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## Ethnic Differences in Resting Heart Rate Variability: A Systematic Review and Meta-Analysis

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### Abstract

**Background**—Ethnic disparities in cardiovascular morbidity and mortality are widely documented in the literature. Recently, research has shown that decreased parasympathetic (PNS) cardiac modulation is associated with the established and emerging risk factors for cardiovascular disease (CVD) and stroke. In consideration of the disproportionate CVD risk and disease profile of African Americans (AAs), it is plausible that decreased cardiac PNS functioning may partially explain these disparities. In the present systematic review and meta-analysis, we assess the available evidence for a reliable ethnic difference in tonic vagally-mediated heart rate variability (HRV), an indicator of PNS cardiac modulation.

**Methods**—A systematic literature search was conducted yielding studies comparing tonic HRV in AAs and European Americans (EAs). Adjusted standardized effect sizes, (Hedges  $g$ ), were calculated using a mixed effects model with restricted maximum likelihood estimation for 17 studies containing appropriate measures of vagally-mediated HRV.

**Results**—Meta-analysis results suggest that AAs have greater HRV than EAs (Hedges  $g = .93$ , 95% C.I. [.25, 1.62]) even after consideration of several covariates including health status, medication use, and subgroup stratification by gender and age.

**Conclusions**—These findings suggest that decreased vagally-mediated HRV is not likely to account for the persistent health disparities experienced by AAs with respect to cardiovascular disease risk and burden. These disparities underscore the need for continued research addressing socio-ethnic cardiovascular differences and the biobehavioral mechanisms involved

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## Keywords

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## Introduction

Ethnic disparities in cardiovascular morbidity and mortality are widely documented in the literature and continue to challenge health delivery efforts (1-3). In particular, African Americans (AAs) evince higher mortality rates from coronary heart disease and stroke (3), as well as the highest prevalence of multiple cardiovascular disease (CVD) risks, including sex- and age-stratified rates of hypertension, diabetes mellitus, elevated cholesterol, physical inactivity, overweight, and current smoking (2, 4). Moreover, racial and social differences in cardiovascular outcomes may be related to lifestyle factors and central obesity (5). With respect to hypertension, frequently cited disparities include an earlier age of onset, greater impairment, and worse prognosis among AAs compared to European Americans (EAs) (6). Similar trends are noted for stroke and diabetes with incidence and mortality rates nearly twice as high for type II diabetes in AAs compared to EAs (7). Given the burden in dollars, lives, and quality of life, research addressing socio-ethnic cardiovascular differences is an essential component in the advancement of efforts (i.e., prevention and intervention) aimed toward attenuating these disparities.

Altered or dysregulated autonomic nervous system (ANS) functioning is one posited mechanism underlying increased CVD risk and outcomes such as hypertension, diabetes and stroke (8). Both cross-sectional and longitudinal studies suggest that autonomic imbalance in the direction of relatively high sympathetic activity and relatively low parasympathetic activity is associated with risk for a wide range of diseases, disorders, and syndromes as well as all-cause mortality (17). According to this view, parasympathetic cardiac (i.e. vagal) activity decreases significantly throughout the lifespan while sympathetic drive increases both centrally (i.e. cardiac) and peripherally (9-11). Importantly, several recent reviews suggest that low vagally-mediated heart rate variability (HRV) — the variation in timing between consecutive heartbeats on the order of milliseconds — is associated with all-cause mortality and increased morbidity from a host of risk factors including total and low-density cholesterol, smoking, obesity, age and positive family history of CVD (8, 13-17). In clinical applications, HRV has been used to predict risk of sudden death after myocardial infarction (19), diabetic neuropathy (20) and hypertension onset (21).

Critically, the mechanisms underlying ethnic disparities in cardiovascular risk are currently not well understood. Given the greater cardiovascular disease burden of AAs and the evidence that decreased vagally-mediated HRV is associated with increased risk, one might expect that a preponderance of research would find that AAs have lower vagally-mediated HRV compared to EAs. However, data from several studies suggests that AAs exhibit *higher* tonic HRV compared to EAs (22-29). For instance, Liao and colleagues (22) examined 2-minute supine, resting HRV recordings in a sample of 1,984 individuals from the Atherosclerotic Risk in Communities study and found higher levels of high frequency (HF) HRV and lower levels of low frequency (LF) HRV in AAs compared to EAs, adjusting

for age and gender. Similarly, Ohira et al. (30) examined 5-minute resting HRV data from 6,652 participants in the Multi-Ethnic Study of Atherosclerosis and found that AAs had higher age- and gender-adjusted HRV compared to white, Hispanic, and Chinese participants. Replications of this effect have been found in postmenopausal women (31), healthy young adults (32, 33), adolescents (34-37), children (38) and infants (39). In addition, results from several twin studies have not only shown higher HRV in AAs (28, 34) but also demonstrated the stability of this pattern longitudinally (29). While large-scale studies have shown greater HRV in AAs, population or sample characteristics such as age, gender, health status, and medication use and study characteristics such as control for potential confounds and explicit testing of ethnic differences require meta-analytic techniques to examine their impact on the observed differences. Moreover, the finding of greater HRV in AAs is not universal and some authors have found lower HRV in AAs (40-43) or no effect of ethnicity (44). As vagally-mediated HRV is generally regarded as “cardio-protective” and high resting levels have been linked to several beneficial health outcomes (8, 17), the presence of higher HRV in AAs would suggest that they should be relatively buffered against cardiovascular risk and disease. That this is not the case requires further investigation.

