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Sexual Orientation Differences in the Association between Physical Activity and Allostatic Load: Results from the National Health And Nutrition Examination Study

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SEXUAL ORIENTATION DIFFERENCES IN THE ASSOCIATION BETWEEN PHYSICAL ACTIVITY AND ALLOSTATIC LOAD: RESULTS FROM THE NATIONAL HEALTH AND NUTRITION EXAMINATION STUDY

A Thesis Presented

by

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ABSTRACT

SEXUAL ORIENTATION DIFFERENCES IN THE ASSOCIATION BETWEEN PHYSICAL ACTIVITY AND ALLOSTATIC LOAD: RESULTS FROM THE NATIONAL HEALTH AND NUTRITION EXAMINATION STUDY

MAY 2023

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Higher levels of allostatic load (AL), a composite measure of the impact of chronic stress on the body, are found among socially marginalized groups compared to privileged groups. AL is associated with premature aging and death, as well as a variety of chronic health conditions that impact quality of life. Effects of AL may be offset by physical activity (PA). Queer populations (including those who identify as lesbian, gay, or bisexual) may be at risk for elevated AL due to repeated exposure to discrimination in the form of sexual minority stress. There is mixed literature on sexual orientation differences in PA and research on AL among queer populations is limited. This study describes sexual orientation differences in the 1) prevalence of PA and mean AL levels and 2) association between PA and AL. Data from the 2001-2015 National Health and Nutrition Examination Survey were used to fit sex-stratified linear regression models assessing sexual orientation (heterosexual, gay/lesbian, bisexual, and heterosexual with same-sex experience) differences as well as sexual orientation-specific associations in PA and AL. AL was assessed using 8 biomarkers, while PA was assessed using metabolic equivalent of task (MET)-hours/week calculated from the Global Physical Activity

Questionnaire. Models were adjusted for race/ethnicity, income, education, relationship status, veteran status, and citizenship status. Overall, heterosexual adults reported more PA than their same-sex queer counterparts. Gay men had lower (0.8), while bisexual men had higher AL scores (1.9) than heterosexual men (1.2). Among women, AL score was similar across sexual orientation groups. Overall, more PA was associated with lower AL scores among men and women ($\beta_{adjusted}$ = -0.00508, $p<0.00$ and $\beta_{adjusted}$=-0.00505, $p<0.00$, respectively). The association between PA and AL was not statistically significant across sexual orientation groups among men. However, more PA was significantly associated with lower AL among heterosexual women ($\beta_{unadjusted}$ =–0.00934, $p<0.00$), gay/lesbian ($\beta_{unadjusted}$ =–0.03269, $p=0.04$), and heterosexual women with same-sex experience ($\beta_{unadjusted}$ =-0.01059, $p=0.02$). After adjusting for covariates the association was no longer statistically significant. Consistent with previous work, PA was inversely associated with AL score. PA may be an important modifiable behavior to mitigate some sexual orientation disparities in health.

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CHAPTER 1
BACKGROUND

A component of queer health research explores the health disparities experienced by sexual minoritized populations, such as those who identify as lesbian, gay, or bisexual (LGB). Queer populations have been shown to experience more poor overall health and a higher prevalence of major chronic diseases such as cardiovascular disease and diabetes than their heterosexual counterparts.[1–3] For example, a large body of research using population-based surveillance data has consistently found that lesbian and bisexual women as well as gay and bisexual men are more likely to have poor self-reported health than their heterosexual counterparts.[2,4–8] Additionally, evidence has suggested that lesbian and bisexual women are more likely to be overweight or obese as compared to heterosexual women.[2,4] Among men, gay men are more likely to have asthma[2,9] and cancer,[10,11] but be less likely to be overweight or obese as compared to heterosexual men.[2,10] Based on this growing body of literature documenting health disparities experienced by queer populations, these groups have been identified as a priority population in the *Healthy People 2030* national health objectives.[12]

The minority stress model provides a potential explanation, at least in part, for these health disparities based on sexual orientation. The minority stress model posits that exposure to chronic stress due to the prejudice, stigma, and discrimination experienced by queer people is an added layer of stress that can negatively affect health.[13] Multiple pathways have been proposed that connect minority stress to health outcomes including changes to physiologic stress responses.[1,14] This pathway can be evaluated through the fundamental concept of allostatic load.

Allostatic load is the cumulative “wear and tear” of chronic, or prolonged, stress on the body. It refers to the physiological effects of repetitive stress and is measured primarily through biomarkers associated with the neuroendocrine, cardiovascular, immune, and metabolic systems.[15] Because allostatic load is an aggregated measure, it can provide a more comprehensive understanding of stress's impact on chronic disease and mortality risk.[16,17] Increased allostatic load, an indicator of physiologic dysregulation, may serve as a precursor for a number of chronic diseases.

Allostatic load is part of the allostasis model, which was proposed to expand upon the concept of homeostasis, the state of steady internal conditions that living beings maintain.[18] Instead of responding to environmental changes to maintain equilibrium, allostasis suggests efficient predictive regulation of bodily functions like blood pressure and insulin.[19] In other words, allostasis predicts needs while homeostasis responds to needs. Allostatic overload, then, occurs when the limits of physiologic adaptation are exceeded. Elevated allostatic load levels are associated with higher rates of adverse health outcomes such as cardiovascular disease, diabetes, and all-cause mortality.[19,20]

McEwen illustrates four conditions that can elevate allostatic load.[18] The first condition represents frequent instances of multiple novel stressors, such as someone who has experienced numerous instances of childhood abuse. Among queer populations, the greater prevalence of adverse childhood experiences compared to heterosexual populations may contribute to differences in allostatic load.[21–23] Those with the second condition, lack of adaptation to a repeated stressor, may not experience excessive stress, but their body fails to adjust their hormonal stress response. For example, someone with test anxiety may not experience exorbitant stress, but the inability to acclimatize leads to undue exposure to stress. Indeed, anxiety as well as depression and poor mental health have been consistently shown to be more prevalent among queer populations than heterosexual populations.[24–27] The third condition is the failure to "turn off' stress responses after encountering a stressor, resulting in a prolonged physiologic response. This may happen when individuals with hypertension experience prolonged elevated blood pressure after a stressful work day. Similarly, trait rumination has been associated with elevated evening cortisol levels in sexual minority adults, suggesting a similar prolonged stress response that impairs expected cortisol rhythms.[28] Lastly, an inadequate stress response may lead to compensatory activity of other allostatic systems, such as inflammatory cytokines.[18] Literature exploring this fourth type of allostatic load is limited, especially among sexual minority populations.

