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The Intersection of Race and Sex in Cardiovascular Health Disparities: Examining Differences in the Relationship Between Heart Rate Variability and Cardiovascular Measures in African American Men and Women

THESIS

submitted in partial satisfaction of the requirements for the degree of

MASTER OF ARTS

in Psychological Science

by

Julia R. Birenbaum

Thesis Committee:
Distinguished University Professor Julian F. Thayer, Chair
Professor and Director Jason Schiffman
Assistant Professor DeWayne P. Williams

2025

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DEDICATION

To

My master's committee members, Dr. Julian F. Thayer, Dr. DeWayne P. Williams and Dr. Jason Schiffman, who offered unique perspectives, thoughtful discussions, and valuable insights that shaped this research

And to my family and friends, whose unwavering support and belief in me made this journey possible.

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ACKNOWLEDGEMENTS

I am grateful to my committee chair, Distinguished University Professor Julian F. Thayer, whose mentorship and scholarly expertise have guided this research journey. His intellectual insights and dedication have significantly shaped both this dissertation and my development as a researcher.

I extend my sincere thanks to my committee members, Professor Jason Schiffman and Assistant Professor DeWayne P. Williams. Their thoughtful feedback and unique perspectives have strengthened this work considerably, and their willingness to share their expertise has been invaluable throughout this process.

The foundation for this dissertation builds upon two seminal works. The text of portions of Chapter 2 is an expansion of the material as it appears in Williams, D.P., Thayer, J.F., Halbert, J.D., Wang, X., and Kapuku, G. (2021) in the American Journal of Physiology-Heart and Circulatory Physiology. Additionally, this work furthers the findings presented in Hill, L.K., Hu, D.D., Koenig, J., Sollers, J.J., Kapuku, G., Wang, X., Snieder, H., and Thayer, J.F. (2015) in Psychosomatic Medicine. I am indebted to the authors of these works for establishing the theoretical and empirical groundwork that made this dissertation possible.

This research was supported by the University of California, Irvine through the Eugene Cota-Robles Fellowship. This funding was instrumental in allowing me to pursue this work and complete my doctoral studies.

ABSTRACT OF THE THESIS

The Intersection of Race and Sex in Cardiovascular Health Disparities:

Examining Differences in the Relationship Between Heart Rate Variability and Cardiovascular Measures in African American Men and Women

By

Julia Birenbaum

Master of Arts in Psychological Science

University of California, Irvine, 2025

Professor Julian F. Thayer, Chair

Background: Cardiovascular health disparities between African Americans (AA) and European Americans (EA) persist despite established evidence that AA populations exhibit higher heart rate variability (HRV), a cardioprotective marker of parasympathetic function. Previous research has demonstrated that higher HRV predicts lower blood pressure in EA but not AA individuals, and these relationships may be further modulated by sex differences. However, the intersectional effects of race and sex on HRV's relationship with cardiovascular measures remain incompletely understood.

Methods: Secondary analyses were conducted using data from the Augusta Heart Study cohort (N=385; 207 AA, 178 EA; 54% female). Participants underwent baseline cardiovascular assessment and 6-year follow-up (mean interval = 6.32 years). High-frequency HRV and comprehensive cardiovascular measures were collected at baseline (T1). Blood pressure (BP), total peripheral resistance (TPR), cardiac output, and related hemodynamic indices were measured at

both time points. Hierarchical regression and moderation analyses examined relationships between T1 HRV and follow-up (T2) cardiovascular measures.

Results: AA participants showed significantly higher BP, TPR, and mean arterial pressure than EA at both time points (all $p < .001$). Higher T1 HRV predicted lower T2 BP measures in EA men ($\beta = -2.498$, $p = .014$) but not in AA participants. Among AA participants, women exhibited higher baseline BMI, systolic BP, diastolic BP, and TPR (all $p < .05$), while men showed higher BP at follow-up ($p < .001$). Three-way interactions between race, sex, and HRV were non-significant, though conditional effects indicated race and sex moderated the HRV-TPR index association specifically in AA men.

Conclusions: These findings demonstrate distinct patterns of cardiovascular regulation between AA and EA populations and reveal important sex differences within racial groups. Results suggest the relationship between autonomic regulation and cardiovascular function varies by both race and sex, potentially reflecting biological factors and psychosocial influences. Future research should employ experimental designs with larger, balanced samples to further elucidate these relationships.

Keywords (5): cardiovascular regulation, racial disparities, autonomic function, blood pressure, intersectionality

Introduction

Background & Significance

Cardiovascular health disparities between African Americans (AA) and European Americans (EA) have been well documented in the literature for decades and continue to persist, with AA experiencing significantly higher rates of hypertension, stroke, heart failure, and other cardiovascular complications compared to EA (Benjamin et al., 2017; Benjamin et al., 2019; Carnethon et al., 2017). These disparities may be due, in part, to the differences in long-term blood pressure (BP) regulation mechanisms, particularly the role of total peripheral resistance (TPR). In a healthy individual, BP is maintained within a normal range through the balance of cardiac output (CO) and TPR. CO refers to the volume of blood pumped by the heart per minute, while TPR is the resistance to blood flow in the peripheral vasculature. This distinction is particularly important when considering racial disparities in these underlying mechanisms of long- and short-term BP regulation, as previous research has found that AA have greater TPR-mediated BP regulation compared to EA.

Increased TPR is associated with hypertension and cardiovascular disease, as it places a greater burden on the heart to pump blood through the vasculature, leading to increased BP (Mayet & Hughes, 2003). Elevations in either CO or TPR can lead to increased BP, however, TPR-mediated increases in BP are a more detrimental mechanism (Brownlow et al., 2020; Heffernan et al., 2008) and are associated with more severe organ damage compared to CO-mediated elevations in BP (Thayer et al., 2010; Williams et al., 2021). However, large bodies of research have also established that AA generally have greater heart rate variability (HRV), a cardioprotective factor, than EA (Hill et al., 2015; Liao et al., 1995; Rosati et al., 2021; Thayer et al., 2020).

HRV is a measure of the beat-to-beat variability in heart rate, which primarily reflects the balance of parasympathetic influences on the heart (Shaffer & Ginsberg, 2017; Thayer et al., 2010, 2012). At present, it is well established that higher HRV is associated with better cardiovascular outcomes, as it reflects a greater capacity for the parasympathetic nervous system to respond and adapt to environmental demands (Koenig & Thayer, 2016; Shaffer & Ginsberg, 2017; Thayer et al., 2012). The finding that AA exhibit higher HRV than EA, despite experiencing greater cardiovascular risk, has been termed the Cardiovascular Conundrum (Hill et al., 2015), and suggests that other underlying mechanisms may be contributing to the observed racial disparities in cardiovascular health.

Additionally, other studies have found sex-specific associations between HRV and other cardiovascular risk factors, as well. For example, a 2016 meta-analysis on sex differences in HRV revealed that women generally have higher HRV and heart rate compared to men (Koenig & Thayer, 2016). Similarly, Williams et al., (2021) found that higher HRV predicted lower TPR in EA but not in AA, and that this relationship was stronger in EA women compared to EA men. The mechanisms underlying these racial and sex-related differences in the relationship between HRV and cardiovascular functioning are not fully understood but may involve a complex interplay of genetic, hormonal, environmental, and psychosocial factors (Williams et al., 2019).

The Current Investigation

In line with these ideas, HRV has been shown to predict hemodynamics underlying BP differentially between AA and EA, as well as between AA and EA men and women. For example, Hill et al., (2015) found that higher HRV predicted lower BP in EA but not in AA. Likewise,

Williams et al., (2021) found that higher HRV predicted lower TPR in EA but not in AA, however, this study did not explore the potential impact of both race and sex on the prospective link between HRV and TPR. In this regard, the Hill et al., (2015) study also found that HRV significantly predicted diastolic BP in AA women but not in AA men suggesting potential racial and sex differences in the relationship between cardiac vagal tone and components of BP regulation within the AA population. This is particularly relevant, as AA women have been shown to have a higher prevalence of diastolic dysfunction compared to others (Eaton et al., 2016).

Study Aims

Building upon the prior works of Hill et al., (2015) and Williams et al., (2021), the present study aims to further examine the potential moderating effects of both race and sex (independently) on the relationship between HRV and several cardiovascular measures and investigate what differences may exist between EA and AA men and women along those relationships.

The second aim is to delve deeper into the moderating role of race and sex on the association between HRV and TPR in AA men compared to AA women. We hypothesize that race and sex, when considered together (intersectionally), will have a significant moderating influence on the predictive relationship between HRV and specific cardiovascular outcomes, namely BP and TPR. More precisely, we predict that a relationship between HRV and BP will be observed in AA women, but not in AA men, similar to the Hill et al., (2015) study.

This investigation will employ a prospective cohort observational design to achieve these aims, combining physiological measures (e.g., HRV, BP, TPR, and CO) with sociodemographic data (e.g., age, BMI, socioeconomic status, and smoking status) in AA and EA men and women.

Methods

Subjects

The present study conducted secondary analyses using data pooled from the Augusta Heart Study (AHS) — a longitudinal study investigating the development of cardiovascular health and risk factors in children with verified family histories of cardiovascular diseases. In a sample of 385 young, normotensive adults, the AHS included 207 AA (127 women) and 178 EA (83 women), with participants between the ages of 15–32 years old at the time of study enrollment (54% AA; M_{Age} = 29.468 years, SD_{Age} = 2.96 years). Recruitment methods for the AHS have been previously reported (Kapuku et al., 2019, 2004), and this study was approved by the Augusta University Institutional Review Board. All participants provided written informed consent, and each individual participated in two study sessions separated by an average of 6.32 years (Min: 2.1 years; Max: 8.2 years).

Heart Rate Variability (HRV) Measures

HRV was assessed at baseline (Time 1; T1) using a 5-minute resting electrocardiogram (ECG) recording, which involves measuring the variations in the time intervals that occur between successive heartbeats, commonly known as inter-beat intervals or RR intervals (Shaffer, 2017). The raw RR interval data were first screened using the following two criteria: (1) intervals between 300 and 2000 ms and (2) successive interval ratios between 0.8 and 1.2. The Kubios HRV analysis software was used to generate HRV parameters from the recorded RR intervals, and we employed a frequency domain measure, high-frequency power (defined as the power between 0.15 and 0.40 Hz, using Fast Fourier Transformation), for all analyses. High frequency HRV (HF-HRV) is a reliable measure of primarily parasympathetic (i.e., vagal) and cardiac control and influence, and has been widely used throughout cardiovascular research. To account for skewness, HF-HRV was

transformed using a natural logarithm (Hillebrand et al., 2013; Shaffer & Ginsberg, 2017; Thayer et al., 2010).

Cardiovascular Measures

Several cardiovascular measures were evaluated at T1 and the 6-year follow-up (Time 2; T2), including systolic blood pressure (SBP), diastolic BP (DBP), mean arterial pressure (MAP), heart rate (HR), total peripheral resistance (TPR), total peripheral index (tPI), cardiac output (CO), and cardiac index (CI). For every participant at T1 and T2, SBP and DBP were collected on the same arm, in the supine position, using a Dinamap model 1846 SX oscillometric BP instrument (Critikon, Inc., Tampa, FL). The mean arterial pressure (MAP) was calculated by averaging three BP readings obtained during the baseline visit. Bioimpedance cardiography (NCCOM-3, BioMeD Medical Manufacturing, Ltd, Big Lake, MN) was used to quantify cardiac output (CO) and stroke volume (SV), with total peripheral resistance (TPR) computed by dividing MAP by CO. The total peripheral resistance index (TPI) and cardiac index (CI) were calculated after normalizing for body surface area ($\sqrt{[(height*weight)/3600]}$) (Kapuku et al. 2004, Zhu et al. 2007). In the primary analysis, CI and TPI were the principal markers of CO and TPR.