Thus the purpose of the present systematic review and meta-analysis is to examine the available evidence for ethnic (specifically AA and EA) differences in vagally-mediated HRV, and importantly to assess population- and study-level covariates of this effect. To our knowledge, no prior systematic or meta-analytic reviews of such comparisons have been performed. An examination of the factors that contribute to ethnic differences in resting HRV may have implications for our understanding of differential cardiovascular disease risk as well as for prevention and treatment.

## Methods

### Literature Search

Cochrane databases were searched to ensure that a similar review had not been previously published. No review to date has been published on the specific topic of race or ethnic differences in HRV. A systematic search of the literature was performed using the electronic databases *PubMed* and *PSYINDEX*. For search terms and filters applied see the Appendix. The database search was conducted between November 2009 and September 2011 with an update and final search in June 2014. Data were collected and extracted by three independent reviewers. Where disagreement arose, reviewers consulted until agreement was reached. Retrieved records were initially screened by title plus abstract.

### Screening of abstracts

Abstracts of studies that reported an (A) empirical investigation (i.e. excluding reviews, meta-analysis, and single case studies) in (B) healthy humans (excluding animal studies, and studies examining solely in-patient or diseased samples), reporting (C) recordings of HRV in (D) AAs and EAs, were considered potentially eligible for inclusion and retrieved in full-text. No restrictions were made for language, age range, or study design. Healthy samples and samples containing proportions of unhealthy individuals, defined as having some

moderate disease risk or burden (e.g., hypertension) were included for review. Samples reporting no or some medication use were also included for review.

### Screening of full-texts

Full-texts that did not report at least one resting, vagally-mediated HRV index (see below) in humans, that did not report results by AA and EA ethnicity, that examined solely in-patient or diseased samples, that reported from completely overlapping study samples, or that did not provide sufficient quantitative data were excluded from review. Where longitudinal or pre-post data were reported, only the baseline resting HRV was included to minimize confounding by experimental manipulation and conflation of effect size estimates. Where multiple citations provided data from overlapping samples, only the citation that contained the most information relevant to covariate testing (e.g., stratification by age and gender) was retained. Authors who reported baseline HRV by ethnicity but who did not report sufficient quantitative data (e.g., only a graphical display) were contacted for necessary quantitative information to derive effect size estimates and confidence limits. Furthermore, authors with potential access to data of interest (i.e. reporting a sample including AAs and EAs, and HRV but no analysis of ethnic differences) were contacted. Finally, in addition to the electronic search of databases a hand search was conducted, screening the reference lists of the included studies and various other sources (i.e. Google, Google scholar).

### Selection of data

Guidelines from the Task Force of the European Society of Cardiology and the North American Society of Pacing and Electrophysiology [Task Force] (45) were used to define the HRV measurements included for review. Time domain indices are derived directly from the RR interval series and generally measure the variability contained therein; whereas frequency domain measures are derived via spectral analytic techniques (i.e. Fast Fourier Transform (FFT) or Autoregressive (AR) algorithm) applied to the RR interval series with the high frequency (HF) component thought to reflect primarily vagal cardiac modulation. Studies that reported respiratory sinus arrhythmia (RSA), root-mean-square successive RR-interval difference (RMSSD); mean successive difference (MSD); percentage of successive normal to normal intervals that differ by more than 50 milliseconds (pNN50); or any spectral measure in the high frequency (HF) range of 0.15 – 0.14 Hz (natural log transform (lnHF), normalized (HFnu) or absolute power (absHF)) were included for review. In addition, only studies containing short-term measures (i.e., < 25 minutes) of HRV were considered. It is noted that guidelines for the measurement of HRV suggest that spectral analysis of 24-hour HRV (where spectral estimates are calculated over long data epochs that are not likely to be stationary) may not accurately reflect autonomic modulation, which may be better captured by estimates based on shorter data epochs (45). Therefore studies based on these longer estimates or where the data epoch was not clearly stated were excluded. Where citations reported multiple vagally-mediated HRV indices, a hierarchical inclusion was implemented to prevent conflation of effect size estimates as follows: HF power only, next RSA only, next RMSSD only, next MSD only, or else pNN50 only.

## Covariates

The exploration of covariates for analysis was of interest in the present review and the following four population level and two study level covariates were documented: *age*, *gender*, *health status of samples*, *use of medication*, *statistical adjustment for baseline confounds*, and the implementation of a *statistical test* of ethnic differences in HRV. Covariates were contrasted as follows: male *versus* female *versus* mixed sample, all healthy sample *versus* some proportion unhealthy, no medication use *versus* some medication use, statistical adjustment *versus* no adjustment for potential confounds, and statistical test performed *versus* no statistical test of ethnic differences in HRV. The age covariate was coded and analyzed as infant (< 2 years), youth (2 to 17 years), adult (18 to 50 years), and older adult (>50 years).