Drawing on work on allostatic load with regard to health disparities based on race/ethnicity as well as socioeconomic (SES) levels,[12,13,16,17,20,29] allostatic load scores are generally higher among socially minoritized and disadvantaged groups. For example, using allostatic load biomarkers, Crimmins et al. found that people living in poverty age earlier than non-poor Americans— someone in their 40s living in or near poverty was observed to have biological risk levels similar to someone in their 60s at higher socioeconomic status.[20] Duru et al. found that Black men had higher mean allostatic load scores compared to White men (2.5 vs 2.1, $p<.01$) and Black women had higher mean allostatic load scores compared to White women (2.5 vs 1.9, $p< .01$).[29] Geronimus et al. found that, across age groups, White men and White women had similar mean allostatic load scores until the oldest age group (55-64 years), while, regardless of age, Black women consistently had higher mean allostatic load scores than Black men.[12] Moreover, among those aged 35-64, the odds of having a high allostatic load score were statistically significantly higher ($p<.01$) among Black people as compared to White people (1.95 for 35–44 years, 1.89 for 45–54, and 2.31 for 55–64).[12] Similarly, poor participants— defined as those with a poverty-income ratio of less than or equal to 1.85 of the federal poverty threshold—

had a higher allostatic load score than affluent participants. However, when examining allostatic load scores by both SES and race, affluent Black participants had higher allostatic load scores than poor White participants.[12] This finding suggests that allostatic load may explain health disparities that are not explained by poverty or access to healthcare.

To further shed light on mechanisms through which discrimination and stress may impact allostatic load, the weathering hypothesis, initially formulated by Geronimus within the scope of maternal health, posits that the accumulation of cultural, social and economic disadvantages may result in early health deterioration among Black women as compared to their non-Hispanic, White counterparts.[12] Using allostatic load as a potential measure for assessing the weathering hypothesis, racial differences in allostatic load may be explained by stressors that disproportionately affect Black people, namely structural, interpersonal, and perceived racism.[29,30] Repeated experiences of prejudice can cause physical stress responses, such as elevated cortisol or blood pressure levels, that accrue over time. In addition, the systemic implications of racism and discrimination often abandons Black people to higher rates of poverty, which has also been associated with higher allostatic load levels. A corollary to the weathering hypothesis is the prolonged effects of physical and social exposures that accumulate over one's lifetime.[31,32] Thus, weathering likely has an impact not only in early health deterioration, but also on later life mortality. As such, allostatic load, a measure of the accumulation of biological burden over one's lifetime, likely captures some of the health impacts of discrimination on individual body systems.[33]

To an extent, the weathering hypothesis is potentially applicable to queer populations as well. However, the length of time one is susceptible to weathering as a queer person is potentially contingent on individual sexual orientation development trajectories as well as time identifying or identified as queer. This contrasts with the experiences of racially/ethnically marginalized groups, who experience disadvantage through historical trauma and social selection that negatively impacts their health even in utero. Additionally, while the weathering hypothesis may incorporate transgenerational trauma that affects communities of color (slavery, segregation, etc.)[12], queer populations likely do not experience these intergenerational effects on the same scale. Nonetheless, the biologic pathways of the weathering hypothesis may be similar, regardless of the nature of the discrimination. Although the social structures that perpetuate racism and homophobia differ in terms of historical context and lifetime biologic impact, it is expected that stress, in the form of either racism or homophobia, would trigger similar physiologic responses.

Research on allostatic load among queer populations is sparse. Only one study using population-based data has examined sexual orientation differences in allostatic load.[34] Mays et al. (2018) found that among men, sexual orientation was associated with significant differences in allostatic load scores ($p<0.05$). Gay men had significantly lower allostatic load scores (adjusted $\beta = -0.22$), while bisexual men had higher allostatic load scores (adjusted $\beta = 0.25$) than heterosexual men. No significant differences in allostatic load were found among women (adjusted Wald $F = 0.51$, $p = 0.67$).

Findings from this study suggests that the minority stress model may not be accurately conceptualizing how discrimination based on sexual orientation may impact physiologic health. This discrepancy could be because differences in the accumulation of sexual minority stress over one's life time varies substantially compared to experiences of racism. In other words, the duration of risk accumulation due to homophobia may on average be less prolonged than the accumulation of risk due to racism. The accumulation of biological burden among queer populations, due to exposure to discrimination, depends on the length of time one is “out” or identified as queer. Because of the realities of a race-conscious society (i.e., inescapable structural racism) the resulting effects of chronic stress among queer populations may be less pervasive than the effects of those subject to racism. The differences in duration, and intensity, or experienced discrimination may explain why research has shown greater allostatic load levels among Black people compared to White people, but mixed results among queer people compared to heterosexual people.

Existing literature on interventions that may lower allostatic load spans multiple health behaviors and risk factors for high allostatic load. Soltani et al. (2018) assessed the effects of an eight-week diet quality intervention on markers of physiological and psychological stress. There was no statistically significant change in allostatic load after the eight-week intervention (p=0.79). However, this study was conducted over a relatively short timeframe with a small sample size (n=42).[35] Carroll et al. (2015) assessed if improving sleep quality in older adults with insomnia is associated with lower allostatic load. The cognitive behavioral therapy (p=0.001) and tai chi (p=0.04) intervention groups had lower allostatic load scores after one-year follow-up compared to the sleep seminar only control group.[36]

Physical activity is another health behavior that may be critical to reducing allostatic load.[16,17,19,37] Exercise as a form of acute stress management is well researched.[38–42] Additionally, physical activity is associated with benefits in numerous biomarkers associated with allostatic load, such as improvements in cardiovascular function, blood pressure, and cholesterol levels.[43–47] Regular physical activity has also been shown to decrease insulin sensitivity and inflammatory markers like C-reactive protein.[39,48–50] A six-month exercise intervention study found statistically significantly lower allostatic load levels among metabolically unhealthy postmenopausal Black women at increased risk for breast cancer in two different intervention groups as compared to the control groups (p=0.023 and p=0.035).[51]