Sociodemographic Variables

Participants reported their race, sex, age, father's education (proxy measure for socioeconomic status; Schultz et al., 2018), and smoking status (smoker vs. non-smoker) at T1. Body mass index (BMI) was calculated as weight/(height^2) using height (in centimeters) and weight (in kilograms) measurements obtained, without shoes, using a Health-O-Meter medical scale calibrated each visit and collected at both time points (T1 and T2).

Statistical Analyses

All statistical tests were conducted using the IBM SPSS (Version 29.0.1.1, IBM Chicago, IL, USA) and conducted using a two-tailed alpha (p) level of 0.05. Data that was missing or not available for any selected study variables was managed through pairwise deletion, resulting in slightly different sample sizes for each analysis depending on the completeness of the data.

The final sample consisted of 385 participants (95 EA-men, 83 EA-women; 127 AAs-women, 80-AA men) provided adequate statistical power (> 0.80) to detect medium-to-large effect sizes (> 0.15) in the hierarchical regression and moderation analyses (Cohen, 1988; Faul et al., 2007).

Preliminary Analyses:

Descriptive statistics were calculated for the aforementioned demographic variables and cardiovascular measures for the full sample as well as for each group stratified by race and sex. Analyses of variance (ANOVAs) were employed to examine group differences in demographic and cardiovascular variables as a function of sex and ethnicity, independently. Subsequently, independent samples t-tests were used to determine group differences along these variables at T1 and T2 as a function of ethnicity, and additional independent samples t-tests were used to assess the change in MAP, TPI, and CI between T1 and T2. Pearson's correlations (r) were used to examine bivariate associations between HRV and cardiovascular measures at both time points.

Primary Analyses:

A series of hierarchical regression models were then conducted to examine whether Time 1 heart rate variability (T1-HRV) predicted cardiovascular outcomes (SBP, DBP, HR, MAP, CO, and TPR) at T2, with analyses were performed for both the entire sample and stratified by ethnicity.

Demographic and Health Covariates (Model 1): The initial model incorporated the primary demographic and health related. These included age, sex (dummy coded), ethnicity, BMI, father's education as a socioeconomic indicator, and smoking status (also dummy coded). This model established the baseline relationship between these primary covariates and cardiovascular outcomes.

Baseline Cardiovascular Measures (Model 2): The second model built upon Model 1 by adding the respective T1 cardiovascular measurements corresponding to each outcome variable. This allowed for the assessment of cardiovascular stability over time while controlling for primary demographic and health-related factors.

Heart Rate Variability (Model 3): The final model incorporated T1-HRV while retaining all variables from Models 1 and 2, which enabled the examination of HRV's unique contribution to predicting cardiovascular outcomes beyond the effects of demographic, health, and baseline cardiovascular measures at T2.

Supplementary Analyses: To further explore the predictive association between high-frequency HRV (HF-HRV) and TPR at the T2 follow-up, additional analyses were performed incorporating baseline measurements. To take the confounding variable's possible impact on the associations between HF-HRV and cardiovascular parameters like TPR, TPI, CO, and CI into account, regression analyses were conducted both with and without BMI (Perticone et al., 2010).

Moderation Analysis: Using the PROCESS macro (Model 3) within IBM SPSS Version 29.0.1.1, moderation analyses were performed to examine potential three-way interactions between HF-HRV, race, and sex in predicting cardiovascular outcomes. These analyses controlled for age, BMI, father's education, smoking status, and the baseline value of the respective cardiovascular measure. Significant moderation effects were followed up with simple slopes analyses to examine the relationship between HRV and the cardiovascular outcome at different levels of the moderator (i.e., for AA men and women, and EA men and women, separately).

Results

Means and standard deviations for the full sample, as well as stratified by race and sex, are presented in Table 1 for various cardiovascular measures. See Table 2 for all findings of racial differences in cardiovascular outcomes, and Table 3 for all findings of sex differences in cardiovascular outcomes. Table 4 contains findings from all hierarchical regression analyses for the full sample and for each subgroup stratified by race and sex. Lastly, Figures 1-8 illustrate simple slopes graphs of the moderating effects of race and sex on each cardiovascular outcome and its corresponding 3-way interaction.

Descriptive Statistics for the Full Sample and by Subgroup

Full Sample: Across the full sample, AA men exhibited the highest mean values for SBP, DBP, TPR, and MAP at both T1 and T2. Conversely, EA women displayed the lowest means for SBP, CO, and CI at both time points, TPR and TPI at T1, as well as for DBP and MAP at T2. EA men had the lowest mean of DBP at T1, while AA women had the lowest mean of TPI at T2.

Differences by Sex: Significant sex differences emerged across several cardiovascular outcome variables, with men exhibiting higher SBP at both time points (T1: M = 117.96 mmHg, SD = 11.57 vs. M = 109.86 mmHg, SD = 10.85, t_{173} = 7.083, $p < 0.001$, d = 0.725; T: M = 120.50 mmHg, SD = 14.84 vs. M = 112.99 mmHg, SD = 12.94; t_{173} = 5.307, $p < 0.001$, d = 0.543). However, women displayed higher BMI (T1-BMI: M = 29.97 kg/m2, SD = 9.26 vs. M = 27.32 kg/m2, SD = 7.13; t_{210} = -3.106, p = 0.002, d = -0.318; T2-BMI: M = 32.14 kg/m2, SD = 10.04 vs. M = 29.48 kg/m2, SD = 6.61, t_{210} = = -3.001, p = 0.003, d = -0.307). TPR was also higher among women at T2 (M = 17.00 mmHg/L/min, SD = 4.17 vs. M = 15.34 mmHg/L/min, SD = 3.90, t_{210} = -4.014, $p < 0.001$, d = -0.411).

Differences by Race: Racial differences were also noted, with AA exhibiting higher BMI (T1: t_{207} = -3.721, $p < 0.001$, d = -0.380; T2: t_{207} = -3.440, $p < 0.001$, d = -0.352), SBP (T1: t_{207} = -4.308, $p < 0.001$, d = -0.440; T2: t_{207} = -5.568, $p < 0.001$, d = -0.569), DBP (T1: t_{207} = -6.123, $p < 0.001$, d = -0.626; T2: t_{207} = -7.168, $p < 0.001$, d = -0.733), TPR (T2: t_{207} = -6.761, $p < 0.001$, d = -0.691), and MAP T1: t_{207} = -6.077, $p < 0.001$, d = -0.621; T2: t_{207} = -6.850, $p < 0.001$, d = -0.700) at both T1 and T2, compared to EA.

Differences by Sex and Race within the AA Population: AA women had significantly higher BMI compared to AA men at both T1 (t_{127} = -3.44, $p < .001$) and T2 (t_{127} = -2.61, p = .010). AA women also had higher SBP (t_{127} = -2.74, p = 0.007), DBP (t_{127} = -2.57, p = 0.011), and TPR (t_{127} = -2.21, p = 0.028) at T1 compared to AA men. At T2, AA men had significantly higher SBP (t_{80} = 4.58, $p < 0.001$) and DBP (t_{80}= 2.03, p = 0.044) compared to AA women. There were no significant sex differences between AA men and women SES (e.g. father's education), smoking status, HRV, CO, CI, or HR at either time point.

Hierarchical Regressions Analyses for the Full Sample and by Subgroup

Hierarchical regression analyses were conducted to examine the predictive relationship between T1 HRV and T2 cardiovascular measures. For DBP, demographic variables (age, race, and BMI) were entered in Model 1, explaining 14.6% of the variance. Subsequently, the addition of T1-DBP in Model 2 significantly improved the model, accounting for an additional 21.2% of the variance. Further, in Model 3, T1-HRV emerged as a significant inverse predictor of T2-DBP (b = -1.074, 95% CI [-1.866, -0.281], $p = 0.008$), contributing an additional 1.6% to the explained variance.

Similar patterns emerged for mean arterial pressure (MAP). Demographic variables (race, sex, age, and BMI) in Model 1 accounted for 19.6% of the variance in T2-MAP. The inclusion of T1-MAP in Model 2 contributed an additional 17.4%, while T1-HRV in Model 3 explained a further 1.4% of the variance. Notably, T1-HRV did not significantly predict other T2 hemodynamic variables, including SBP, TPR, TPI, CO, CI, and HR.

When examining racial and sex differences, EA men showed significant inverse relationships between T1-HRV and several T2 cardiovascular measures. Specifically, T1-HRV predicted SBP ($b = -2.498$, 95% CI [-4.472, -0.524], $p = 0.014$, $\Delta R^2 = 0.044$), DBP ($b = -1.311$, 95% CI [-2.588, -0.034], $p = 0.044$, $\Delta R^2 = 0.033$), MAP ($b = -1.903$, 95% CI [-3.293, -0.514], $p = 0.008$, $\Delta R^2 = 0.054$), and CO ($b = -0.231$, 95% CI [-0.455, -0.007], $p = 0.044$, $\Delta R^2 = 0.042$) at T2.

Among EA women, a marginally significant positive association emerged between T1-HRV and T2-DBP ($b = -1.324$, 95% CI [-2.771, 0.122], $p = 0.072$, $\Delta R^2 = 0.044$). No significant associations were found between T1-HRV and T2 cardiovascular measures in AA men or women.

Additionally, across all subgroups, T1-HRV showed no significant relationships with T2 measures of HR, TPR, TPI, CO, or CI.

Sensitivity analyses comparing models with and without BMI revealed no meaningful differences in the association between HF-HRV and cardiovascular measures, suggesting the robustness of these findings regardless of BMI inclusion.

Moderation Analyses

Moderation analyses revealed non-significant 3-way interactions for SBP (ΔR^2 = 0.0007, F(1, 268) = 0.36, p = 0.552; *Figure 1*) and DBP (ΔR^2 = 0.0013, F(1, 268) = 0.55, p = 0.459; *Figure 2*). Additionally, moderation analyses for TPR (ΔR^2 = 0.0005, F(1, 268) = 0.18, p = 0.676; *Figure 3*) and TPI (ΔR^2 = 0.0005, F(1, 268) = 0.18, p = 0.676; *Figure 4*) yielded non-significant three-way interactions. While the three-way interaction for CO approached significance (ΔR^2 = 0.0047, F(1, 268) = 1.82, p = 0.179; *Figure 5*), none of the conditional effects of HRV on CO were significant for any combination of race and sex (all ps > 0.05). Similarly, moderation analyses for CI (ΔR^2 = 0.0029, F(1, 268) = 0.88, p = 0.348; *Figure 6*), MAP (ΔR^2 = 0.0007, F(1, 268) = 0.33, p = 0.565; *Figure 7*), and HR (ΔR^2 = 0.0023, F(1, 268) = 0.88, p = 0.349; *Figure 8*) revealed non-significant three-way interactions.

Although the overall interactions were non-significant, conditional effects revealed race and sex significantly moderated the association between HRV and TPI in AA men (p > 0.05). However, this conditional effect was not found in AA women.

Discussion

The present study aimed to examine the moderating relationship of race and sex on the association between HRV and select cardiovascular measures, in a large sample of normotensive

AA and EA individuals. Study hypotheses were partially supported, but the overall findings of this study will expand on the available literature exploring combined effects of racial and sex differences observed in longitudinal associations between important mechanisms of BP regulation and various cardiovascular outcomes.