## Quantitative Analysis

True effect estimates were computed as adjusted standardized mean differences (Hedges  $g$ ) and combined with inverse variance weights using a mixed effects model with restricted maximum likelihood estimation (46-48).

The mixed effects approach assumes heterogeneity between studies as do random effects models; however, the total heterogeneity in the mixed effects model also includes *residual* heterogeneity not accounted for by covariates (49). The aim of a mixed effects model is to estimate the degree of influence of covariates on the point and interval estimates of effect size (49); a mixed effects model was thus the most appropriate for the exploration of covariation of ethnic differences in HRV by age, gender, healthy status, medication use, the implementation of statistical test, and statistical adjustment for baseline confounds. Various estimators for effect size and residual heterogeneity have been frequently used and published, including the Hedges and Olkin (47) as well as DerSimonian and Laird (50) estimators. However, these estimators may yield biased estimation of between-study heterogeneity and narrower effect size interval estimates (46, 51). Restricted maximum likelihood estimation (REML) addresses biased underestimation of residual heterogeneity, is of comparable efficiency, and is generally recommended (52, 53). Effect size and heterogeneity estimates are achieved iteratively through REML and this procedure was used in the present analyses. Each covariate was tested using meta-regression with a single covariate at a time (48), in line with a published meta-analysis of HRV variables (54). Heterogeneity was tested with the standard  $I^2$  index (55). Bias was examined using a funnel plot of effect size against standard error for asymmetry as well as Egger's regression test (56). Meta-analytic and meta-regression computations were performed using the **metafor** package in *R* (49) in conjunction with *OpenMetaAnalyst* software (57).

## Results

### Retrieved Literature

The search yielded 330 citations, of which 312 were screened by abstract and title after duplicate removal. Of these, 255 studies were excluded based on non-human samples ( $n = 2$ ), clinical samples ( $n = 21$ ), no HRV reported ( $n = 55$ ), no comparison between AA and EA ethnicities ( $n = 146$ ), and other criteria as depicted in Figure 1. The remaining 51 citations

were screened by full text. Twenty-three studies were excluded due to overlapping samples ( $n = 6$ ), insufficient data ( $n = 9$ ), the inclusion of less than 3% AA sample ( $n = 3$ ), and the use of spectral estimates on the entire 24-hour EKG series or non-stationary epochs (i.e., not strictly at rest;  $n = 6$ ). In 16 cases authors of studies were contacted and studies were excluded due to contact with authors who did not respond ( $n = 3$ ) or who responded but could not provide sufficient information in time ( $n = 13$ ). The final inclusion for quantitative synthesis comprised 17 studies involving 11,162 participants and  $k = 27$  effect sizes (see Table 1).

### Study Characteristics

Six of the 17 citations yielded multiple effect size values with HRV stratified independently by age, gender, or both (see Table 1). Of the 27 effect size values, 12 were among men only, ten were among women only, and five involved both sex groups. The most frequent age group reported was among adults (age 18 to 50 years; 40%), followed by youth (age 2 to 17 years; 33%), older adults (> 50 years; 22%), and one study reported ethnic differences in 12-month-old infants (39). The majority of effect sizes involved only healthy samples (63%), while the remainder included participants in their samples with some disease burden or risk factor (e.g., hypertension, diabetes; 37%). These latter effect sizes were predominantly derived from large-scale studies that included both healthy and unhealthy participants (22, 30). The percentage of effect sizes from samples reporting no medication use (63%) or some medication use (37%) was identical to that of health status.

Only reports of resting HRV reflecting short-term, predominantly parasympathetic activity were included for review; the majority of effect sizes were computed from HF power (67%), followed by MSD (15%), RMSSD (11%), and RSA (7%). Notably, a majority of the studies (82%) reported ethnic differences in potentially confounding baseline variables such as systolic blood pressure, body mass index, or socio-economic status, while only one study reported no significant baseline differences (40). In contrast, only a minority of studies ( $n = 5$ ; 29%) statistically adjusted for such variables when reporting baseline HRV. Lastly, the majority of studies ( $n = 12$ ; 70%) reported the implementation of some statistical test of ethnic differences in HRV, while the remainder reported baseline differences without statistical testing. Please refer to Table 1 for a summary of study characteristics.

### Ethnic Differences in Resting Heart Rate Variability

Meta-analyses revealed a sizeable and significant effect of ethnicity on HRV (Hedges'  $g = 0.93$ ; 95% CI (0.25, 1.62);  $k = 27$ ) suggesting higher vagal activity in AAs compared to EAs (see Figure 2; positive effect estimates reflect higher HRV in AAs). Two effect-size estimates representing 129 AAs and 380 EAs showed significantly lower HRV in AAs. Twelve effect-size estimates representing 944 AAs and 965 EAs were not significant. Thirteen effect-size estimates representing 3,362 AAs and 5,382 EAs showed higher HRV in AAs (see Figure 2). Significant heterogeneity across all true effects was found ( $I^2 = 99\%$ ,  $p < 0.001$ ), while the Egger's test for publication bias was significant ( $p = 0.013$ ) and a visual examination of the funnel plot for asymmetry suggested publication or other sources of bias (see Figure 3).

