

Geronimus AT. 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 2001;56(4):133–136. 149–150.

Geronimus AT, Thompson JP. To denigrate, ignore, or disrupt: Racial inequality in health and the impact of a policy-induced breakdown of African American communities. Du Bois Review: Social Science Research on Race 2004;1(2):247–279.

Geronimus AT, Bound J, Waidmann TA, Hillemeier MM, Burns PB. Excess mortality among blacks and whites in the United States. New England Journal of Medicine 1996;335(21):1552–1558. [PubMed: 8900087]

Geronimus AT, Bound J, Waidmann TA. Poverty, time, and place: variation in excess mortality across selected US populations, 1980-1990. Journal of Epidemiology and Community Health 1999;53(6): 325–334. [PubMed: 10396478]

Geronimus AT, Bound J, Waidmann TA, Colen CG, Steffick D. Inequality in life expectancy, functional status, and active life expectancy across selected black and white populations in the United States. Demography 2001;38(2):227–251. [PubMed: 11392910]

Geronimus AT, Hicken M, Keene D, Bound J. “Weathering” and age patterns of allostatic load scores among blacks and whites in the United States. American Journal of Public Health 2006;96(5):826–833. [PubMed: 16380565]

Geronimus AT, Bound J, Keene D, Hicken M. Black-white differences in age trajectories of hypertension prevalence among adult women and men, 1999–2002. Ethnicity and Disease 2007;17(1):40–48. [PubMed: 17274208]

Geronimus, AT.; Bound, J.; Colen, CG. To live and die in the United States: Race, place, and black-white health inequalities during the 1990s. Paper presented at the Annual Meeting of the Population Association of America; New Orleans. 2008.

Gil ME, Coetzer TL. Real-time quantitative PCR of telomere length. Molecular Biotechnology 2004;27 (2):169–172. [PubMed: 15208457]

Gil AG, Wagner EF, Tubman JG. Culturally sensitive substance abuse intervention for Hispanic and African American adolescents: Empirical examples from the Alcohol Treatment Targeting Adolescents in Need (ATTAIN) Project. Addiction 2004;99(Suppl 2):140–150. [PubMed: 15488112]

Graakjaer J, Bischoff C, Korsholm L, Holstebroe S, Vach W, Bohr VA, et al. The pattern of chromosome-specific variations in telomere length in humans is determined by inherited, telomere-near factors and is maintained throughout life. Mechanisms of Ageing and Development 2003;124(5):629–640. [PubMed: 12735903]

Green RL, Roinestad IC, Boland C, Hennessy LK. Developmental validation of the Quantifiler (TM) real-time PCR kits for the quantification of human nuclear DNA samples. Journal of Forensic Sciences 2005;50(4):809–825. [PubMed: 16078482]

Guthrie BJ, Young AM, Williams DR, Boyd CJ, Kintner EK. African American girls' smoking habits and day-to-day experiences with racial discrimination. Nursing Research 2002;51(3):183–190. [PubMed: 12063417]

Haider S, Solon G. Life-cycle variation in the association between current and lifetime earnings. American Economic Review 2006;96(4):1308–1320.

Harrison D, Griendling KK, Landmesser U, Hornig B, Drexler H. Role of oxidative stress in atherosclerosis. American Journal of Cardiology 2003;91(3A):7A–11A.

Hayward MD, Heron M. Racial inequality in active life among adult Americans. Demography 1999;36 (1):77–91. [PubMed: 10036594]

Hicks-Bartlett, S. Between a rock and a hard place: The labyrinth of working and parenting in a poor community. In: Danziger, S.; Lin, AC., editors. Coping with poverty: The social contexts of neighborhood, work, and family in the African-American community. Ann Arbor: University of Michigan Press; 2000. p. 27-51.

Holzer HJ, Offner P, Sorensen E. Declining employment among young black less-educated men: The role of incarceration and child support. Journal of Policy Analysis and Management 2005;24(2):329–350.