Replication Results

Consistent with Williams et al., (2021), the current investigation found significant differences between AA and EA along key cardiovascular outcomes, with AA exhibiting higher BP, TPR, and MAP. Both studies also demonstrated that higher HRV at baseline (t1) was associated with lower BP measures at follow-up (t2) in EA, but not in AA. Similarly to Hill et al., (2015) findings, the inverse relationship between baseline HRV and BP indices at follow-up varied as a function of ethnicity and sex. However, results deviated from the original findings, with subgroup analyses revealing a significant inverse association between HRV and DBP in EA men and women, but not in AA men or women.

Further, this study expanded investigations into sex differences between racial groups, particularly within the AA community, as explored by Hill et al., (2015). Analyses of the current study revealed that AA women exhibited significantly higher BMI, SBP, DBP, and TPR compared to AA men at baseline, however, at follow-up, AA men had significantly higher SBP and DBP compared to AA women. Further, the present study found that AA exhibited significantly higher BMI, SBP, DBP, TPR, and MAP at both baseline and follow-up compared to EA, independent of crucial covariates like age, sex, and BMI similar to Williams et al., (2021). However, in contrast, the current study did not find a significant association between baseline HRV and follow-up TPR or MAP in either AA or EA.

Although we did not replicate the findings of Hill et al., (2015) and Williams et al., (2021) exactly, the results still underscore the profound ethnic disparities in BP regulation and cardiovascular risk over time. Notably, Hill et al., (2015) found that higher baseline HRV inversely predicted lower future DBP in AA women but not AA men, and even though the current investigation did not find a significant predictive relationship between HRV, BP, or TPR in AA, it did produce contrasting results within conditional effects of moderation analyses.

Specifically, in post-hoc analyses probing the three-way interaction, significant conditional effects revealed that the interaction between race and sex significantly moderated the relationship between higher HRV at T1 and lower TPI at T2 in AA men but not in AA women. Despite analyzing similar cardiovascular outcomes, and while the overall three-way interactions were non-significant in the present study, the contrasting sex differences uncovered across these studies emphasize the importance of examining within-group differences between AA and EA in future research, to gain a more comprehensive understanding of the factors contributing to cardiovascular health disparities within this marginalized population.

The Role of Race and Sex in Cardiovascular Health Disparities

The pathophysiological mechanisms underlying the ethnic differences in BP regulation are complex, multifactorial, and multi-layered. Most importantly, it is crucial to recognize that the observed disparities in cardiovascular health outcomes cannot be attributed to race itself, as race is a social construct rather than a biological reality (Yudell et al., 2016). Instead, these disparities in the relationship between HRV and cardiovascular outcomes may be attributed to a complex interplay of factors, including biological differences in cardiovascular regulation (e.g., NO bioavailability, salt sensitivity, and RAAsS activity), psychosocial stressors (e.g., discrimination, caregiving responsibilities, and the "superwoman schema"), and social determinants of health

(e.g., socioeconomic status, education, and access to healthcare) (Havranek et al., 2015; Schultz et al., 2018; Williams et al., 2019).

Another often overlooked but profoundly impactful factor contributing to these disparities is the dual burden of interpersonal and internalized racism. Interpersonal racism, manifested through discriminatory interactions and prejudiced treatment, has been consistently linked to adverse cardiovascular outcomes, with a meta-analysis revealing a 32% increased risk of hypertension among AA exposed to racial discrimination (Dolezsar et al., 2014). Simultaneously, internalized racism, where AA individuals unknowingly adopt and perpetuate negative societal stereotypes about their own racial group, further exacerbates the deleterious effects of racism on cardiovascular health (Jones & Shorter-Gooden, 2003), leading to heightened allostatic load due to the chronic stress associated with navigating and grappling with both interpersonal and internalized racism (Geronimus et al., 2006; Juster et al., 2010; McEwen, 1998, 2017; Upchurch et al., 2015).

The concept of allostatic load, which refers to the cumulative physiological burden of chronic stress, is also relevant to this research (McEwen, 1998, 2017; McEwen & Stellar, 1993). Allostatic load is influenced by a complex interplay of biological, psychological, and social factors, and has been proposed as a key mechanism linking chronic stress to adverse health outcomes. AA individuals, particularly AA women, may be more vulnerable to the effects of allostatic load on cardiovascular health due to the unique psychosocial stressors they face (Geronimus et al., 2006; Juster et al., 2010; Upchurch et al., 2015). These stressors include discrimination, caregiving responsibilities, the pressure to conform to the "superwoman schema" (Woods-Giscombé, 2010; Woods-Giscombé & Lobel, 2008), and the intersectional experience of sexism within their own ethnic community and racism from outside their community. This

combination of stressors and complex interplay of cultural expectations and stress may contribute to chronic stress and allostatic load, potentially counteracting the beneficial influence of HRV on TPR, or at least in part, explain the inconsistent results regarding the relationship between HRV and cardiovascular outcomes in AA women.

The intersection of race and sex should be a critical consideration in cardiovascular health research, as the combination of these salient traits can significantly influence the prevalence, presentation, and outcomes of cardiovascular diseases and treatment. For example, higher TPR in AA populations may be attributed to a combination of physiological factors, such as increased sympathetic nervous system activity (Calhoun et al., 1993), reduced nitric oxide bioavailability (Förstermann & Sessa, 2012; Gao & Mann, 2009; Kalinowski et al., 2004), or lower renin-angiotensin-aldosterone system (RAAsS) activity compared to EA. Previous research has also found AA have a higher prevalence of salt sensitivity (Weinberger, 1996; Wright et al., 2003), obesity (Khan et al., 2014), and insulin resistance, all three of which are associated with increased sympathetic nervous system activity and TPR (Dubowitz et al., 2012).

The baroreflex is an important vagally-mediated mechanism involved in long-term BP regulation and is comprised of three primary branches: cardiac (heart-period adjustment), vascular (peripheral resistance adjustment), and myocardial (stroke volume adjustment). Baroreflex sensitivity indicates the magnitude of cardiovascular activity changes following BP fluctuations, whereas baroreflex effectiveness reflects the frequency with which BP changes lead to a cardiovascular response. Disparities in cardiovascular health outcomes between AA and EA may be partly attributed to differences in baroreflex function. Ethnic differences in cardiovascular health between AA and EA could be influenced by variations in baroreflex function. More specifically, a recent study found that AA display reduced vascular baroreflex effectiveness

compared to EA, even though AA exhibited higher resting HRV (Chantler & Lakatta, 2012; Williams et al., 2024). This suggests that the vascular branch of the baroreflex may be less effective in regulating TPR among AA, potentially leading to elevations in TPR-mediated BP and poorer health outcomes over time.

Nitric oxide (NO) bioavailability is also crucial for the regulation of TPR via the baroreflex, and thus also might be an important factor underlying cardiovascular health disparities. NO is a potent vasodilator that plays a crucial role in maintaining vascular homeostasis and reducing TPR (Förstermann & Sessa, 2012). Studies have shown that AA individuals have reduced NO bioavailability compared to EA individuals, which may contribute to the higher TPR and increased cardiovascular risk (Kalinowski et al., 2004). The reduced NO bioavailability in AA individuals may be attributed to a combination of genetic and environmental factors, however, investigating the factors that influence NO bioavailability, such as oxidative stress, inflammation, and endothelial dysfunction, and how these factors differ between AA and EA populations may provide valuable insights in this area (Gao & Mann, 2009).

Limitations & Future Directions

Although the present study has several notable strengths, including its large sample size, prospective design, and consideration of both race and sex as potential moderators, there are some limitations that should be acknowledged.

First, the observational nature of the study precludes causal inferences about the relationships between HRV and cardiovascular outcomes. While the prospective design helps to establish temporal precedence and reduces the likelihood of reverse causality, it cannot completely rule out the possibility of unmeasured confounding variables influencing the observed associations

(Cohen, 1988). Additionally, the study sample consisted of normotensive young adults, which may limit the generalizability of the findings to older or hypertensive populations. The age range of the sample (15-32 years at baseline) may not capture the full spectrum of cardiovascular risk across the lifespan, and the relationships between HRV and cardiovascular outcomes may differ in individuals with established cardiovascular disease or those at higher risk for developing such conditions (Visseren et al., 2021).

Second, the unequal sample sizes across the four race-sex subgroups (95 EA men, 83 EA women, 127 AA women, and 80 AA men) may have affected the power to detect significant effects within each subgroup. This is particularly concerning for the moderation analyses, where the power to detect significant interaction effects may have been limited by the sample size and the number of predictors in the models (Cohen, 1988; Faul et al., 2007). Future studies should aim to recruit more balanced samples across race and sex and consider using larger sample sizes or more sensitive measures to ensure adequate power for subgroup analyses and to detect smaller effects.

Third, while the study accounted for several important covariates, such as age, BMI, socioeconomic status, and smoking status, there may be other relevant factors that were not included in the analyses. Further, the study relied on a single measure of HRV (i.e., HF-HRV) and did not assess other aspects of autonomic function, such as baroreflex sensitivity. While HF-HRV is a well-established marker of parasympathetic activity (Shaffer & Ginsberg, 2017; Thayer et al., 2010), it may not fully capture the complex interplay between the sympathetic and parasympathetic branches of the autonomic nervous system in regulating cardiovascular function (Chantler & Lakatta, 2012; Thayer et al., 2012).

Future research should address these limitations by: (1) employing experimental designs, such as randomized controlled trials, to better establish causal relationships between HRV and

cardiovascular health (SPRINT Research Group, 2015); (2) replicating these findings in larger more evenly distributed samples (Faul et al., 2007), including older adults and those with varying degrees of cardiovascular health (Benjamin et al., 2017, 2019); (3) incorporating more comprehensive assessments of autonomic function, including measures of sympathetic activity (e.g., pre-ejection period) and baroreflex sensitivity, to gain a more nuanced understanding of the relationships between autonomic regulation and cardiovascular health across different racial and sex groups (Chantler & Lakatta, 2012; Thayer et al., 2012).

Conclusions

This study investigated the combined influence of race and sex on the relationship between heart HRV and select cardiovascular outcomes in AA and EA young adults. While no significant three-way interactions were found, the study revealed racial and sex differences along some of these relationships. AA had higher BP, TPR, and MAP compared to EA. Higher HRV at baseline was associated with lower BP at follow-up in EA, particularly EA males, but not in AA. AA women had higher BMI, BP, and TPR than AA men at baseline, but AA men had higher BP at follow-up.

The mechanisms underlying these racial and sex differences are complex, multifactorial, and remain unresolved. Despite this study's limitations, these findings highlight the importance of considering the intersection of race and sex in cardiovascular health research and recommends future studies employ experimental designs, replicate findings in larger, more evenly distributed samples, and assess a more comprehensive range of autonomic function to better understand these complex relationships.