## Covariate Meta-Regression

Meta-regression coefficients and confidence limits for each tested covariate are reported in Table 2. Significant covariates were age ( $\beta = 0.97$ ,  $p = 0.009$ ) and the statistical adjustment of baseline confounds ( $\beta = 1.81$ ,  $p = 0.003$ ). Specifically, AAs showed significantly higher HRV among youth ( $g = 0.346$ ; 95% CI (0.220, 0.473);  $k = 9$ ) and among older adults ( $g = 2.853$ ; 95% CI (1.072, 4.635);  $k = 6$ ), and whereas the effect was not significant in adults ( $g = 0.405$ ; 95% CI (-0.633, 1.444);  $k = 11$ ) the average effect size was larger than for the youths and the confidence intervals showed significant overlap with the other age groups (see Supplemental Digital Content 1). Too few studies in infants ( $k = 1$ ) prevent firm conclusions in this age group. Studies that made statistical adjustments for baseline confounds when reporting HRV showed a much stronger effect for higher HRV in AAs ( $g = 2.08$ ; 95% CI (0.46, 3.69);  $k = 10$ ) compared to those that did not adjust for confounds ( $g = 0.27$ ; 95% CI (0.09, 0.45);  $k = 17$ ). However, both effects were significant and in the same direction of higher HRV for AAs.

Health status and medication use were also significant covariates. The studies included within these subgroups were coincidentally identical and so were their respective parameters ( $\beta$ s = 1.89,  $p$ 's = 0.002). Studies including some unhealthy populations who used medication showed a larger effect of higher HRV in AAs but with wider confidence limits ( $g = 2.12$ ; 95% CI (0.53, 3.72);  $k = 10$ ) compared to studies incorporating only healthy samples that did not report any medication use ( $g = 0.23$ ; 95% CI (0.06, 0.40);  $k = 17$ ). Results from partly unhealthy samples may reflect contributions by several of the largest studies included for review (see Table 1). A sensitivity analysis was performed with the two largest studies removed ( $n > 1000$ , each) (30, 57) to examine whether this finding was an artifact of large sample size. The effect estimate remained significant and large after removal ( $g = 2.40$ ; 95% CI (0.43, 4.36);  $k = 8$ ), although the remaining studies within this subgroup also comprised large samples.

Gender and statistically testing baseline ethnic differences in HRV were not significant covariates in the model ( $p$ 's = 0.095; 0.190, respectively). Subgroup analysis revealed that female-only samples showed significantly higher HRV in AAs, ( $g = 1.78$ ; 95% CI (0.33, 3.23);  $k = 10$ ), while the effect was not significant for male or mixed gender samples. However, again the confidence intervals among these groups showed a high degree to overlap. Moreover, two large studies (23, 30) adjusted for gender. When excluding these studies in sensitivity analyses for gender subgroups, the lack of significance remained (data not shown). Similarly, studies that implemented statistical testing showed significantly greater HRV in AAs ( $g = 1.19$ ; 95% CI (0.30, 2.08);  $k = 20$ ), while the effect was not significant among studies that did not statistically test baseline differences. Again however the estimates were in the same direction of higher HRV in AAs. Forest plots and meta-regression plots for all covariate subgroups are available in Supplemental Digital Content 1.

## Discussion

In the present systematic-review and meta-analysis, we quantitatively synthesized the literature on ethnic differences in resting vagally-mediated heart rate variability (HRV), a marker linked to cardiovascular outcomes, better overall health, and the capacity to adapt to

shifting environmental demands. The synthesized literature suggests that African Americans (AAs) show higher resting HRV compared to European Americans (EAs), and this effect of nearly a full standard deviation across all studies (Hedges'  $g = 0.93$ ; 95% CI (0.25, 1.62);  $k = 27$ ), though moderated by age, health status, medication use, and study methodology, was consistent across these population and study based covariates. These findings suggest that HRV as a risk factor may not carry the same information value for AAs as it does for EAs. We will return to this point later.

One of the most consistent findings in the HRV literature is that vagally-mediated HRV decreases with increasing age (8, 17). Despite this fact, we found that AAs showed higher HRV than EAs at all age levels from infants to the elderly. Therefore it is unlikely that some age-related factor such as a healthy survivor effect could completely account for our results. Similarly, the effects of medication have been consistently shown to influence HRV levels (60). Again, however, the ethnic difference we report remained robust, whether or not the participants were unhealthy and thus medicated or healthy and un-medicated. In addition, study level covariates such as statistical control of potential confounders and explicit testing of ethnic differences did not alter the finding that AAs showed higher levels of HRV than EAs. Whereas the examined covariates did not alter our findings, it remains possible that other unexamined covariates may have affected the results. Future analyses will be needed to address that possibility.