Existing research has primarily focused on the association between physical activity and allostatic load among marginalized racial and ethnic groups.[17,37] Gay et al. (2015) investigated the association between meeting physical activity guidelines and allostatic load in Mexican-Americans and found that those that met physical activity guidelines were at significantly lower risk of high allostatic load scores (OR = 0.50, 95%CI 0.30, 0.84) compared to those not meeting the guidelines. Compared to sedentary participants, those with high activity levels had significantly decreased risk of total allostatic load (OR = 0.32, 95%CI 0.17, 0.62).[37] Copeland et al. (2021) examined the effects of physical activity on the relationship between racial discrimination and allostatic load among Indigenous adults.[17] Among those that were insufficiently active, a one point increase in racial discrimination resulted in a 0.35 point increase in allostatic load (range=0-7). Regular physical activity attenuated the relationship between racial discrimination and allostatic load in this study. These findings suggest that physical activity may confer some resilience that can attenuate allostatic load among minoritized populations, such as LGB populations, and may reduce the lifelong accumulation of allostatic load from continuous exposure to discrimination and stigma. However, research on the association of physical activity on allostatic load has not been done among queer populations.

Among men and women, current literature using population-based studies have resulted in inconsistent findings on the association between sexual orientation and physical activity.[2,52–57,57,58] VanKim et al. and Lindström & Rosvall found that lesbian and bisexual women reported engaging in more physical activity as compared to heterosexual women,[55,56] yet Caceres et al found no sexual orientation differences in physical activity among women.[57] Fredriksen-Goldsen et al and Caceres et al (2019) found no statistically significant difference in physical activity levels between gay and bisexual men and heterosexual men.[2,58,59] Lindström & Rosvall found that bisexual men and women reported less leisure-time physical activity as compared to heterosexual men and women.[56] Caceres et al (2018b), Fricke et al., and Frederick et al. found no associations between sexual orientation identity and meeting physical activity recommendations among men and women.[59–61] Many of these inconsistencies are likely due to the lack of a standardized measurement and operationalization of physical activity. Regardless, physical activity is an important health behavior with numerous health benefits (such as lower allostatic load), and it is unclear if and how these benefits may extend to queer populations.

This study aims to begin identifying potential strategies that may help queer populations' cope with the physiologic impact of discrimination and stigma. Based on the gaps identified in the existing research, this study will describe sexual orientation differences in 1) the prevalence of physical activity and mean allostatic load scores and 2) the association between physical activity and allostatic load. As an exploratory aim, we will also explore potential sexual orientation-specific age differences in physical activity and allostatic load.

CHAPTER 2
METHODS

Study Population

Data are from the 2001-2015 National Health and Nutrition Examination Survey (NHANES), a population-based health survey comprised of interviews and physical examinations. Participants answer demographic, socioeconomic, dietary, and health-related questions; the physical examination includes medical and physiologic measurements as well as laboratory tests.[62] NHANES is nationally representative sample of the civilian, noninstitutionalized US population. Beginning in 2001, NHANES began collecting information on sexual orientation identity for individuals aged 20-59 years. Sexual behavior data was not released to the public in the 2017-March 2020 Pre-Pandemic combined cycle.[63] We limited the current analysis to those between the ages of 20 and 59 (n=43,466), as this group is consistently administered the sexual behavior module across all survey years. From this group, we excluded those who were pregnant at the time of NHANES examination (n=1,798) because their biomarkers may be affected by their pregnancy. Among those that completed the sexual behavior module (n=29,561), we excluded those who responded, "Something else", "Not sure", "Don't know", or refused to answer (n=667) and could not be coded for sexual orientation. After exclusions, 28,894 participants remained in the analytic sample.

Sexual Orientation

NHANES assesses sexual orientation identity using the question "Which of the following best represents how you think of yourself?" Response options are "Heterosexual or straight", "Homosexual or gay/lesbian", "Bisexual", "Something else", and "Not sure". For this analysis, males were categorized as heterosexual (n=14,498), gay (n=336), bisexual (n=195), or heterosexual with same-sex experience (n=286) if they identified as heterosexual but reported at least one lifetime same-sex partner; females were categorized as heterosexual (n=12,389), lesbian/gay (n=179), bisexual (n=452), or heterosexual with same-sex experience (n=559) if they identified as heterosexual but reported at least one lifetime same-sex partner.

Physical Activity

NHANES cycles 2001-2005 asked about daily activities, leisure time activities, and sedentary activities. Respondents were asked to recall any moderate or vigorous PA in the past 30 days, including any moderate-vigorous home or yard tasks. If participants responded that they did engage in any leisure-time physical activity in the past 30 days, they were asked what activities they did, how many times in the past 30 days, and approximately how many minutes they spent in each activity each time. Participants were also asked to describe their average level of daily physical activity. Response options are "Sits during the day and does not walk about very much, "Stands or walks about a lot during the day, but does not have to carry or lift things very often", "Lifts light loads or has to climb stairs or hills often", and "Does heavy work or carries heavy loads".

Beginning in 2007, NHANES adapted the Global Physical Activity Questionnaire (GPAQ) to measure average weekly physical activity.[64] Participants are asked to recall, in a typical week, how many days in week they performed work-related or recreational moderate or vigorous physical activity and how many minutes, on a typical day, they perform physical activity. Participants are also asked about their daily sedentary time and time spent walking or biking as transportation.

NHANES provided suggested metabolic equivalent task (MET) values- an estimated measure of the energy expended while performing a specific physical activity task- for work-related PA, recreational PA, walking or biking for transportation, home/yard task activities, average daily activity levels, and the reported leisure-time activities.[1] MET-hours/week for each activity were calculated by multiplying the MET value for each activity by the minutes reported over the past 30 days, then divided by 4. The MET-hours/week from all activities were summed to estimate total weekly PA. MET-hours/week for each category were calculated by multiplying the MET value by the minutes reported over the past week, then summed across intensity levels. The MET-hours/week from both physical activity measures were summed to calculate the overall MET-hours/week for all survey cycles.