Houben JM, Moonen HJ, van Schooten FJ, Hageman GJ. Telomere length assessment: biomarker of chronic oxidative stress? Free Radical Biology and Medicine 2008;44(3):235–246. [PubMed: 18021748]

Iwama H, Ohyashiki K, Ohyashiki JH, Hayashi S, Yahata N, Ando K, et al. Telomeric length and telomerase activity vary with age in peripheral blood cells obtained from normal individuals. Human Genetics 1998;102(4):397–402. [PubMed: 9600234]

Jarrett RL, Burton LM. Dynamic dimensions of family-structure in low-income African American families: Emergent themes in qualitative research. Journal of Comparative Family Studies 1999;30 (2):177–187.

Kalinowski L, Dobrucki IT, Malinski T. Race-specific differences in endothelial function: Predisposition of African Americans to vascular diseases. Circulation 2004;109(21):2511–2517. [PubMed: 15159296]

Kaufman JS, Cooper RS, McGee DL. Socioeconomic status and health in blacks and whites: The problem of residual confounding and the resiliency of race. Epidemiology 1997;8(6):621–628. [PubMed: 9345660]

Khansari N, Shakiba Y, Mahmoudi M. Chronic inflammation and oxidative stress as a major cause of age-related diseases and cancer. Recent Patents on Inflammation & Allergy Drug Discovery 2009;3 (1):73–80. [PubMed: 19149749]

Khera A, McGuire DK, Murphy SA, Stanek HG, Das SR, Vongpatanasin W, et al. Race and gender differences in C-reactive protein levels. Journal of the American College of Cardiology 2005;46(3): 464–469. [PubMed: 16053959]

Lancaster, JB. Evolutionary and cross-cultural perspectives on single parenthood. In: Bell, R.; Bell, N., editors. Sociobiology and the social sciences. Lubbock: Texas Tech University Press; 1989. p. 63-72.

Lantz PM, House JS, Lepkowski JM, Williams DR, Mero RP, Chen J. Socioeconomic factors, health behaviors, and mortality: Results from a nationally representative prospective study of US adults. Journal of the American Medical Association 1998;279(21):1703–1708. [PubMed: 9624022]

LaViest, TA.; Wallace, JM. Health risk and inequitable distribution of liquor stores in African American neighborhoods. In: LaViest, T., editor. Race, ethnicity and health. San Francisco: Jossey-Bass; 2002. p. 487-493.

Lee DC, Im JA, Kim JH, Lee HR, Shim JY. Effect of long-term hormone therapy on telomere length in postmenopausal women. Yonsei Medical Journal 2005;46(4):471–479. [PubMed: 16127770]

Leon KA, Hyre AD, Ompad D, Desalvo KB, Muntner P. Perceived stress among a workforce 6 months following hurricane Katrina. Social Psychiatry and Psychiatric Epidemiology 2007;42(12):1005–1011. [PubMed: 17932611]

Levine RS, Foster JE, Fullilove RE, Fullilove MT, Briggs NC, Hull PC, et al. Black-white inequalities in mortality and life expectancy, 1933–1999: Implications for healthy people 2010. Public Health Reports 2001;116(5):474–483. [PubMed: 12042611]

Lindsey J, McGill NI, Lindsey LA, Green DK, Cooke HJ. In vivo loss of telomeric repeats with age in humans. Mutation Research 1991;256(1):45–48. [PubMed: 1944386]

Ljung T, Holm G, Friberg P, Andersson B, Bengtsson BA, Svensson J, et al. The activity of the hypothalamic-pituitary-adrenal axis and the sympathetic nervous system in relation to waist/hip circumference ratio in men. Obesity Research 2000;8(7):487–495. [PubMed: 11068954]

Lum TY. Understanding the racial and ethnic differences in caregiving arrangements. Journal of Gerontological Social Work 2005;45(4):3–21. [PubMed: 16219597]