Given that the covariate analysis did not find a systematic source for the reported ethnic difference, the natural question is what could the source be? In addition to the possible unexamined covariates, our group has investigated two other potential sources for this ethnic difference. One potential source is genetic differences between AAs and EAs. In one study designed to assess the genetic contribution to HRV using behavioral genetics methodology it was shown that AA adolescents had higher resting vagally mediated HRV than similarly aged EAs and that HRV was highly heritable and but there was no evidence for an ethnic difference in heritability estimates (34). A related study (28) found similar results when HRV was assessed during both rest and in response to a psychological stressor. Whereas these studies did not find any differences in heritability of HRV measures it does not completely rule out the possibility of ethnic differences based on genetics but it does suggest that genetics is not an obvious source for this difference.

Another potential source for the observed greater HRV in AAs may be ethnic differences in neural control of the heart. Whereas this is an extremely under investigated area we have recently reported ethnic differences in the association between resting brain perfusion measured using pulsed arterial spin labeling (PASL) and resting HRV (61). There were several differences noted between AAs and EAs. First, greater whole brain perfusion was positively associated with vagally mediated HRV in EAs but was uncorrelated with HRV in AAs. Second, and perhaps most importantly, regions of the anterior cingulate and the medial prefrontal cortex that are associated with emotional regulation and the assessment of threat and safety were negatively associated with HRV in AAs but uncorrelated with HRV in EAs. Specifically, we and others have found that successful emotion regulation is associated with both greater resting HRV as well as HRV increases during emotion regulation including reappraisal and suppression (62,63). In addition, research suggests that AAs often must



inhibit or suppress their anger in response to unfair treatment (25). Thus, the greater HRV in AAs may be related to their need to regulate their emotion responses to unfair treatment. This explanation for the present observed ethnic differences in HRV is highly speculative but given the paucity of research in ethnic differences in neural activity it represents a potentially fruitful area for brain-body research into health disparities.

### Strengths and Limitations

Our systematic search and meta-analytic synthesis of the literature bears a number of strengths, including quantitative rigor with respect to effect estimates as well as the unique exploration and testing of covariates with meta-regression. However, some limitations warrant mention. First, it should be noted that meta-regression is hypothesis generating and its results are not intended to be causally conclusive. The aims of our covariate analyses were to explore the role of potential population level and study level factors that might account for the observed ethnic differences. Whereas the finding of higher HRV in AAs was consistent and largely independent of these covariates, other potential covariates might still possibly be related to the current results. In addition, the iterative procedures and conclusions drawn from subgroup meta-analyses are limited when too few studies meet criteria for inclusion, for example in the age covariate with only one infant study included. Next, high heterogeneity was present as well as a positive test for bias. The presence of bias in meta-analysis warrants caution in the interpretation of results. However, it should be noted that the source of such bias is not conclusive, and asymmetry of the funnel plot does not accurately predict publication bias (64). For example, funnel plot asymmetry may reflect publication bias, high heterogeneity, methodological variation, and other factors (56). Upon examining the funnel plot, the largest effect sizes were not derived from smaller, imprecise studies but rather from large-scale studies (e.g. 22). This relatively high degree of heterogeneity may reflect the nature of our review question on ethnic differences—one that necessitates quasi-experimental designs that lend to greater heterogeneity across studies. Lastly, our review aims and exclusion criteria were specific to resting, vagally-mediated HRV among mostly healthy populations according to the Task Force guidelines (45). While this enhanced our inclusion consistency, it resulted in stringent exclusion of certain studies. For example, data were excluded from citations that reported spectral estimates on the entire 24-hour EKG series or from long-term recordings within the 24-hour period without specification of whether these data were derived from resting states. The problem of stationarity during long-term recordings is explicitly discussed in the Task Force guidelines and spectral estimates over long epochs are less reliable estimates of cardiac autonomic modulation (45). Some authors have contrarily espoused greater reliability and stability with spectral estimation over the entire 24-hour period and these papers were excluded (e.g., 41). Whereas studies over 24 hours allow for the estimation of circadian variation, this is only true when spectral estimates are derived from shorter, more likely stationary data epochs and the periods over which the shorter estimates are averaged are specified (65). Importantly, night time HRV measures, appropriately estimated, may be the best estimates of cardiac autonomic modulation and studies have shown night time estimates to be more closely associated with risk factors than other time periods (66,67).

## Future Directions

The present analyses suggest that low resting HRV may not represent the same risk for disease, disability, and mortality for AAs as it does for EAs. At first, given the strong evidence for low HRV as a risk factor for a wide range of diseases (8) this might seem to question low HRV as a risk factor. However before we reach this conclusion, we must first understand the nature of risk factors. Offord and Kraemer (68) have written informatively about risk factors and note several aspects of risk factors relevant to the present discussion. First, whereas risk factors should have certain characteristics such as preceding the outcome of interest and stratifying individuals in to high and low risk categories, risk factors may not exhibit these characteristics universally. That is, a risk factor may have different value at different points in the disease process or for different populations. This latter situation may be the case for HRV with respect to ethnic differences and health disparities. However, this situation, in which a high score for an ostensibly protective factor is found in an at risk group, is not necessarily uncommon. For example, researchers have noted that despite AAs having higher high-density lipoprotein (HDL) and lower triglycerides than EAs, AAs still have higher insulin resistance and greater death and disability from cardiovascular disease (69). These paradoxical findings have led some to suggest that a different pattern or different levels of risk factors be adopted for different ethnic groups at least with respect to the metabolic syndrome (69,70). The present results suggest that yet another risk factor may be differentially related in different groups to disease risk. It should be noted that similar differences in the relationship between risk factors and disease risk are widely noted with respect to gender differences (e.g., heart attack symptoms are different for women than for men).