References

1. Appel, L. J. (2003). Lifestyle modification as a means to prevent and treat high blood pressure. Journal of the American Society of Nephrology, 14(7 Suppl 2), S99-S102. https://doi.org/10.1097/01.asn.0000070141.69483.5a
2. Benjamin, E. J., Blaha, M. J., Chiuve, S. E., Cushman, M., Das, S. R., Deo, R., de Ferranti, S. D., Floyd, J., Fornage, M., Gillespie, C., Isasi, C. R., Jiménez, M. C., Jordan, L. C., Judd, S. E., Lackland, D., Lichtman, J. H., Lisabeth, L., Liu, S., Longenecker, C. T., . . . Muntner, P. (2017). Heart disease and stroke statistics—2017 update: A report from the American Heart Association. Circulation, 135(10), e146-e603. https://doi.org/10.1161/CIR.0000000000000485
3. Benjamin, E. J., Muntner, P., Alonso, A., Bittencourt, M. S., Callaway, C. W., Carson, A. P., Chamberlain, A. M., Chang, A. R., Cheng, S., Das, S. R., Delling, F. N., Djousse, L., Elkind, M. S. V., Ferguson, J. F., Fornage, M., Jordan, L. C., Khan, S. S., Kissela, B. M., Knutson, K. L., . . . Virani, S. S. (2019). Heart disease and stroke statistics—2019 update: A report from the American Heart Association. Circulation, 139(10), e56-e528. https://doi.org/10.1161/CIR.0000000000000659
4. Brewer, L. C., Redmond, N., Slusser, J. P., Scott, C. G., Chamberlain, A., Djousse, L., Patten, C. A., Roger, V. L., & Sims, M. (2018). Stress and achievement of cardiovascular health metrics: The American Heart Association Life's Simple 7 in blacks of the Jackson Heart Study. Journal of the American Heart Association, 7(13), Article e008855. https://doi.org/10.1161/JAHA.118.008855
5. Brownlow, B. N., Williams, D. P., Kapuku, G., Vasey, M. W., Anderson, N. B., Koenig, J., Thayer, J. F., & Hill, L. K. (2020). Ethnic differences in resting total peripheral

resistance: A systematic review and meta-analysis. Psychosomatic Medicine, 82(6), 548-560. https://doi.org/10.1097/psy.0000000000000820

6. Calhoun, D. A., Mutinga, M. L., Collins, R., Wyss, J. M., & Oparil, S. (1993). Normotensive blacks have heightened sympathetic response to cold pressor test. Hypertension, 22(6), 801-805. https://doi.org/10.1161/01.HYP.22.6.801
7. Carnethon, M. R., Pu, J., Howard, G., Albert, M. A., Anderson, C. A., Bertoni, A. G., Mujahid, M. S., Palaniappan, L., Taylor, H. A., Jr., Willis, M., & Yancy, C. W. (2017). Cardiovascular health in African Americans: A scientific statement from the American Heart Association. Circulation, 136(21), e393-e423. https://doi.org/10.1161/CIR.0000000000000534
8. Chantler, P. D., & Lakatta, E. G. (2012). Arterial-ventricular coupling with aging and disease. Frontiers in Physiology, 3, Article 90. https://doi.org/10.3389/fphys.2012.00090
9. Cohen, J. (1988). Statistical power analysis for the behavioral sciences (2nd ed.). Lawrence Erlbaum Associates.
10. Davis, S. K., Liu, Y., Quarells, R. C., Din-Dzietham, R., & Metro Atlanta Heart Disease Study Group. (2005). Stress-related racial discrimination and hypertension likelihood in a population-based sample of African Americans: The Metro Atlanta Heart Disease Study. Ethnicity & Disease, 15(4), 585-593. https://doi.org/10.18865/ed.15.4.585
11. Dolezsar, C. M., McGrath, J. J., Herzig, A. J. M., & Miller, S. B. (2014). Perceived racial discrimination and hypertension: A comprehensive systematic review. Health Psychology, 33(1), 20-34. https://doi.org/10.1037/a0033718
12. Dorr, D. A., Jones, S. S., Burns, L., Donnelly, S. M., Brunker, C. P., Wilcox, A., & Clayton, P. D. (2006). Use of health-related, quality-of-life metrics to predict mortality

and hospitalizations in community-dwelling seniors. Journal of the American Geriatrics Society, 54(4), 667-673. https://doi.org/10.1111/j.1532-5415.2006.00681.x

13. Drazner, M. H., Dries, D. L., Peshock, R. M., Cooper, R. S., Klassen, C., Kazi, F., Willett, D., & Victor, R. G. (2005). Left ventricular hypertrophy is more prevalent in blacks than whites in the general population: The Dallas Heart Study. Hypertension, 46(1), 124-129. https://doi.org/10.1161/01.HYP.0000169972.96201.8e
14. Dubowitz, T., Ghosh-Dastidar, M., Eibner, C., Slaughter, M. E., Fernandes, M., Whitsel, E. A., Bird, C. E., Jewell, A., Margolis, K. L., Li, W., Michael, Y. L., Shih, R. A., Manson, J. E., & Escarce, J. J. (2012). The Women's Health Initiative: The food environment, neighborhood socioeconomic status, BMI, and blood pressure. Obesity, 20(4), 862-871. https://doi.org/10.1038/oby.2011.141
15. Eaton, C. B., Pettinger, M., Rossouw, J., Martin, L. W., Foraker, R., Quddus, A., Liu, S., Wampler, N. S., Hank Wu, W. C., Manson, J. E., Margolis, K., Johnson, K. C., Allison, M., Corbie-Smith, G., Rosamond, W., Breathett, K., & Klein, L. (2016). Risk factors for incident hospitalized heart failure with preserved versus reduced ejection fraction in a multiracial cohort of postmenopausal women. Circulation: Heart Failure, 9(10), Article e002883. https://doi.org/10.1161/CIRCHEARTFAILURE.115.002883
16. Faul, F., Erdfelder, E., Lang, A. G., & Buchner, A. (2007). G*Power 3: A flexible statistical power analysis program for the social, behavioral, and biomedical sciences. Behavior Research Methods, 39(2), 175-191. https://doi.org/10.3758/BF03193146
17. Förstermann, U., & Sessa, W. C. (2012). Nitric oxide synthases: Regulation and function. European Heart Journal, 33(7), 829-837. https://doi.org/10.1093/eurheartj/ehr304

18. Gao, Y., & Mann, G. E. (2009). Vascular NAD(P)H oxidase activation in diabetes: A double-edged sword in redox signaling. Cardiovascular Research, 82(1), 9-20. https://doi.org/10.1093/cvr/cvp002

19. Geronimus, A. T., Hicken, M., Keene, D., & Bound, J. (2006). "Weathering" and age patterns of allostatic load scores among blacks and whites in the United States. American Journal of Public Health, 96(5), 826-833. https://doi.org/10.2105/AJPH.2004.060749

20. Ginty, A. T., Carroll, D., Roseboom, T. J., Phillips, A. C., & de Rooij, S. R. (2013). Depression and anxiety are associated with a diagnosis of hypertension 5 years later in a cohort of late middle-aged men and women. Journal of Human Hypertension, 27(3), 187-190. https://doi.org/10.1038/jhh.2012.18

21. Havranek, E. P., Mujahid, M. S., Barr, D. A., Blair, I. V., Cohen, M. S., Cruz-Flores, S., Davey-Smith, G., Dennison-Himmelfarb, C. R., Lauer, M. S., Lockwood, D. W., Rosal, M., & Yancy, C. W. (2015). Social determinants of risk and outcomes for cardiovascular disease: A scientific statement from the American Heart Association. Circulation, 132(9), 873-898. https://doi.org/10.1161/CIR.0000000000000228

22. Hackney, K. J., Daniels, S. R., Paustian-Underdahl, S. C., Perrewé, P. L., Mandeville, A., & Eaton, A. A. (2021). Examining the effects of perceived pregnancy discrimination on mother and baby health. Journal of Applied Psychology, 106(5), 774-783. https://doi.org/10.1037/apl0000788

23. Hayes, A. F. (2013). Introduction to mediation, moderation, and conditional process analysis: A regression-based approach. Guilford Press.

24. Heffernan, K. S., Jae, S. Y., Wilund, K. R., Woods, J. A., & Fernhall, B. (2008). Racial differences in central blood pressure and vascular function in young men. American

Journal of Physiology-Heart and Circulatory Physiology, 295(6), H2380-H2387. https://doi.org/10.1152/ajpheart.00902.2008

25. Hillebrand, S., Gast, K. B., de Mutsert, R., Swenne, C. A., Jukema, J. W., Middeldorp, S., RosendAAsl, F. R., & Dekkers, O. M. (2013). Heart rate variability and first cardiovascular event in populations without known cardiovascular disease: meta-analysis and dose–response meta-regression. EP Europace, 15(5), 742-749. https://doi.org/10.1093/europace/eus341
26. Hill, L. K., Hu, D. D., Koenig, J., Sollers, J. J., Kapuku, G., Wang, X., Snieder, H., & Thayer, J. F. (2015). Ethnic differences in resting heart rate variability: A systematic review and meta-analysis. Psychosomatic Medicine, 77(1), 16-25. https://doi.org/10.1097/PSY.0000000000000133
27. Israel, B. A., Coombe, C. M., Cheezum, R. R., Schulz, A. J., McGranaghan, R. J., Lichtenstein, R., Reyes, A. G., Clement, J., & Burris, A. (2010). Community-based participatory research: A capacity-building approach for policy advocacy aimed at eliminating health disparities. American Journal of Public Health, 100(11), 2094-2102. https://doi.org/10.2105/AJPH.2009.170506
28. Jarczok, M. N., Jarczok, M., Mauss, D., Koenig, J., Li, J., Herr, R. M., & Thayer, J. F. (2013). Autonomic nervous system activity and workplace stressors—A systematic review. Neuroscience & Biobehavioral Reviews, 37(8), 1810-1823. https://doi.org/10.1016/j.neubiorev.2013.07.004
29. Johnson, D. A., Thorpe, R. J., McGrath, J. A., Jackson, W. B., & Jackson, C. L. (2018). Black-white differences in housing type and sleep duration as well as sleep difficulties in

the United States. International Journal of Environmental Research and Public Health, 15(4), Article 564. https://doi.org/10.3390/ijerph15040564

30. Jones, C. P., & Shorter-Gooden, K. (2003). Shifting: The double lives of black women in America. HarperCollins.
31. Juster, R. P., McEwen, B. S., & Lupien, S. J. (2010). Allostatic load biomarkers of chronic stress and impact on health and cognition. Neuroscience & Biobehavioral Reviews, 35(1), 2-16. https://doi.org/10.1016/j.neubiorev.2009.10.002
32. Kalinowski, L., Dobrucki, I. T., & Malinski, T. (2004). Race-specific differences in endothelial function: predisposition of African Americans to vascular diseases. Circulation, 109(21), 2511-2517. https://doi.org/10.1161/01.CIR.0000129774.29166.9B
33. Kapuku, G., Ghosh, S., Doshi, V., Hall, P., Strong, W., Treiber, F., Pollock, D., Pollock, J., Harris, R., Halbert, J., Harshfield, G., & George, V. (2019). The Augusta Heart study. Journal of Environment and Health Science. 5:15–23.
34. Khan, S. S., Ning, H., Wilkins, J. T., Allen, N., Carnethon, M., Berry, J. D., Sweis, R. N. & Lloyd-Jones, D. M. (2014). Association of body mass index with lifetime risk of cardiovascular disease and compression of morbidity. JAMA Cardiology, 3(4), 280-287. https://doi.org/10.1001/jamacardio.2018.0022
35. Koenig, J., & Thayer, J. F. (2016). Sex differences in healthy human heart rate variability: A meta-analysis. Neuroscience & Biobehavioral Reviews, 64, 288-310. https://doi.org/10.1016/j.neubiorev.2016.03.007
36. Liao, D., Barnes, R. W., Chambless, L. E., Simpson, R. J., Sorlie, P., & Heiss, G. (1995). Age, race, and sex differences in autonomic cardiac function measured by spectral

analysis of heart rate variability—The ARIC study. The American Journal of Cardiology, 76(12), 906-912. https://doi.org/10.1016/S0002-9149(99)80260-4