Allostatic Load

NHANES measured nine biomarkers that have been used in previous literature to estimate allostatic load: systolic blood pressure, diastolic blood pressure, resting heart rate, glycohemoglobin (HbA1C), body mass index (BMI), total cholesterol, high-density lipoprotein cholesterol (HDL), serum albumin, and C-reactive protein (CRP).[12,34,37] Three consecutive blood pressure measurements were taken during the physical examination, with a fourth attempt made if a measurement is incomplete or interrupted. For this analysis, the average of the last two readings were calculated and used.

Consistent with previous research we used the following clinical cutoffs: systolic blood pressure ≥ 140 mm, diastolic blood pressure ≥ 90 mm, resting heart rate ≥ 90 beats/min, HbA1C ≥ 6.4%, BMI ≥ 30 kg/m2, total cholesterol ≥ 240 mg/dL, HDL < 40 mg/dL, serum albumin < 3.8 g/dL, and CRP > 0.3 mg/dL.[34,37] CRP was measured at five of the eight surveys (2001, 2003, 2005, 2007, and 2009). Primary allostatic load analyses were restricted to the eight indicators measured consistently across survey cycles, however, the inclusion of CRP as part of allostatic load is explored where data were available.

Participants were scored as positive or not, based on the clinical cutoffs, for each biomarker, then allostatic load was indexed by a count of positive biomarkers (range=0-8).[34]

Participants that reported that they were taking high blood pressure, cholesterol, or diabetes medication or insulin were scored positive for systolic and diastolic blood pressure, total cholesterol, and/or HbA1c, regardless of their laboratory values.

Covariates

NHANES collected information on participants' demographics during the health surveys. For this analysis, age, race/ethnicity, income, education level, relationship status, citizenship status, and veteran status were included as covariates.

Statistical analysis

All analyses were stratified by sex. To assess sociodemographic differences by sexual orientation, we performed Pearson χ^2 tests. Pearson χ^2 tests were also used to test differences in allostatic load biomarkers and physical activity levels across sexual orientation groups. Linear regression models were used to assess differences in mean allostatic load scores and mean MET-hours/week.

Linear regression models were also fit to assess the relationship between physical activity and allostatic load scores. We fit both unadjusted and adjusted (for sexual orientation, age, race/ethnicity, relationship status, income, education level, citizenship status, and veteran status) models. We also fit unadjusted and adjusted models (same covariates but not controlling for sexual orientation) for each sexual orientation group to assess for potential subgroup differences in the association between physical activity and allostatic load. We tested for effect modification using an adjusted Wald test, and further (females: p=0.86; males: p=0.79), stratified results by sexual orientation. We stratified by age (20-40 and 41-59) to assess differences in allostatic load due to aging.

To assess the robustness of physical activity findings, we conducted a sensitivity analysis where physical activity was measured using pre-defined categories of MET-hours/week:

sedentary (0 MET-hours/week), low active (less then 500 MET-hours/week), moderate active (500-1,000 MET-hours/week), and high active (greater than 1,000 MET-hours/week).[65] Sedentary was used as the reference group.

Significance of all tests are evaluated at $p < 0.05$ and all reported confidence intervals are at 95% confidence with heterosexuals as the reference group. For physical activity models, those categorized as sedentary were used as the reference group. Analyses were conducted using Stata/SE version 17. Because multiple 2-year surveys were combined, a new sample weight was calculated and included in all analyses, per NHANES guidelines.[66]

CHAPTER 3
RESULTS

Tables 1 and 2 list sociodemographic characteristics by sex and sexual orientation. Among males, 94.4% were heterosexual, 2.5% were gay, 1.2% were bisexual, and 1.9% were heterosexual with same-sex lifetime experience. Among females, 91.2% identified as straight, 1.4% identified as gay or lesbian, 3.1% identified as bisexual, and 4.3% identified as heterosexual with same-sex lifetime experience. A higher proportion of gay men had at least a bachelor's degree (62.2% vs 30.3%, p<0.00) and were never married (59.8% vs 24.9%, p<0.00) compared to heterosexual men. Bisexual men were more likely to be in the lowest income category (66.0% vs 52.0%, p=0.04) and be divorced or separated (19.9% vs 9.5%, p<0.00) compared to heterosexual men. Men with lifetime same-sex experience were older (40.1 years vs 38.1 years, p=0.05), had some college education (44.2% vs 32.4%, p=0.03), and more likely to live with a partner (18.8% vs 8.6%, p=0.01) compared to heterosexual men. There were no statistically significant differences in race/ethnicity.

Gay/lesbian women were more likely to be in the lowest income category (75.1% vs 52.9%, p<0.00) and never married (54.9% vs 20.9%, p<0.00) compared to heterosexual women. Bisexual women were younger and more likely to have some college education (42.5% vs 35.3%, p=0.01) than heterosexual women. Women with lifetime same-sex experience were more likely to be divorced/separated (21.2% vs 13.8%, p=0.02) compared to heterosexual women. A smaller proportion of bisexual women identified as Hispanic/Latine compared to heterosexual women (7.4% vs 11.7%, p=0.04).

Tables 3 and 4 compare allostatic load biomarkers and physical activity by sex and sexual orientation. Among men, a smaller proportion of gay men had a BMI ≥30 kg/m^2 (17.1% vs 30.2%, p<0.00) compared to heterosexual men. Among bisexual men, a greater proportion had higher systolic and diastolic blood levels (40.4% and 34.2% vs 18.1% and 17.8%, $p<0.00$). While gay men had a statistically significant lower mean allostatic load score than heterosexual men (0.8 vs 1.2, $p<0.00$), bisexual men had a statistically significant higher mean score (1.9 vs 1.2, $p=0.01$). Heterosexual men had greater mean MET-score/week than gay, bisexual, and heterosexual men with same-sex experience (856.0 vs 583.1 METs, 340.8, and 617.7 METs; p=0.02, 0.00, and 0.05, respectively).