Therefore, other mechanisms for the well-documented health disparities between AAs and EAs may warrant exploration. For example, chronically elevated vascular resistance has been implicated as one marker of heightened sympathetic activity in AAs. Several studies have reported exaggerated vasoconstriction and attenuated vasodilation in response to pharmacologic challenge (71-73) as well as associations of elevated vascular resistance with increased cardiac mass and left ventricle thickness in AAs (71). These and other findings have been recently summarized by Tehzarahada and colleagues (74), in which they note that differences in vascular activity exist between AAs and EAs and that these differences may contribute to the greater cardiovascular disease prevalence in AAs. Relatedly, blood pressure seems to be a much more important risk factor for AAs than for EAs in the metabolic syndrome profile (69,70).

The findings of higher tonic HRV in AAs raise the possibility that AAs may exhibit both higher vagally-mediated HRV and higher vascular resistance. At least one investigation has reported such a pattern: Dorr et al. (25) found that AA males exhibited higher tonic HRV and elevated basal total peripheral resistance compared to EAs. This pattern may represent something of a 'Cardiovascular Conundrum' as the potentially cardio-protective effects of HRV may be counteracted by chronically elevated vascular resistance. This could be evidence of impaired vasodilation in response to a vasodilatory stimulus as noted above (71, 74). Thus, in addition to replicating findings of higher HRV in AAs, future research should also consider the mechanisms that contribute to the regulation of both vagal tone and

vascular resistance. One candidate is the arterial baroreflex, which works to decrease blood pressure (BP) via an increase in cardiac parasympathetic outflow and inhibition of peripheral sympathetic activity (75). As the short-term (i.e. beat-to-beat) adjustments necessary to maintain, raise or lower arterial BP are largely reflexively governed, ethnic differences in baroreflex sensitivity may account for some portion of the observed between-group variation in tonic HRV.

Presently, few investigations have evaluated ethnic differences in tonic baroreflex sensitivity (BRS). Of these, most have reported no differences in BRS between hypertensive black Africans or African-Caribbeans and White Europeans (76, 77) and in young healthy EAs and AAs (78, 79), respectively. Two investigations have reported lower BRS in AAs (40, 80) while others have indicated that a positive family history of hypertension may be more predictive of BRS than ethnicity (81). As indicated by these inconsistent findings, as well as the heterogeneity of the studies reporting higher tonic HRV in AAs, additional research is needed. This might entail re-examination of existing large-scale and smaller datasets to further evaluate the reliability and magnitude of these differences as well as rigorous new investigations focused on at-risk individuals or those in early stages of hypertension. Thus, prospective studies might be particularly important in ascertaining whether the higher vascular resistance appears first, in which case the higher HRV may represent a type of compensatory response, or whether the higher HRV comes first. It may also be useful to track tonic HRV medically as an added component of routine triage typically conducted in community and private health centers. This approach could be especially fruitful in longitudinal designs and aid in identifying developmental factors as well as the influence of various acute and chronic conditions such as obesity and inflammation, both of which have been linked to decreased HRV (17).

## Conclusions

The results of the present meta-analysis suggest that healthy African Americans have greater resting, vagally-mediated heart rate variability compared to European Americans. These differences were found rather consistently across studies that differed in several population and study level covariates. Whereas the present study could not begin to address the potential source for these differences, genetic and neuroimaging studies may yield some insights. Finally, that HRV may represent a differential risk factor for EAs and for AAs adds to a growing list of seemingly paradoxical relationships between risk factor levels and disease burden. The further identification and examination of these paradoxical relationships may begin to increase our understanding of the persistent health disparities that continue to affect our nation's health.

## Supplementary Material

Refer to Web version on PubMed Central for supplementary material.

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## Appendix

Search strategy: The period of 1948 to 2014 was selected as the publication range for inclusion; PubMed syntax: (black OR African American OR ethnic OR race) AND (cardiac vagal OR HRV OR heart rate variability); active filters: Abstract available, Publication date: From 1948/01/01 to 2014/06/17, humans; Psyn dex syntax: (TX HRV OR TX heart rate variability OR TX cardiac vagal) AND (S3 AND S4); active filters: Publication Date: 1948-2014, humans

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## Glossary

<b>CVD</b>	cardiovascular disease
<b>ANS</b>	autonomic nervous system
<b>PNS</b>	parasympathetic nervous system
<b>SNS</b>	sympathetic nervous system
<b>HRV</b>	heart rate variability
<b>RSA</b>	respiratory sinus arrhythmia
<b>RMSSD</b>	root-mean-square successive RR-interval difference
<b>MSD</b>	mean successive difference
<b>pNN50</b>	percentage of successive normal to normal intervals that differ by more than 50 milliseconds
<b>HF</b>	high frequency power
<b>lnHF</b>	natural logarithmic transform high frequency power
<b>HFnu</b>	normalized high frequency power