37. Mayet, J., & Hughes, A. (2003). Cardiac and vascular pathophysiology in hypertension. Heart. 89(9):1104-9. DOI: 10.1136/heart.89.9.1104.
38. McEwen, B. S. (1998). Protective and damaging effects of stress mediators. Dialogues in Clinical Neuroscience, 8(4), 367-381. https://doi.org/10.31887/DCNS.2006.8.4/bmcewen
39. McEwen, B. S. (2017). Neurobiological and systemic effects of chronic stress. Chronic Stress, 1, Article 2470547017692328. https://doi.org/10.1177/2470547017692328
40. McEwen, B. S., & Stellar, E. (1993). Stress and the individual: mechanisms leading to disease. Archives of Internal Medicine, 153(18), 2093-2101. https://doi.org/10.1001/archinte.1993.00410180039004
41. Nabi, H., Kivimäki, M., Batty, G. D., Shipley, M. J., Britton, A., Brunner, E. J.,Hemmingsson, T., Vahtera, J., Marmot, M. G., & Singh-Manoux, A. (2013). Increased risk of coronary heart disease among individuals reporting adverse impact of stress on their health: The Whitehall II prospective cohort study. European Heart Journal, 34(34), 2697-2705. https://doi.org/10.1093/eurheartj/eht216
42. Palatini, P., & Julius, S. (2009). The role of cardiac autonomic function in hypertension and cardiovascular disease. Current Hypertension Reports, 11(3), 199-205. https://doi.org/10.1007/s11906-009-0035-4
43. Perticone, F., Ceravolo, R., Candigliota, M., Ventura, G., Iacopino, S., Sinopoli, F., & Mattioli, P. L. (2001). Obesity and body fat distribution induce endothelial dysfunction by oxidative stress: protective effect of vitamin C. Diabetes, 50(1), 159-165. https://doi.org/10.2337/diabetes.50.1.159

44. Pool, L. R., Ning, H., Lloyd-Jones, D. M., & Allen, N. B. (2017). Trends in racial/ethnic disparities in cardiovascular health among US adults from 1999-2012. Journal of the American Heart Association, 6(9), Article e006027. https://doi.org/10.1161/JAHA.117.006027

45. Rosati, F., Williams, D.P., Juster, R.P., Thayer, J.F., Ottaviani, C., & Baiocco, R. (2021). The Cardiovascular Conundrum in Ethnic and Sexual Minorities: A Potential Biomarker of Constant Coping With Discrimination. Frontier Neuroscience. 15:619171. DOI: 10.3389/fnins.2021.619171.

46. Schultz, W. M., Kelli, H. M., Lisko, J. C., Varghese, T., Shen, J., Sandesara, P., Quyyumi, A. A., Taylor, H. A., Gulati, M., Harold, J. G., Mieres, J. H., Ferdinand, K. C., Mensah, G. A., & Sperling, L. S. (2018). Socioeconomic status and cardiovascular outcomes: Challenges and interventions. Circulation, 137(20), 2166-2178. https://doi.org/10.1161/CIRCULATIONAHA.117.029652

47. Shaffer, F., & Ginsberg, J. P. (2017). An overview of heart rate variability metrics and norms. Frontiers in Public Health, 5, Article 258. https://doi.org/10.3389/fpubh.2017.00258

48. SPRINT Research Group, Wright, J. T., Jr., Williamson, J. D., Whelton, P. K., Snyder, J. K., Sink, K. M., Rocco, M. V., Reboussin, D. M., Rahman, M., Oparil, S., Lewis, C. E., Kimmel, P. L., Johnson, K. C., Goff, D. C., Jr., Fine, L. J., Cutler, J. A., Cushman, W. C., Cheung, A. K., & Ambrosius, W. T. (2015). A randomized trial of intensive versus standard blood-pressure control. The New England Journal of Medicine, 373(22), 2103-2116. https://doi.org/10.1056/NEJMoa1511939

49. Spruill, T. M. (2010). Chronic psychosocial stress and hypertension. Current Hypertension Reports, 12(1), 10-16. https://doi.org/10.1007/s11906-009-0084-8

50. Sternberg, E. M., Chrousos, G. P., Wilder, R. L., & Gold, P. W. (2021). The stress response and the regulation of inflammatory disease. Annals of Internal Medicine, 117(10), 854-866. https://doi.org/10.7326/0003-4819-117-10-854

51. Thayer, J. F., Ahs, F., Fredrikson, M., Sollers, J. J., & Wager, T. D. (2012). A meta-analysis of heart rate variability and neuroimaging studies: Implications for heart rate variability as a marker of stress and health. Neuroscience & Biobehavioral Reviews, 36(2), 747-756. https://doi.org/10.1016/j.neubiorev.2011.11.009

52. Thayer, J. F., Carnival, L., Sgiofo, A., & Williams, D. P.(2020). Angry in America: Psychophysiological Responses to Unfair Treatment. Annals of Behavioral Medicine, 55(9), 933. https://doi.org/10.1093/abm/kAAsb023

53. Thayer, J. F., Yamamoto, S. S., & Brosschot, J. F. (2010). The relationship of autonomic imbalance, heart rate variability and cardiovascular disease risk factors. International Journal of Cardiology, 141(2), 122-131. https://doi.org/10.1016/j.ijcard.2009.09.543

54. Upchurch, D. M., Stein, J., Greendale, G. A., Chyu, L., Tseng, C. H., Huang, M. H., Lewis, T. T., Kravitz, H. M., & Seeman, T. (2015). A longitudinal investigation of race, socioeconomic status, and psychosocial mediators of allostatic load in midlife women: findings from the Study of Women's Health Across the Nation. Psychosomatic Medicine, 77(4), 402-412. https://doi.org/10.1097/PSY.0000000000000175

55. Visseren, F. L. J., Mach, F., Smulders, Y. M., Carballo, D., Koskinas, K. C., Bäck, M., Benetos, A., Biffi, A., Boavida, J. M., Capodanno, D., Cosyns, B., Crawford, C., Davos, C. H., Desormais, I., Di Angelantonio, E., Franco, O. H., Halvorsen, S., Hobbs, F. D. R.,

Hollander, M., . . . ESC Scientific Document Group. (2021). 2021 ESC Guidelines on cardiovascular disease prevention in clinical practice. European Heart Journal, 42(34), 3227-3337. https://doi.org/10.1093/eurheartj/ehab484

56. Weinberger, M. H. (1996). Salt sensitivity of blood pressure in humans. Hypertension, 27(3 Pt 2), 481-490. https://doi.org/10.1161/01.hyp.27.3.481
57. Williams, D. P., Thayer, J. F., Halbert, J. D., Wang, X., & Kapuku, G. (2021). Higher cardiac vagal activity predicts lower peripheral resistance 6 years later in European but not African Americans. American Journal of Physiology-Heart and Circulatory Physiology, 320(5), H2058-H2065. https://doi.org/10.1152/ajpheart.00023.2021
58. Williams, D. P., Wiley, C. R., Birenbaum, J., Fishback, G., Speller, L. F., Koenig, J., Wang, X., Hosseinbor, A. P., Cohen, D., & Thayer, J. F. (2024). Racial differences in baroreflex function: Implications for the cardiovascular conundrum. [Unpublished manuscript]
59. Williams, D. R., Lawrence, J. A., & Davis, B. A. (2019). Racism and health: evidence and needed research. Annual Review of Public Health, 40, 105-125. https://doi.org/10.1146/annurev-publhealth-040218-043750
60. Williams, D. R., Lawrence, J. A., Davis, B. A., & Vu, C. (2019). Understanding how discrimination can affect health. Health Services Research, 54(Suppl 2), 1374-1388. https://doi.org/10.1111/1475-6773.13222
61. Williams, D. R., Priest, N., & Anderson, N. B. (2016). Understanding associations among race, socioeconomic status, and health: patterns and prospects. Health Psychology, 35(4), 407-411. https://doi.org/10.1037/hea0000242

62. Woods-Giscombé, C. L. (2010). Superwoman schema: African American women's views on stress, strength, and health. Qualitative Health Research, 20(5), 668-683. https://doi.org/10.1177/1049732310361892

63. Woods-Giscombé, C. L., & Lobel, M. (2008). Race and gender matter: A multidimensional approach to conceptualizing and measuring stress in African American women. Cultural Diversity and Ethnic Minority Psychology, 14(3), 173-182. https://doi.org/10.1037/1099-9809.14.3.173

64. Wright, J. T., Rahman, M., Scarpa, A., Fatholahi, M., Griffin, V., Jean-Baptiste, R., Islam, M., Eissa, M., White, S., & Douglas, J. G. (2003). Determinants of salt sensitivity in Black and White normotensive and hypertensive women. Hypertension, 42(6), 1087-1092. https://doi.org/10.1161/01.HYP.0000101687.89160.19

65. Yudell, M., Roberts, D., DeSalle, R., & Tishkoff, S. (2016). Taking race out of human genetics. Science, 351(6273), 564-565. https://doi.org/10.1126/science.AAsc4951

	Full-T1		*Full-T2*		*AA-T1*		*AA-T2*		*EA-T1*		*EA-T2*		*Women-T1*		*Women-T2*		*Men-T1*		*Men-T2*	
	Mean	***SD***	***Mean***	***SD***	***Mean***	***SD***	***Mean***	***SD***	***Mean***	***SD***	***Mean***	***SD***	***Mean***	***SD***	***Mean***	***SD***	***Mean***	***SD***	***Mean***	***SD***
Age	23.16	2.85	29.47	2.85	23.58	2.77	29.93	2.91	22.66	2.88	28.93	2.94	23.32	2.73	29.79	2.82	22.96	2.99	29.33	3.12
BMI	28.77	8.45	30.92	8.74	30.22	9.44	32.33	9.44	27.06	6.77	29.30	7.55	29.97	9.26	32.14	10.04	27.32	7.13	29.48	6.61
Education	13.45	2.37	4.94	1.29	12.93	2.18	4.69	1.28	14.05	2.44	5.16	1.27	13.37	2.13	4.84	1.23	13.55	2.63	5.07	1.37
Smoking	.35	.48			.32	.47			.38	.49			.26	.44			.45	.50		
HF-HRV	7.17	1.06			17.21	1.01			7.13	1.11			7.16	1.10			7.18	1.01		
HR	64.64	9.40	64.60	9.48	65.28	9.66	65.17	9.13	63.91	9.10	63.93	9.86	66.89	9.72	66.53	8.94	61.94	8.24	62.27	9.63
SBP	113.54	11.88	116.40	14.32	115.91	11.89	120.03	14.79	110.79	11.28	112.18	12.52	109.86	10.84	112.97	12.94	117.96	11.57	120.50	14.84
DBP	63.44	7.94	68.93	9.09	65.63	8.39	71.82	9.43	60.88	6.53	65.57	7.38	64.16	8.12	68.71	9.00	62.56	7.65	69.19	9.21
TPR	16.82	4.69	16.25	4.13	17.49	5.06	17.49	4.34	16.03	4.09	14.79	3.32	17.14	4.91	17.00	4.17	16.43	4.38	15.34	3.90
TPI	32.16	8.06	32.25	8.10	33.73	8.83	34.87	8.61	30.34	6.65	29.18	6.22	31.41	7.79	32.53	8.38	33.06	8.31	31.90	7.77
CO	5.20	1.36	5.61	1.34	5.16	1.39	5.42	1.38	5.24	1.33	5.82	1.26	5.04	1.36	5.25	1.15	5.39	1.35	6.04	1.43
CI	2.67	0.58	2.79	0.54	2.63	0.61	2.69	0.56	2.71	0.55	2.92	0.49	2.69	0.60	2.74	0.54	2.64	0.56	2.87	0.54
MAP	81.63	8.40	86.30	10.39	83.94	8.64	89.48	10.50	78.95	7.26	82.60	8.95	80.28	8.56	84.91	10.18	83.26	7.92	87.96	10.42
SV	80.97	20.07	87.88	21.16	79.82	20.95	84.11	21.06	82.31	18.97	92.26	20.47	75.60	18.49	79.43	16.67	87.42	20.05	98.02	21.56

Table 1. Descriptive statistics for all variables of interest in the full sample, stratified by race (AA vas. EA, and separately by sex (Women vs. Men) at Time 1 and Time 2 (T1; T2). Means (*M*) and standard deviations (*SD*) for all variables of interest for the full sample and each stratified by race and sex, respectively are presented here. Age was measured in years; body mass index (BMI) was measured in kg/(m^2); father's education was measured in years on a 7-point scale that ranged from less than high school to postgraduate education; smoking status collected as either never a smoker, past, or current smoker; high-frequency power heart rate variability (HF-HRV) in milliseconds squared (ms^2); heart rate (HR) in beats per minute (bpm); systolic blood pressure (SBP) in millimeters of mercury (mmHg); diastolic blood pressure (DBP) in millimeters of mercury (mmHg); total peripheral resistance (TPR) in millimeters of mercury per liter per minute (mmHg/l/min); TPR adjusted (TPI) in millimeters of mercury per liter per min divided by height in meters squared (mmHg/l/min/m^2); cardiac output (CO) in liters per minute (L/min); cardiac index (CI) in liters per min (L/min); mean arterial pressure (MAP) in millimeters of mercury (mmHg); and stroke volume (SV) in milliliters per beat (mL/beat).