Among women, a smaller proportion of gay/lesbian women had elevated total cholesterol levels (7.2% vs 12.6%, $p=0.04$) and lower mean MET-score/week than heterosexual women (426.8 vs 615.6, $p=0.02$). A greater proportion of gay/lesbian women had higher HbA1c levels than heterosexual women (17.9% vs 8.1%, $p=0.04$). A smaller proportion of bisexual women had elevated systolic and diastolic blood pressure levels compared to heterosexual women (8.3% and 7.6% vs 17.7% and 16.3%, $p=0.01$). More bisexual women also had elevated HDL cholesterol levels and a BMI ≥30 kg/m^2 compared to heterosexual women (14.6% vs 9.0%, $p=0.02$ and 43.7% and 31.1%, $p=0.01$). There were no statistically significant differences in mean allostatic load scores across sexual orientations.

Tables 5 and 6 describe the association between allostatic load and physical activity by sex and sexual orientation. Among all men, 100 additional MET-hours/week of physical activity was statistically significantly associated with lower allostatic load scores ($\beta_{unadjusted}$=–0.00508, $p<0.00$; $\beta_{adjusted}$ =-0.00367, $p=0.01$). Heterosexual men had similar findings ($\beta_{unadjusted}$= -0.00405, $p<0.00$; $\beta_{adjusted}$ =-0.0374, $p=0.01$). For the other, smaller sexual orientation groups, there was no significant association between physical activity and allostatic load.

Similarly, more physical activity was statistically significantly associated with lower allostatic load scores among all women ($\beta_{unadjusted}$=–0.0096, $p<0.00$; $\beta_{adjusted}$

$=-0.00505$, $p<0.00$) and heterosexual women ($\beta_{unadjusted}=-0.00934$, $p<0.00$; $\beta_{adjusted}=-0.0058$, $p<0.00$). Across queer sexual orientations, 100 additional MET-hours/week of physical activity was associated with a statistically significant lower allostatic load scores among gay/lesbian women ($\beta_{unadjusted}=-0.03269$, $p=0.04$), and heterosexual women with same-sex experience ($\beta_{unadjusted}=-0.01059$, $p=0.02$). However, after adjusting for confounders, the associations were attenuated and no longer statistically significant for all queer sexual orientations.

In our sensitivity analyses utilizing categories of physical activity, all men in low ($\beta_{unadjusted}=-0.31$, $p<0.00$), moderate ($\beta_{unadjusted}=-0.31$, $p<0.00$), and high active ($\beta_{unadjusted}=-0.32$, $p<0.00$) groups had statistically significantly lower allostatic load scores than the sedentary group. Similarly, among heterosexual men, the low ($\beta_{unadjusted}=-0.24$, $p<0.00$), moderate ($\beta_{unadjusted}=-0.25$, $p<0.00$), and high active ($\beta_{unadjusted}=-0.26$, $p<0.00$) groups had statistically significantly lower allostatic load scores than the sedentary group. Significant associations among gay ($\beta_{unadjusted}=-0.56$, $p=0.02$) and heterosexual men with same-sex experience ($\beta_{unadjusted}=-0.74$, $p<0.00$) only appeared in the high active groups. There were no statistically significant associations among bisexual men.

Likewise, all women in low ($\beta_{unadjusted}=-0.45$, $p<0.00$), moderate ($\beta_{unadjusted}=-0.37$, $p<0.00$), and high active ($\beta_{unadjusted}=-0.37$, $p<0.00$) groups had statistically significantly lower allostatic load scores than the sedentary group. Similarly, among heterosexual women, the low ($\beta_{unadjusted}=-0.44$, $p<0.00$), moderate ($\beta_{unadjusted}=-0.39$, $p<0.00$), and high active ($\beta_{unadjusted}=-0.39$, $p<0.00$) groups had statistically significantly lower allostatic load scores than the sedentary group. There were no statistically significant associations among gay/lesbian women. The only statistically significant association among bisexual women was in the moderate active group ($\beta_{unadjusted}$ =–0.47, p=0.04). Among heterosexual women with same-sex experience, only those in the low active group had statistically significant lower allostatic load scores ($\beta_{unadjusted}$ =–0.86, p<0.00).

After stratifying based on age, gay men continued to have lower allostatic load scores than heterosexual men. Younger gay men (aged 20-40) had statistically significantly lower allostatic load scores than younger heterosexual men (0.6 vs 0.9, p=0.04). Older gay men also had lower allostatic load scores than older heterosexual men (1.2 vs 1.7, p=0.01), but this was not statistically significant. Younger bisexual men had statistically significantly higher allostatic load scores than younger heterosexual men (1.6 vs 0.9, p=0.05). Older bisexual men also had higher allostatic load scores than older heterosexual men, but this was not statistically significant. Heterosexual men with same-sex experience did not have statistically significant differences in allostatic load after age stratification.

Among women, only younger bisexual women had statistically significantly different allostatic load scores than younger heterosexual women (1.0 vs 0.8, p=0.01). All older queer women had higher allostatic load scores than older heterosexual women, but these differences were not statistically significant.

CHAPTER 4
DISCUSSION

Overall, physical activity was inversely associated with allostatic load. We found that heterosexual adults reported greater levels of physical activity than queer adults. Compared to heterosexual men, gay men had lower allostatic load scores, but bisexual men had greater allostatic load scores. There were no statistically significant allostatic load score differences among women. The association between physical activity and allostatic load was only statistically significant among all men, heterosexual men, all women, and heterosexual women. Exploration of sexual orientation-specific estimates of the association between physical activity and allostatic load yielded inconsistent results.

Findings regarding allostatic load scores across sex orientation groups are consistent with a previous study using NHANES by Mays et al. that found lower allostatic load in gay men, elevated allostatic load in bisexual men, and no significant differences among women.[34] Our study utilized a larger analytic sample by incorporating in 6 additional years of data (Mays et al. had a total n of 13,911 with 12,969 heterosexuals, 211 gay/lesbian, 307 bisexuals, and 424 heterosexuals with same-sex experience. This study had a total n of 28,894 with 26,887 heterosexuals, 515 gay/lesbian, 647 bisexuals, and 845 heterosexuals with same-sex experience.), thus improving on statistical power to detect differences. This suggests that perhaps allostatic load may not capture the potential impact of sexual minority stress on health.