Martin-Ruiz C, Dickinson HO, Keys B, Rowan E, Kenny RA, Von Zglinicki T. Telomere length predicts poststroke mortality, dementia, and cognitive decline. Annals of Neurology 2006;60(2):174–180. [PubMed: 16685698]

Matthews C, Gorenne I, Scott S, Figg N, Kirkpatrick P, Ritchie A, et al. Vascular smooth muscle cells undergo telomere-based senescence in human atherosclerosis: Effects of telomerase and oxidative stress. Circulation Research 2006;99(2):156–164. [PubMed: 16794190]

Mayer SE, Jencks C. Poverty and the distribution of material hardship. Journal of Human Resources 1988;24:88–114.

McEwen BS. Protective and damaging effects of stress mediators. New England Journal of Medicine 1998;338(3):171–179. [PubMed: 9428819]

McEwen BS, Seeman T. Protective and damaging effects of mediators of stress. Elaborating and testing the concepts of allostasis and allostatic load. Annals of the New York Academy of Sciences 1999;896:30–47. [PubMed: 10681886]

Mokdad AH, Ford ES, Bowman BA, Nelson DE, Engelgau MM, Vinicor F, et al. The continuing increase of diabetes in the US. Diabetes Care 2001;24(2):412. [PubMed: 11213906]

Morello-Frosch R, Lopez R. The riskscape and the color line: Examining the role of segregation in environmental health disparities. Environmental Research 2006;102(2):181–196. [PubMed: 16828737]

Morillas JR. Assets, earnings mobility and the black-white gap. Social Science Research 2007;36(2): 808–833.

Moyer AE, Rodin J, Grilo CM, Cummings N, Larson LM, Rebuffe-Scrive M. Stress-induced cortisol response and fat distribution in women. Obesity Research 1994;2(3):255–262. [PubMed: 16353426]

Mullings, L.; Wali, A. Stress and resilience: The social context of reproduction in Central Harlem. New York: Kluwer Academic/Plenum Publishers; 2001.

Neitzel H. A routine method for the establishment of permanent growing lymphoblastoid cell lines. Human Genetics 1986;73(4):320–326. [PubMed: 3017841]

Okuda K, Bardeguez A, Gardner JP, Rodriguez P, Ganesh V, Kimura M, et al. Telomere length in the newborn. Pediatric Research 2002;52(3):377–381. [PubMed: 12193671]

Ondrich J, Ross S, Yinger J. Now you see it, now you don't: Why do real estate agents withhold available houses from black customers? Review of Economics and Statistics 2003;85(4):854–873.

Oths KS, Dunn LL, Palmer NS. A prospective study of psychosocial job strain and birth outcomes. Epidemiology 2001;12(6):744–746. [PubMed: 11679805]

Panagiotakos DB, Pitsavos C, Yannakoulia M, Chrysohoou C, Stefanadis C. The implication of obesity and central fat on markers of chronic inflammation: The ATTICA study. Atherosclerosis 2005;183 (2):308–315. [PubMed: 16285994]

Pearson JA. Can't buy me whiteness: New lessons from the Titanic on race, ethnicity, and health. DuBois Review: Social Science Research on Race 2008;5(1):27–47.

Sampson MJ, Winterbone MS, Hughes JC, Dozio N, Hughes DA. Monocyte telomere shortening and oxidative DNA damage in type 2 diabetes. Diabetes Care 2006;29(2):283–289. [PubMed: 16443874]

Sapolsky, RM. Why zebras don't get ulcers: An updated guide to stress, stress-related diseases, and coping. New York: W. H. Freeman; 1998.

Sapolsky RM. Organismal stress and telomeric aging: An unexpected connection. Proceedings of the National Academy of Sciences of the United States of America 2004;101(50):17323–17324. [PubMed: 15579535]

Sapolsky RM, Romero LM, Munck AU. How do glucocorticoids influence stress responses? Integrating permissive, suppressive, stimulatory, and preparative actions. Endocrinology Review 2000;21(1): 55–89.