	AA		EA		*t*	*d*	*p*
T1-BMI	30.23	9.44	27.07	6.77	-3.72	-0.380	***<.001*** **
T2-BMI	32.33	9.44	29.30	7.55	-3.44	-0.352	***<.001*** **
T1-HRV	7.21	1.01	7.13	1.11	-0.72	-0.073	9.475
T1-SBP	115.91	11.89	110.79	11.28	-4.31	-0.440	***<.001*** **
T2-SBP	120.03	14.79	112.18	12.52	-5.57	-0.569	***<.001*** **
T1-DBP	65.63	8.39	60.88	6.53	-6.12	-0.626	***<.001*** **
T2-DBP	71.82	9.43	65.57	7.38	-7.17	-0.733	***<.001*** **
T1-TPR	17.49	5.06	16.03	4.10	-3.08	-0.315	***.002****
T2-TPR	17.49	4.34	14.79	3.32	-6.76	-0.691	***<.001*** **
T1-TPI	33.73	8.83	30.35	6.65	-4.19	-0.428	***<.001*** **
T2-TPI	34.87	8.61	29.18	6.22	-7.33	-0.749	***<.001*** **
T1-CO	5.16	1.39	5.24	1.33	0.53	0.054	.596
T2-CO	5.42	1.38	5.82	1.26	2.98	0.305	***.003****
T1-CI	2.63	0.61	2.71	0.55	1.33	0.136	.184
T2-CI	2.69	0.56	2.92	0.49	4.23	0.432	***<.001*** **
T1-MAP	83.94	8.64	78.95	7.26	6.078	-0.621	***< 0.001*** **
T2-MAP	89.48	10.50	82.60	8.95	-6.85	-0.700	***< 0.001*** **
T1-HR	65.28	9.66	63.91	9.10	-1.43	-0.146	.154
T2-HR	65.17	9.13	63.93	9.86	-1.29	-0.132	.199

Table 2. Racial group differences in all variables of interest at Time 1 (T1) and Time 2 (T2).

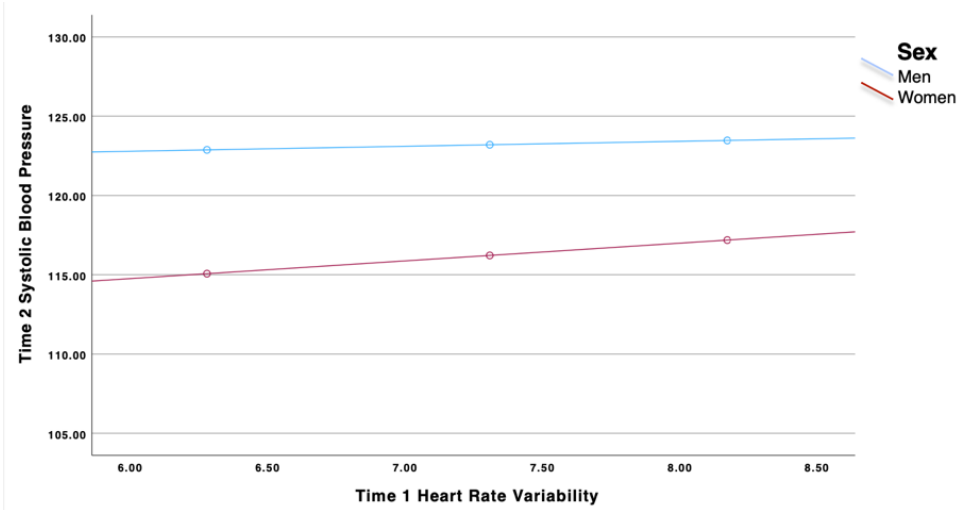
	Men		Women				
	Mean	***SD***	***Mean***	***SD***	***t***	***d***	***p***
T1-BMI	27.32	7.13	29.97	9.26	-3.11	-0.318	***.002****
T2-BMI	29.48	6.61	32.14	10.04	-3.00	-0.307	***.003****
T1-HRV	7.18	1.01	7.16	1.10	.166	0.017	.868
T1-SBP	117.96	11.57	109.86	10.85	7.08	0.725	***<.001****
T2-SBP	120.50	14.84	112.99	12.94	5.31	0.543	***<.001****
T1-DBP	62.56	7.65	64.16	8.12	-1.98	-0.202	***.049****
T2-DBP	69.19	9.21	68.71	9.00	.510	0.052	.611
T1-TPR	16.43	4.38	17.14	4.92	-1.47	-0.150	.142
T2-TPR	15.34	3.90	17.00	4.17	-4.014	-0.411	***<.001****
T1-TPI	33.06	8.31	31.41	7.80	2.01	0.205	***.045****
T2-TPI	31.90	7.77	32.53	8.38	-.766	-0.078	.444
T1-CO	5.39	1.35	5.04	1.36	2.54	0.260	***.011****
T2-CO	6.04	1.43	5.25	1.15	6.05	0.619	***<.001****
T1-CI	2.87	.54	2.74	.54	2.38	0.244	***.018****
T2-CI	2.87	.54	2.74	.54	2.38	0.244	***. 018****
T1-MAP	83.26	7.92	80.28	8.56	3.52	0.360	***<.001****
T2-MAP	87.96	10.42	84.91	10.18	2.89	0.296	***.004****
T1-HR	61.94	8.24	66.89	9.72	-5.33	-0.545	***<.001****
T2-HR	62.27	9.63	66.54	8.94	-4.50	-0.461	***<.001****

Table 3. Sex group differences in all variables of interest at Time 1 (T1) and Time 2 (T2).

	Full Sample				***AA Women***				***AA Men***				***EA Women***				***EA Men***			
	B	***95% CI***	**ΔR²**	***p***	***b***	***95% CI***	**ΔR²**	***p***	***b***	***95% CI***	**ΔR²**	***p***	***b***	***95% CI***	**ΔR²**	***p***	***b***	***95% CI***	**ΔR²**	***p***
HR	.776	-.354, 1.906	.005	.177	.117	-2.152, 2.386	.000	.918	1.577	-1.186, 4.340	.020	.255	1.089	-1.212, 3.390	.009	.348	-.113	-2.345, 2.119	.000	.920
SBP	-.896	-2.048, .310	.004	.148	1.050	-1.384, 3.483	.005	.393	-.534	-4.084, 3.016	.001	.762	-1.552	-3.927, .822	.022	.196	-2.498	-4.472, -.524	.044	***.014****
DBP	-1.074	-1.866, -.281	.016	***.008****	-1.240	-3.150, .670	.013	.200	.150	-2.380, 2.681	.000	.905	-1.324	-2.771, .122	.044	.072	-1.311	-2.588, -.318	.033	***.044****
TPR	-.028	-.451, .395	.000	.895	.335	-.905, 1.576	.003	.592	.144	-1.186, 1.473	.001	.828	-.177	-.828, .475	.004	.590	-.048	-.689, .594	.000	.882
TPI	-.178	-.991, .635	.001	.667	.724	-1.640, 3.088	.004	.544	.539	-1.999, 3.076	.004	.670	-.662	-1.929, .605	.012	.301	-.332	-1.524, .860	.004	.580
CO	-.101	-.230, .029	.006	.126	-.208	-.500, .085	.020	.162	-.106	-.584, .371	.004	.655	.039	-.170, .249	.001	.710	-.231	-.455, -.007	.042	***.044****
CI	-.045	-.103, .013	.007	.130	-.107	-.252, .037	.023	.142	-.078	-.268, .113	.016	.415	.003	-.101, .107	.000	.954	-.064	-.159, .030	.024	.177
MAP	-1.126	-2.012, -.240	.014	***.013****	-.383	-2.428, 1.662	.001	.710	-.330	-2.880, 2.220	.001	.795	-1.294	-3.045, .457	.029	.145	-1.903	-3.293, -.514	.054	***.008****

Table 4. Full sample and subgroup analyses of hierarchical regression models.

A)



B)

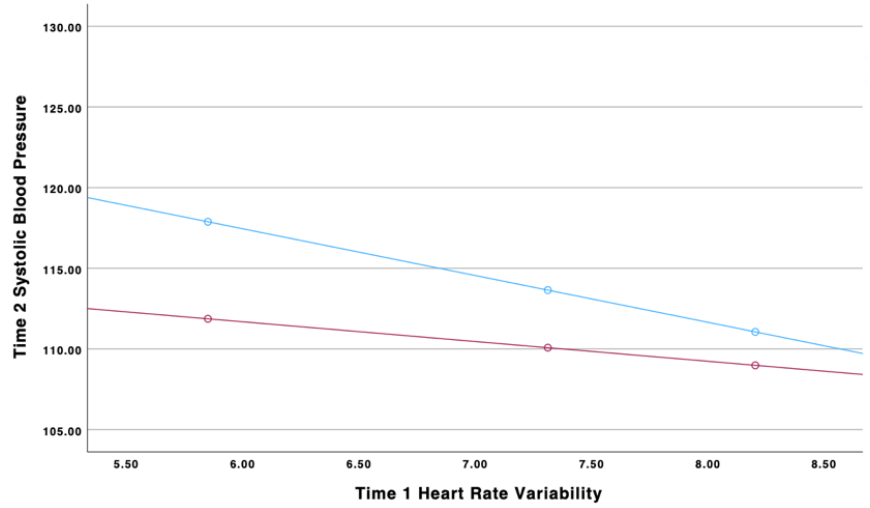
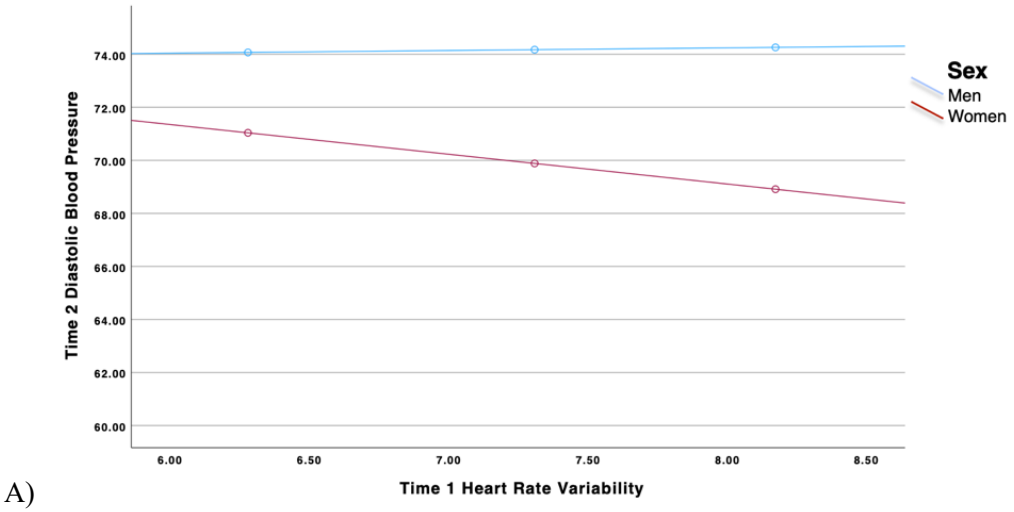
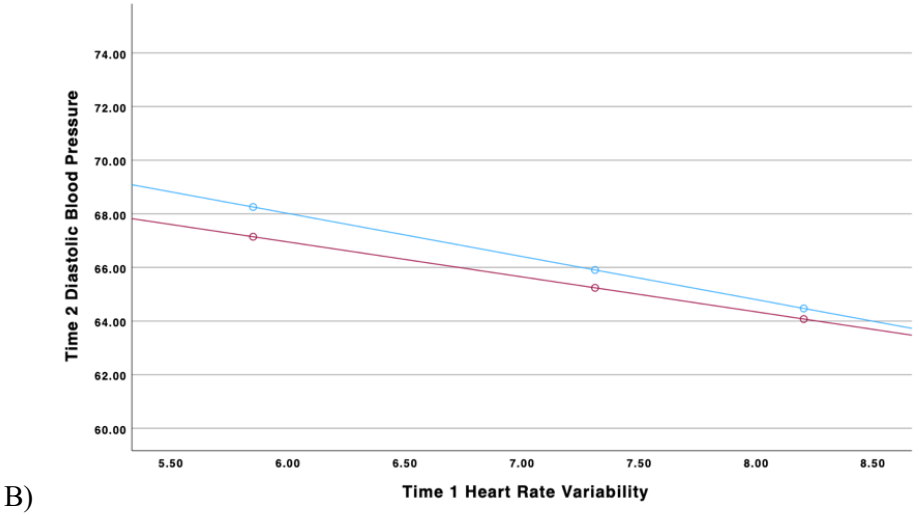