Additionally, the statistically significant associations between physical activity and allostatic load among all men and women are consistent with the findings from Gay et al. and Copeland et al.[17,37] This suggests that physical activity may buffer or offset the physiologic effects associated with increased allostatic load, such as adverse inflammatory and metabolic health outcomes. This is consistent with established research on the benefits of physical activity on cardiometabolic health.[43–47] Although sexual orientation-specific estimates of the association between physical activity and allostatic load were not consistently statistically significant and also not statistically significantly different from heterosexual, this may actually highlight the potential positive impact physical activity can have on allostatic load for diverse groups of people. Additionally, some estimates were larger among queer groups than heterosexual groups, but may have been insignificant solely due to sample size.

Additionally, there appears to be a slight non-linear relationship present among all, heterosexual, and gay men when modeling physical activity as categorical. This dose-response relationship is strongest among gay men. In combination with existing literature describing gay men's negative experiences with body image,[67–70] the physiologic factors involved with disordered eating, over exercising, and body dissatisfaction may explain the lower allostatic load scores in gay men in this study and Mays et al. While physiologically these socially reinforced ideals result in ideal metabolic profiles, these negative experiences require further research to investigate the health impacts.

After stratifying by age, it appears that any differences in allostatic load may be due to aging as opposed to sexual orientation differences. Differences in allostatic load across sexual orientations were consistent in the younger (20-40 years) and older (41-59 years) groups, as mean scores roughly doubled with age for men and women. Interestingly, gay men had the lowest mean allostatic load scores regardless of age stratification, which may suggest that there are protective factors for increased allostatic load across the lifespan for gay men. Furthermore, bisexual men had the highest allostatic load scores regardless of age stratification, which may be due to adverse experiences in early life that caused early increases in allostatic load that then leveled out to expected changes.

We found that bisexual men and women have consistently higher allostatic load scores in this study, regardless of differences in aging or physical activity. These disparities among bisexual adults may be explained by the unique discrimination that bisexual people face from both heterosexual and queer communities. Bisexual-specific stressors include targeted discrimination, hostility, prejudice, and stigma related to the bisexual identity (being confused about their identity, assumptions about their commitment or loyalty, exclusion from heterosexual and queer spaces, etc.).[71,72]

The large population-based sample was a major strength of this study. However, due to data collection of sexual orientation being limited to participants under the age of 59, we are unable to assess allostatic load for specific sexual orientations during older adulthood. Expanding allostatic load research to include older adults for whom sexual orientation data are also available may help deepen our understanding of allostatic load across the life span for queer adults. The cross-sectional nature of NHANES does not enable us to determine temporality, account for duration of exposure to sexual minority stress that may more accurately reflect its impact on allostatic load, or comprehensively assess the impact of prolonged physical activity on allostatic load. Sexual orientation is fluid, so capturing it at one instance in time may not accurately represent an individual's identity or experiences.[33] Further research is needed to continue understanding differences in physical activity engagement, intensity, and duration among queer populations as well to continue establishing knowledge of the association between physical activity and allostatic load in these groups. This research would benefit from longitudinal studies that collect comprehensive data on sexual orientation, physical activity, and allostatic load biomarkers. Furthermore, additional research should employ an intersectional approach and include race/ethnicity as the accumulation of allostatic load due to racial discrimination may manifest differently across sexual orientation.

Increasing physical activity has been a long-standing public health objective.[73] Accruing research, including this cross-sectional analysis, continues to document the potential benefits of physical activity to improve, or prevent, chronic diseases—including those associated with allostatic load. While more research is needed to augment these findings, this study suggests that physical activity may be an important modifiable behavior to mitigate some sexual orientation disparities in health.

Tables

Table 1. Sociodemographic characteristics by sexual identity among males, NHANES (2001-2016)

	Heterosexual 14,498		**Gay** 336			**Bisexual** 195			**Same-sex experience** 286		
	mean	SE	mean	SE	p-value[a]	mean	SE	p-value[a]	mean	SE	p-value[a]
Age	38.1	0.2	38.2	1.2	0.98	39.0	1.2	0.49	40.1	1.0	0.05
	n	wtd %[c]	n	wtd %[c]	p-value[b]	n	wtd %[c]	p-value[b]	n	wtd %[c]	p-value[b]
Race/Ethnicity					0.10			0.64			0.46
Hispanic/Latine	3,307	12.8 %	77	9.2 %		46	13.1 %		69	12.9 %	
Non-Hispanic White	7,141	71.5 %	173	73.3 %		98	73.0 %		147	74.5 %	
Non-Hispanic Black	3,052	10.1 %	49	5.9 %		40	10.9 %		59	10.1 %	
Multiracial, Other	998	5.7 %	37	11.6 %		11	3.0 %		11	2.6 %	
Annual Family Income					0.09			0.04			1.00
$0-$44,999	6,745	52.0 %	163	60.3 %		119	66.0 %		134	51.1 %	
$45,000-$74,999	2,896	30.2 %	67	31.1 %		28	21.5 %		49	30.4 %	
$75,000-$99,999	567	6.0 %	6	2.7 %		4	1.2 %		11	6.4 %	
$100,000 and above	1,021	11.8 %	13	5.9 %		12	11.3 %		17	12.1 %	
Education Level					0.00			1.00			0.03
<High school	2,840	13.1 %	13	1.8 %		32	13.3 %		40	6.8 %	
High school	3,538	24.2 %	28	8.2 %		50	23.9 %		55	16.2 %	
Some college	4,487	32.4 %	95	27.9 %		64	32.7 %		110	44.2 %	
>=Bachelor's degree	3,625	30.3 %	200	62.2 %		49	30.2 %		81	32.8 %	
Relationship Status					0.00			0.00			0.01
Married	7,643	56.6 %	4	1.1 %		64	35.6 %		137	50.7 %	
Living with partner	1,416	8.6 %	84	33.4 %		6	2.7 %		49	18.8 %	
Never married	3,905	24.9 %	221	59.8 %		91	41.6 %		57	17.3 %	
Widowed	68	.4 %	26	5.7 %		1	.3 %		3	.8 %	
Divorced or separated	1,458	9.5 %				33	19.9 %		40	12.4 %	
Served in the US Armed Forces					0.01			0.03			0.17
No	9,803	83.6 %	243	92.7 %		142	91.4 %		179	76.3 %	
Yes	1,738	16.4 %	20	7.3 %		13	8.6 %		46	23.7 %	
Citizenship Status					0.00			0.95			0.93
Not a US citizen	2,005	9.0 %	16	2.2 %		28	8.8 %		44	9.2 %	
Citizen by birth or naturalization	12,478	91.0 %	320	97.8 %		166	91.2 %		242	90.8 %	