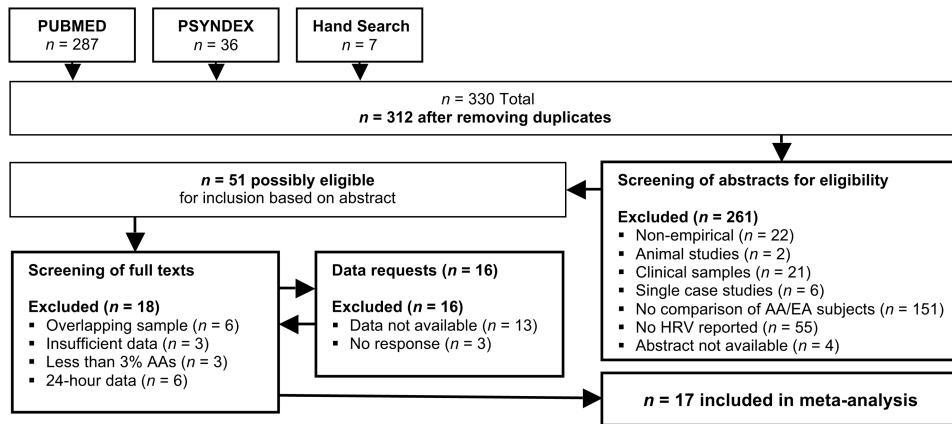
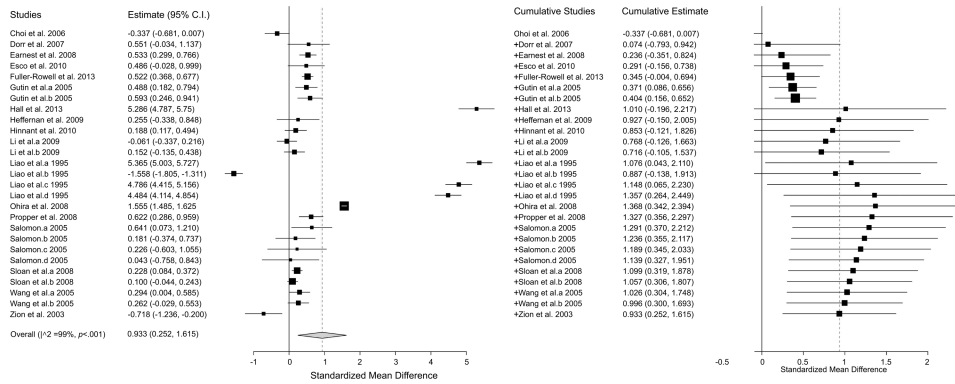


Figure 1. Systematic review flow chart



**Figure 2.** Forest plot of effect estimates (g) obtained from studies with adequate quantitative data (n = 19). Effects are grouped identically to Table 1 based on gender and recording length with boundaries between groupings indicated by a bold symbol enclosed in parenthesis (i.e. M for males). Bolded triangles represent the combined (i.e. across multiple HRV indices), weighted effect size for each study. Error bars represent 95% confidence intervals. Positive values indicate studies reporting higher HRV in African Americans.

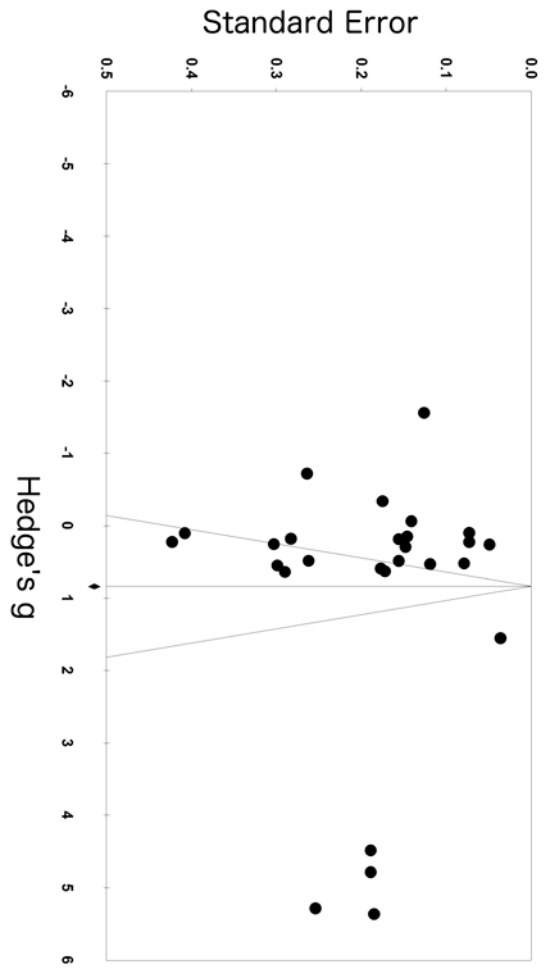


Figure 3. Funnel plot

Table 1

Summary of included literature.