Schoendorf KC, Hogue CJ, Kleinman JC, Rowley D. Mortality among infants of black as compared with white college-educated parents. New England Journal of Medicine 1992;326(23):1522–1526. [PubMed: 1579135]

Seeman TE, McEwen BS, Singer BH, Albert MS, Rowe JW. Increase in urinary cortisol excretion and memory declines: MacArthur studies of successful aging. Journal of Clinical Endocrinology and Metabolism 1997;82(8):2458–2465. [PubMed: 9253318]

Selye, H. The stress of life. New York: McGraw-Hill; 1956.

Sharp LK, Kimmel LG, Kee R, Saltoun C, Chang CH. Assessing the Perceived Stress Scale for African American adults with asthma and low literacy. Journal of Asthma 2007;44(4):311–316. [PubMed: 17530531]

Slagboom PE, Droog S, Boomsma DI. Genetic determination of telomere size in humans: A twin study of 3 age-groups. American Journal of Human Genetics 1994;55(5):876–882. [PubMed: 7977349]

Sowers, M.; Crawford, SL.; Sternfeld, B.; Morganstein, D.; Gold, EB.; Greendale, GA., et al. SWAN: A multicenter, multiethnic, community-based cohort study of women and the menopausal transition. In: Lobo, RA.; Kelsey, JL.; Marcus, R., editors. Menopause: Biology and pathobiology. San Diego: Academic; 2000. p. 175-188.

Stack, CB. All our kin: Strategies for survival in a black community. New York: Harper and Row; 1974.

Stack CB, Burton LM. Kinscripts. Journal of Comparative Family Studies 1993;24(2):157–170.

Steptoe A, Marmot M. Psychosocial, hemostatic, and inflammatory correlates of delayed poststress blood pressure recovery. Psychosomatic Medicine 2006;68(4):531–537. [PubMed: 16868261]

Stoddard JL, Johnson CA, Sussman S, Dent C, Boley-Cruz T. Tailoring outdoor tobacco advertizing to minorities in Los Angeles County. Journal of Health Communication 1998;3(2):137–146. [PubMed: 10977250]

Taylor, SE. The health status of women. In: Braithwaite, RL.; Taylor, SE., editors. Health issues in the black community. San Francisco: Jossey-Bass; 2001. p. 55-72.

Taylor J, Turner RJ. Perceived discrimination, social stress, and depression in the transition to adulthood: Racial contrasts. Social Psychology Quarterly 2002;65(3):213–225.

Valdes AM, Andrew T, Gardner JP, Kimura M, Oelsner E, Cherkas LF, et al. Obesity, cigarette smoking, and telomere length in women. Lancet 2005;366(9486):662–664. [PubMed: 16112303]

Vines AI, Baird DD, Stevens J, Hertz-Picciotto I, Light KC, McNeilly M. Associations of abdominal fat with perceived racism and passive emotional responses to racism in African American women. American Journal of Public Health 2007;97(3):526–530. [PubMed: 17267721]

von Zglinicki T. Oxidative stress shortens telomeres. Trends in Biochemical Science 2002;27(7):339–344.

von Zglinicki T, Pilger R, Sitte N. Accumulation of single-strand breaks is the major cause of telomere shortening in human fibroblasts. Free Radical Biology and Medicine 2000;28(1):64–74. [PubMed: 10656292]

Wall FE, Henkel RD, Stern MP, Jenson HB, Moyer MP. An efficient method for routine Epstein-Barr virus immortalization of human B lymphocytes. In Vitro Cellular and Developmental Biology Animal 1995;31(2):156–159. [PubMed: 7735567]

Wallace, RB. Applying genetic study designs to social and behavioral population surveys. In: Finch, EF.; Vaupel, JW.; Kinsella, K., editors. Cells and surveys: Should biological measures be included in social science research?. Washington: National Academy Press; 2001. p. 229-249.