[a]p-values derived from linear regression for age with heterosexual as referent group

[b]p-values derived from Pearson $\chi 2$ tests for categorical variables with heterosexual as referent group

[c]Wtd % = Weighted percentages using sampling weights per NHANES guidelines for combining 2-year surveys

Table 2. Sociodemographic characteristics by sexual orientation among females, NHANES (2001-2016)

	Heterosexual 12,389		Gay/Lesbian 179			Bisexual 452			Same-sex experience 559		
	mean	SE	mean	SE	p-value[a]	mean	SE	p-value[a]	mean	SE	p-value[a]
Age	38.9	0.3	37.0	1.7	0.29	32.9	0.7	0.00	37.4	0.9	0.10
	n	wtd %[c]	n	wtd %[c]	p-value[b]	n	wtd %[c]	p-value[b]	n	wtd %[c]	p-value[b]
Race/Ethnicity					0.10			0.04			0.64
Hispanic/Latine	2,849	11.7 %	22	6.2 %		53	7.4 %		83	8.8 %	
Non-Hispanic White	6,189	72.2 %	103	77.6 %		251	74.2 %		312	74.1 %	
Non-Hispanic Black	2,550	10.8 %	46	13.2 %		118	14.2 %		124	10.8 %	
Multiracial, Other	801	5.3 %	8	2.9 %		30	4.2 %		40	6.3 %	
Annual Family Income					0.00			0.07			0.15
$0-$44,999	5,871	52.9 %	129	75.1 %		293	65.0 %		309	62.2 %	
$45,000-$74,999	2,487	29.4 %	30	19.5 %		78	22.7 %		100	24.7 %	
$75,000-$99,999	514	5.9 %	7	3.7 %		16	4.6 %		19	4.5 %	
$100,000 and above	922	11.8 %	2	1.6 %		25	7.6 %		34	8.5 %	
Education Level					0.86			0.01			0.49
<High school	2,043	11.0 %	23	8.5 %		78	15.2 %		70	10.0 %	
High school	2,425	19.2 %	42	23.1 %		114	21.7 %		88	17.1 %	
Some college	4,369	35.3 %	63	35.1 %		184	42.5 %		235	42.3 %	
>=Bachelor's degree	3,549	34.4 %	51	33.2 %		76	20.5 %		166	30.6 %	
Relationship Status					0.00			0.00			0.02
Married	6,364	56.5 %	6	2.9 %		118	32.3 %		216	42.6 %	
Living with partner	975	7.2 %	38	23.1 %		67	14.3 %		62	12.1 %	
Never married	2,878	20.9 %	105	54.9 %		208	40.5 %		147	21.4 %	
Widowed	240	1.6 %	1	1.1 %		3	.4 %		19	2.7 %	
Divorced or separated	1,925	13.8 %	29	18.0 %		56	12.5 %		115	21.2 %	
Served in the US Armed Forces					0.51			0.34			0.87
No	9,559	98.3 %	133	97.6 %		296	96.6 %		398	98.1 %	
Yes	172	1.7 %	5	2.4 %		8	3.4 %		12	1.9 %	
Citizenship Status					0.54			0.00			0.01
Not a US citizen	1,434	7.0 %	11	5.2 %		15	1.7 %		26	3.3 %	
Citizen by birth or naturalization	10,937	93.0 %	168	94.8 %		437	98.3 %		533	96.7 %	

[a]p-values derived from linear regression for age with heterosexual as referent group
[b]p-values derived from Pearson $\chi 2$ tests for categorical variables with heterosexual as referent group
[c]Wtd % = Weighted percentages using sampling weights per NHANES guidelines for combining 2-year surveys

Table 3. Physical Activity and allostatic load biomarkers by sexual orientation among males, NHANES (2001-2016)

	Heterosexual 14,498		Gay 336			Bisexual 195			Same-sex experience 286		
	n	wtd %[a]	n	wtd %	p-value[b]	n	wtd %	p-value[b]	n	wtd %	p-value[b]
Physical Activity Level					0.50			0.08			0.97
Sedentary	8,594	52.6 %	174	47.7 %		137	67.7 %		176	53.4 %	
Low active	1,350	10.8 %	42	16.0 %		23	12.6 %		23	11.1 %	
Moderate Active	1,471	12.0 %	42	14.2 %		12	7.3 %		25	13.2 %	
High Active	3,083	24.6 %	78	22.0 %		23	12.4 %		62	22.3 %	
	m	SE	m	SE	p-value[b]	m	SE	p-value[b]	m	SE	p-value[b]
Physical Activity METs											
MET-score/week, mean	856.0	58.8	583.1	113.2	0.02	340.8	99.1	0.00	617.7	107.7	0.05
MET-score/week, mean/100	8.6	0.6	5.8	1.1	0.02	3.4	1.0	0.00	6.2	1.1	0.05
Allostatic Load without CRP, mean	1.2	0.0	.8	0.1	0.00	1.9	0.2	0.01	1.2	0.1	0.58
Allostatic Load, mean	1.4	0.0	.9	0.1	0.00	2.1	0.3	0.01	1.3	0.1	0.41
	n	wtd %	n	wtd %	p-value[c]	n	wtd %	p-value[c]	n	wtd %	p-value[c]
Allostatic Load Indicators											
Systolic blood pressure, >=140mm	2,344	18.1 %	29	9.7 %	0.13	62	40.4 %	0.00	49	21.3 %	0.55
Diastolic blood pressure, >=90mm	2,253	17.8 %	31	9.9 %	0.15	54	34.2 %	0.00	36	11.8 %	0.09
Resting heart rate, >=90 BPM	979	6.5 %	29	5.8 %	0.71	20	11.0 %	0.18	19	6.3 %	0.91
HDL Cholesterol, <40 mg/dL	3,726	26.8 %	83	26.3 %	0.92	49	31.3 %	0.49	73	22.4 %	0.31
Total cholesterol, >=240 mg/dL	1,933	14.6 %	31	10.5 %	0.18	26	11.4 %	0.42	50	17.8 %	0.47
Glycated hemoglobin, >=6.4%	1,513	8.4 %	15	4.3 %	0.12	31	16.2 %	0.02	16	3.3 %	0.00
Albumin, <3.8 g/dL[c]	213	1.30%	3	0.60%	0.26	4	2.70%	0.20	5	0.80%	0.36
C-reactive protein, >0.3 mg/dL	2,755	22.8 %	44	11.7 %	0.01	38	28.4 %	0.41	43	16.3 %	0.13
BMI, >=30 kg/m2	4,455	30.2 %	63	17.1 %	0.00	59	36.5 %	0.24	76	23.3 %	0.09