Figure 1. Moderation analysis revealing non-significant 3-way interaction of race, sex, and HRV on SBP in the AAs (A) and EAs (B) sample ($\Delta R^2 = 0.0007$, $F(1, 268) = 0.36$, $p = 0.552$).



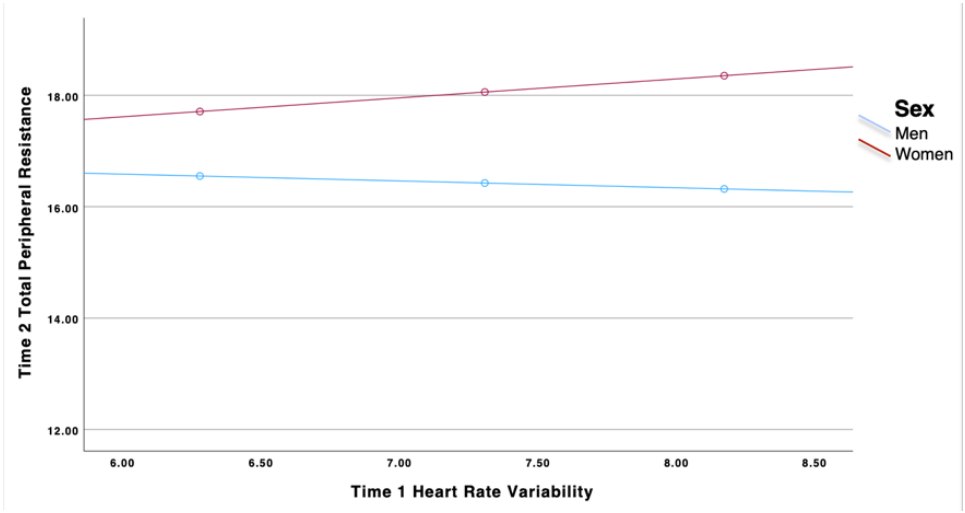
A)



B)

Figure 2. Moderation analysis revealing non-significant 3-way interaction of race, sex, and HRV on DBP in the AAs (A) and EAs (B) sample ($\Delta R^2 = 0.0013$, $F(1, 268) = 0.55$, $p = 0.459$).

A)



B)

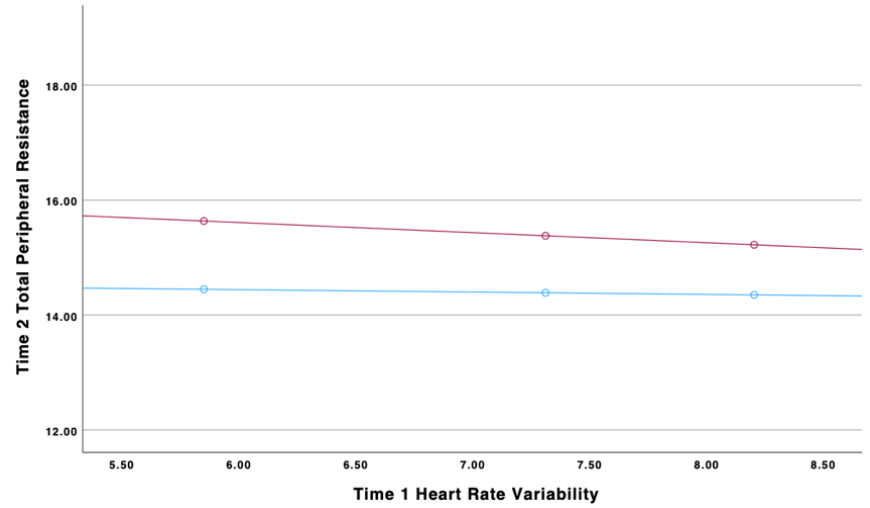
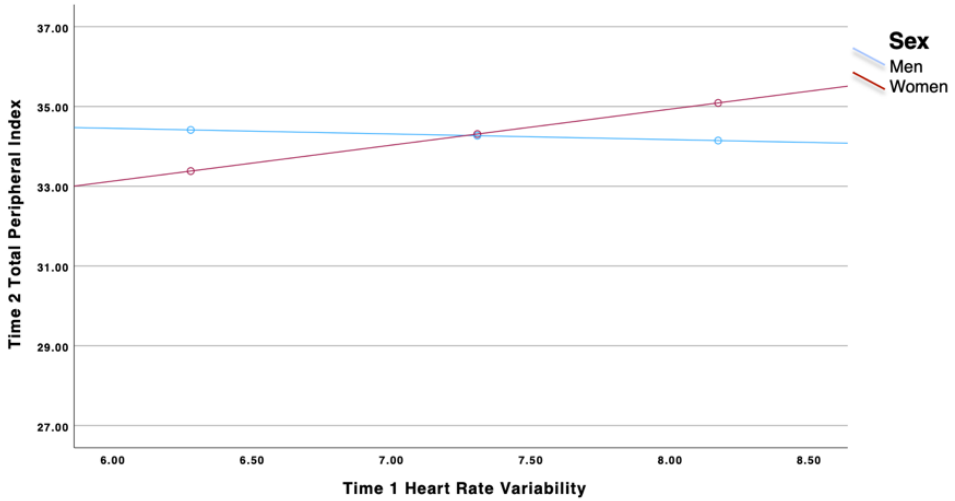


Figure 3. Moderation analysis revealing non-significant 3-way interaction of race, sex, and HRV on TPR in the AAs (A) and EAs (B) sample ($\Delta R^2 = 0.0005$, $F(1, 268) = 0.18$, $p = 0.676$).

A)



B)

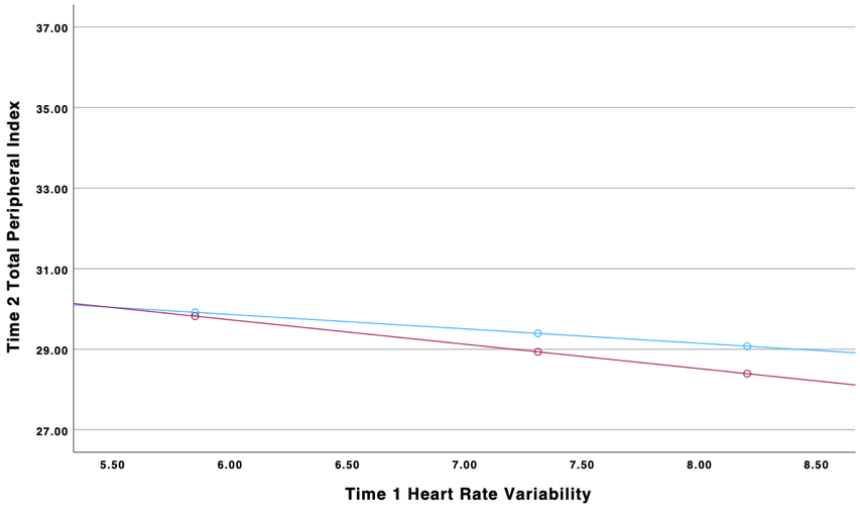
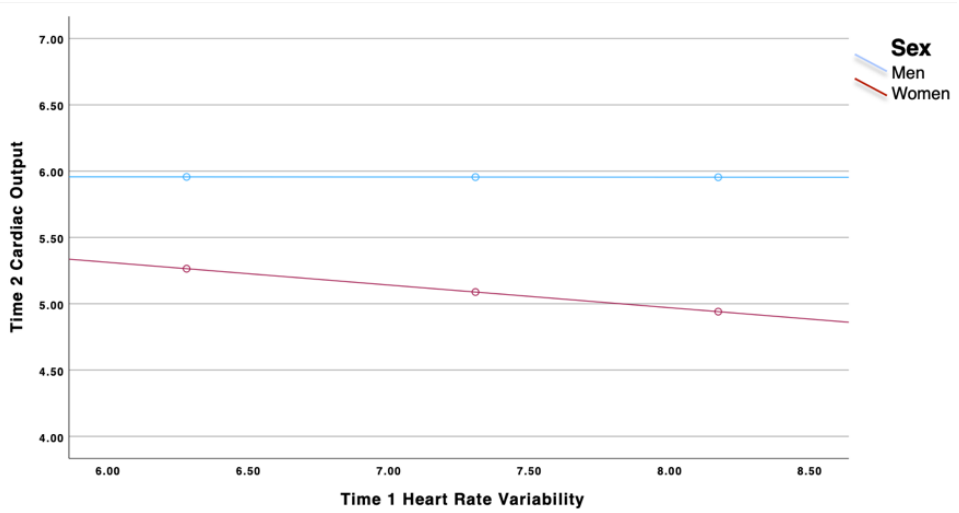


Figure 4. Moderation analysis revealing non-significant 3-way interaction of race, sex, and HRV on TPI in the AAs (A) and EAs (B) sample ($\Delta R^2 = 0.0005$, $F(1, 268) = 0.18$, $p = 0.676$).