Warren-Findlow J. Weathering: Stress and heart disease in African American women living in Chicago. Qualitative Health Research 2006;16(2):221–237. [PubMed: 16394211]

Western, B. Punishment and inequality in America. New York: Russell Sage Foundation; 2006.

Wiemann SU, Satyanarayana A, Tsahuridu M, Tillmann HL, Zender L, Klempnauer J, et al. Hepatocyte telomere shortening and senescence are general markers of human liver cirrhosis. Federation of American Societies for Experimental Biology Journal 2002;16(9):935–942.

Williams DR. Race, socioeconomic status, and health. The added effects of racism and discrimination. Annals of the New York Academy of Sciences 1999;896:173–188. [PubMed: 10681897]

Wilson M, Daly M. Life expectancy, economic inequality, homicide, and reproductive timing in Chicago neighbourhoods. British Medical Journal 1997;314(7089):1271–1274. [PubMed: 9154035]

Wong MD, Shapiro MF, Boscardin WJ, Ettner SL. Contribution of major diseases to disparities in mortality. New England Journal of Medicine 2002;347(20):1585–1592. [PubMed: 12432046]

Wooldridge, JM. Econometric analysis of cross section and panel data. Cambridge: MIT; 2002.

Yen IH, Ragland DR, Greiner BA, Fisher JM. Workplace discrimination and alcohol consumption: Findings from the San Francisco Muni Health and Safety Study. Ethnicity and Disease 1999;9(1):70–80. [PubMed: 10355476]

Yinger J. Evidence on discrimination in consumer markets. Journal of Economic Perspectives 1998;12 (2):23–40.

Zenk SN, Schulz AJ, Israel BA, James SA, Bao S, Wilson ML. Neighborhood racial composition, neighborhood poverty, and the spatial accessibility of supermarkets in metropolitan Detroit. American Journal of Public Health 2005;95:660–667. [PubMed: 15798127]

Zenk SN, Schulz AJ, Israel BA, James SA, Bao S, Wilson ML. Fruit and vegetable access differs by community racial composition and socioeconomic position in Detroit, Michigan. Ethnicity and Disease 2006;16(1):275–280. [PubMed: 16599383]

Biographies

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Margaret T. Hicken (MPH) is a doctoral student in the University of Michigan School of Public Health and an NIA predoctoral trainee at the University of Michigan Population Studies Center. Her research integrates biological and social mechanisms in order to explain black-white health disparities with a particular emphasis on the stress process, including cellular and molecular aspects of the biological stress response system.

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Table 1

Correlations among model variables

	Telomere length	Race	Perceived stress	Poverty	Current smoker	Ever smoker	WHR
Telomere length	1.000						
Race	−0.078	1.000					
Perceived stress	−0.070	0.186	1.000				
Poverty	−0.095	0.296	0.238	1.000			
Current smoker	−0.061	0.128	0.237	0.085	1.000		
Ever smoker	−0.083	−0.049	0.175	0.094	0.486	1.000	
WHR	−0.134	0.295	0.179	0.304	0.104	0.103	1.000

Table 2

Estimated black-white differences in telomere length

Model[a]	b race[b]	$p <$	Upper bound[c]	R^2
(1) Race	−371*	0.07	−42	0.095
(2) Race, perceived stress	−338*	0.10	−2	0.097
(3) Race, perceived stress, poverty	−272	ns	76	0.101
(4) Race, perceived stress, poverty, current smoker	−252	ns	98	0.104
(5) Race, perceived stress, poverty, current smoker, ever smoker	−290	ns	68	0.106
(6) Race, perceived stress, poverty, current smoker, ever smoker, WHR	−213	ns	134	0.113

[a] all models include controls for age, estradiol, qPCR batch, and site

[b] estimated difference in the number of base pairs

[c] the upper bound can be thought of as analogous to the top of the confidence interval, appropriate to a one-tailed test; for example, the upper bound on the black-white difference in model (1) suggests we are confident that average black telomere length is lower by no less than 42 base pairs below average white telomere length.

* $p<0.10$, one-tailed test