[a]Wtd % = Weighted percentages using sampling weights per NHANES guidelines for combining 2-year surveys
[b]p-values dervied from regression models using heterosexual as the referent group
[c]p-values derived from Pearson $\chi 2$ tests using heterosexual as the reference group

Table 4. Physical Activity and allostatic load biomarkers by sexual orientation among females, NHANES (2001-2016)

	Heterosexual 12,389		Gay/Lesbian 179			Bisexual 452			Same-sex experience 559		
	n	wtd %[a]	n	wtd %	p-value[b]	n	wtd %	p-value[b]	n	wtd %	p-value[b]
Physical Activity Level					0.68			0.07			0.57
Sedentary	7,860	55.8 %	113	54.8 %		321	65.5 %		356	55.6 %	
Low active	1,163	11.1 %	19	11.8 %		31	8.7 %		54	14.3 %	
Moderate Active	1,288	12.8 %	22	17.8 %		29	5.8 %		64	14.3 %	
High Active	2,078	20.2 %	25	15.7 %		71	20.0 %		85	15.8 %	
	m	SE	m	SE	p-value[b]	m	SE	p-value[b]	m	SE	p-value[b]
Physical Activity METs											
MET-score/week, mean	615.6	31.7	426.8	79.2	0.02	600.7	106.0	0.89	546.3	85.8	0.43
MET-score/week, mean/100	6.2	0.3	4.3	0.8	0.02	6.0	1.1	0.89	5.5	0.9	0.43
Allostatic Load without CRP, mean	1.1	0.0	1.2	0.2	0.64	1.1	0.1	0.79	1.0	0.1	0.32
Allostatic Load, mean	1.4	0.0	1.5	0.3	0.79	1.5	0.1	0.50	1.3	0.1	0.32
	n	wtd %	n	wtd %	p-value[c]	n	wtd %	p-value[c]	n	wtd %	p-value[c]
Allostatic Load Indicators											
Systolic blood pressure, >=140mm	2,105	17.7 %	30	20.5 %	0.67	37	8.3 %	0.00	87	13.1 %	0.11
Diastolic blood pressure, >=90mm	1,913	16.3 %	23	17.1 %	0.90	36	7.6 %	0.00	92	15.1 %	0.70
Resting heart rate, >=90 BPM	1,249	10.0 %	15	6.7 %	0.16	47	11.6 %	0.49	55	11.0 %	0.67
HDL Cholesterol, <40 mg/dL	1,222	9.0 %	18	9.1 %	0.96	66	14.6 %	0.02	55	8.7 %	0.88
Total cholesterol, >=240 mg/dL	1,395	12.6 %	16	7.2 %	0.04	51	14.7 %	0.64	66	10.3 %	0.27
Glycated hemoglobin, >=6.4%	1,283	8.1 %	28	17.9 %	0.04	30	6.0 %	0.23	39	5.7 %	0.24
Albumin, <3.8 g/dL[c]	946	6.60%	5	1.30%	0.00	41	7.90%	0.56	46	6.30%	0.92
C-reactive protein, >0.3 mg/dL	3,707	36.4 %	40	34.6 %	0.84	143	47.5 %	0.03	136	37.3 %	0.87
BMI, >=30 kg/m2	4,401	31.1 %	74	43.4 %	0.08	209	43.7 %	0.01	202	30.0 %	0.78

[a]Wtd % = Weighted percentages using sampling weights per NHANES guidelines for combining 2-year surveys
[b]p-values dervied from regression models using heterosexual as the referent group
[c]p-values derived from Pearson $\chi 2$ tests using heterosexual as the reference group

Table 5. Association between physical activity and allostatic load, by sexual orientation among males, NHANES (2001-2016)

	Unadjusted Model		Adjusted Model[a]	
	Beta	**95% CI**	**Beta**	**95% CI**
Overall	-0.005084	(-0.007 -0.003)	-0.003674	(-0.006 -0.001)
Heterosexual	-0.004051	(-0.006 -0.002)	-0.00374	(-0.006 -0.001)
Gay	-0.018891	(-0.039 0.001)	-0.001867	(-0.030 0.026)
Bisexual	0.01702	(-0.030 0.064)	0.02042	(-0.039 0.080)
Same-sex experience	-0.010656	(-0.032 0.010)	0.00059	(-0.014 0.016)

[a]Adjusted for sociodemographic factors (race/ethnicity, relationship status, veteran status, citizenship, income, and education level)

Table 6. Association between physical activity and allostatic load, by sexual orientation among females, NHANES (2001-2016)

	Unadjusted Model		Adjusted Model[a]	
	Beta	**95% CI**	**Beta**	**95% CI**
Overall	-0.009658	(-0.012 -0.007)	-0.005054	(-0.008 -0.002)
Heterosexual	-0.009336	(-0.012 -0.006)	-0.005871	(-0.009 -0.003)
Gay/Lesbian	-0.032688	(-0.064 -0.001)	-0.032994	(-0.072 0.006)
Bisexual	-0.011647	(-0.024 0.000)	-0.005792	(-0.023 0.012)
Same-sex experience	-0.010587	(-0.020 -0.002)	-0.010365	(-0.027 0.006)

[a]Adjusted for sociodemographic factors (race/ethnicity, relationship status, veteran status, citizenship, income, and education level)

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