A)



B)

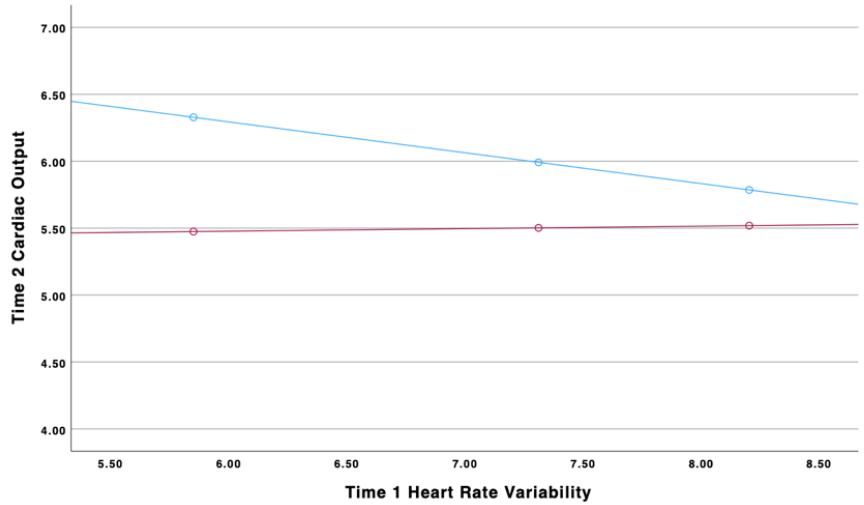


Figure 5. Moderation analysis revealing non-significant 3-way interaction of race, sex, and HRV approaching significance for CO in the AAs (A) and EAs (B) sample ($\Delta R^2 = 0.0047$, $F(1, 268) = 1.82$, $p = 0.179$).

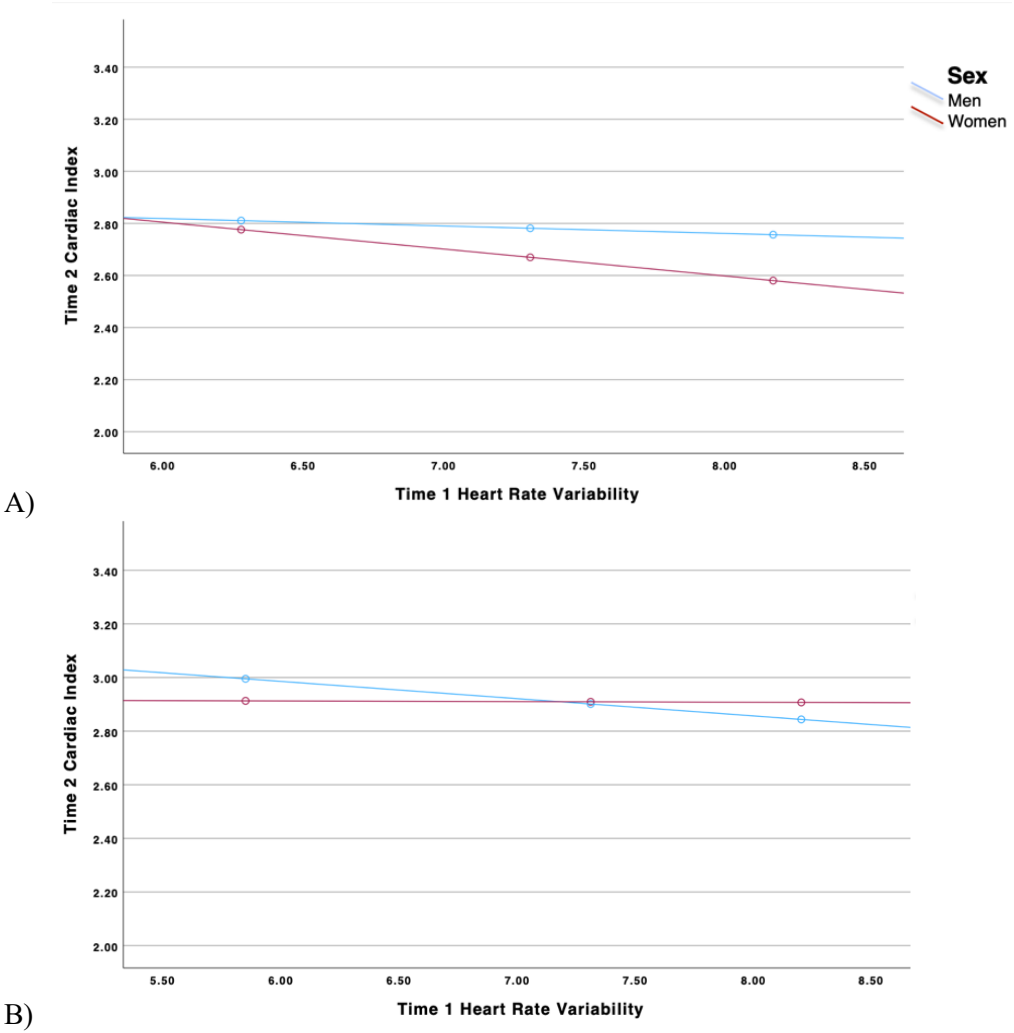
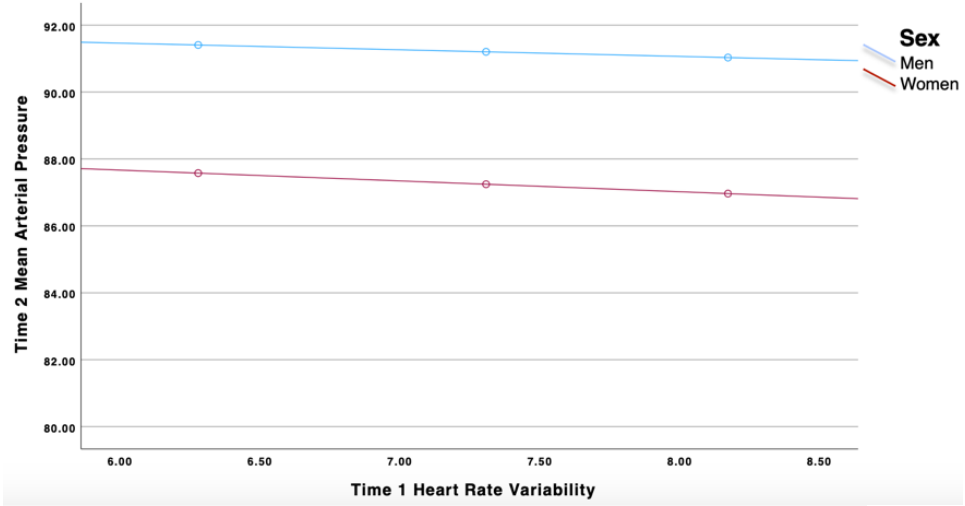


Figure 6. Moderation analysis revealing non-significant 3-way interaction of race, sex, and HRV on CI in the AAs (A) and EAs (B) sample ($\Delta R^2 = 0.0029$, $F(1, 268) = 0.88$, $p = 0.348$).

A)



B)

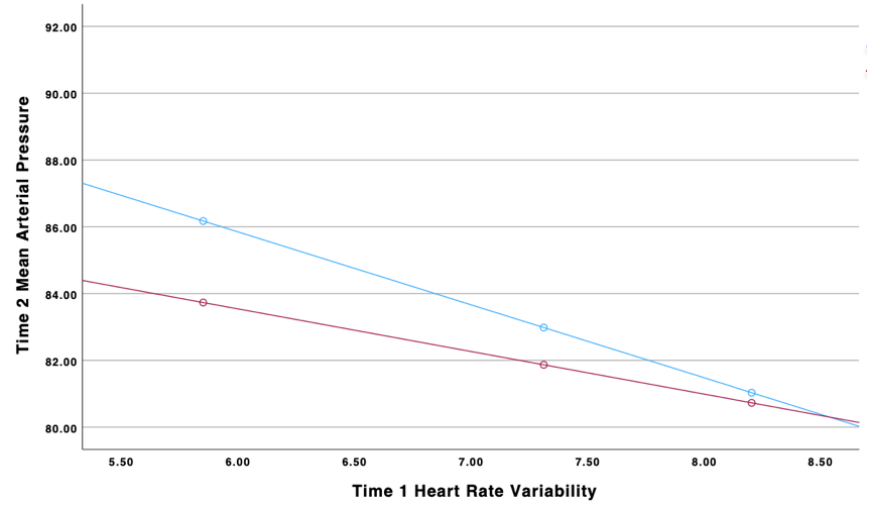
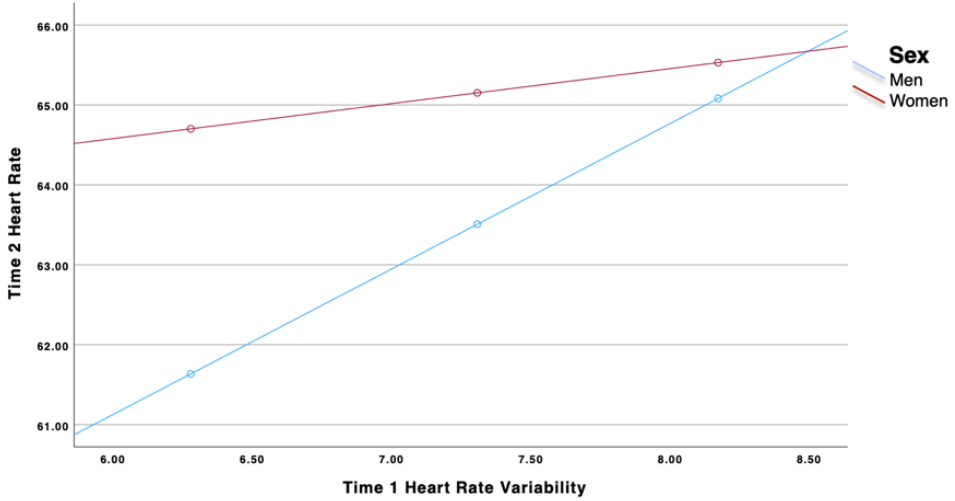


Figure 7. Moderation analysis revealing non-significant 3-way interaction of race, sex, and HRV on MAP in the AAs (A) and EAs (B) sample ($\Delta R^2 = 0.0007$, $F(1, 268) = 0.33$, $p = 0.565$).

A)



B)

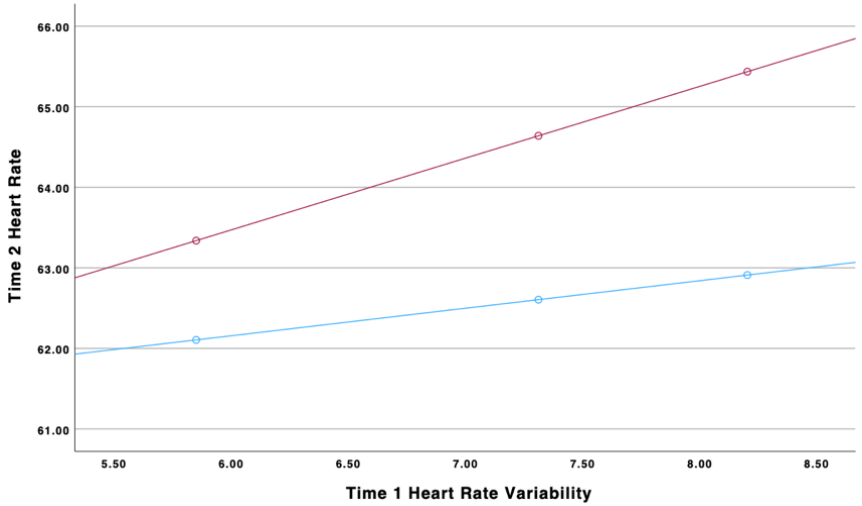


Figure 8. Moderation analysis revealing non-significant 3-way interaction of race, sex, and HRV on HR responses in the AAs (A) and EAs (B) sample ($\Delta R^2 = 0.0023$, $F(1, 268) = 0.88$, $p = 0.349$).