Author	Year	n	AA	n	EA	Gender	Age M (yr)	Age Range	Health Status	Med. Use	HRV Index	Baseline Diff.	Stat. Adjust	Stat. Test	Record Length
Choi et al.	2006	57		78		Mixed	36.9	23 to 54	Healthy	None	logHF	1,2	No	Yes	3min
Dorr et al.	2007	21		26		Mixed	n/a	n/a	Healthy	None	RMSSD	2, 6	No	Yes	10min
Earnest et al.	2008	102		248		Female	57.5	45 to 75	J	Some	RMSSD	n/a	No	Yes	25min
Esco et al.	2010	30		30		Male	22.8	n/a	Healthy	None	HFnu	3,6	No	Yes	5min
Fuller-Rowell et al.	2013	204		833		Mixed	53.7	34 to 83	K	Some	logHF	4	No	Yes	11min
Gutin et al.a	2005	95		76		Female	16.2	n/a	Healthy	None	HFnu	1,2	No	Yes	10min
Gutin et al.b	2005	64		69		Male	16.2	14 to 18	Healthy	None	HFnu	1,2	No	Yes	10min
Hall et al.	2013	119		160		Female	51	46 to 57	J, K, M, N	Some	logHF	1,4,5,6	Yes	Yes	2min, night
Heffernan et al.	2009	22		22		Male	23	n/a	Healthy	None	HFnu	6	No	Yes	15min
Hinnant et al.	2010	65		113		Mixed	8.23	8 to 10	Healthy	None	pvRSA	4	No	Yes	3min
Li et al.a	2009	125		84		Female	23.1	15 to 39	Healthy	None	absHF	1,2,3	No	No	15min
Li et al.b	2009	85		105		Male	23.1	15 to 39	Healthy	None	absHF	1,2,3	No	No	15min
Liao et al.a	1995	150		423		Female	n/a	45 to 54	K,L,N	Some	logHF	1,2,3,5,6	Yes	Yes	2min
Liao et al.b	1995	97		351		Male	n/a	45 to 54	K,L,N	Some	logHF	1,2,3,5,6	Yes	Yes	2min
Liao et al.c	1995	114		359		Female	n/a	55 to 64	K,L,N	Some	logHF	1,2,3,5,6	Yes	Yes	2min
Liao et al.d	1995	79		411		Male	n/a	55 to 64	K,L,N	Some	logHF	1,2,3,5,6	Yes	Yes	2min
Ohira et al.	2008	1843		2250		Mixed	n/a	45 to 84	K,M,N,O	Some	RMSSD	6	Yes	Yes	5min
Propper et al.	2008	72		70		Mixed	12 mo.	12 mo.	Healthy	None	RSA	6	No	Yes	5min
Salomon.a	2005	25		25		Female	n/a	9 to 14	Healthy	None	MSD	n/a	No	No	3min
Salomon.b	2005	22		29		Male	n/a	9 to 14	Healthy	None	MSD	n/a	No	No	3min
Salomon.c	2005	9		15		Female	n/a	17 to 21	Healthy	None	MSD	n/a	No	No	3min
Salomon.d	2005	10		15		Male	n/a	17 to 21	Healthy	None	MSD	n/a	No	No	3min
Sloan et al.a	2008	421		336		Female	40	n/a	K,M,N	Some	absHF	1,2,3	Yes	Yes	10min
Sloan et al.b	2008	421		336		Male	40	n/a	K,M,N	Some	absHF	1,2,3	Yes	Yes	10min
Wang et al.a	2005	74		122		Female	16	n/a	Healthy	None	absHF	2,3,4,6	Yes	Yes	4min
Wang et al.b	2005	77		112		Male	16	n/a	Healthy	None	absHF	2,3,4,6	Yes	Yes	4min
Zion et al.	2003	32		29		Male	22.8	n/a	Healthy	None	logHF	None	No	Yes	5min

Note: The letters a, b, c, or d following author names indicate an independent effect size derived from non-overlapping stratification (e.g., by gender or age). For healthy status: J=overweight/obese; K=hypertension; L=atherosclerosis; M=smoking; N=diabetes; O=high cholesterol. For baseline differences: 1=body mass index; 2=systolic blood pressure; 3=diastolic blood pressure; 4=socio-economic

status; 5=smoking; 6=other. HF = high frequency power; absHF = absolute high frequency power; logHF = natural log HF; HFnu = high frequency normalized units; RMSSD = root-mean-square successive RR-interval difference; RSA = respiratory sinus arrhythmia; MSD = mean successive difference; AA = African American; EA = European American; Med.=Medication; Stat.=Statistical.

Table 2

## Meta-regression covariate results

Covariate	$\beta$	SE $\beta$	95% CI Lower	95% CI Upper	p-value
Age	0.97	0.37	0.24	1.70	0.009
Gender	-0.75	0.45	-1.63	0.13	0.095
Health Status	1.89	0.61	0.70	3.07	0.002
Medication Use	1.89	0.61	0.70	3.07	0.002
Statistical Adjustment	1.81	0.62	0.60	3.01	0.003
Statistical Test	0.99	0.19	-0.49	2.48	0.190