Journal of Racial and Ethnic Health Disparities
https://doi.org/10.1007/s40615-021-01103-7

Sleep Buffers the Effect of Discrimination on Cardiometabolic Allostatic Load in Native Americans: Results from the Oklahoma Study of Native American Pain Risk

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Received: 25 March 2021 / Revised: 18 June 2021 / Accepted: 2 July 2021

Abstract

Objectives Compared to other racial/ethnic groups, Native Americans (NAs) are more likely to develop health conditions associated with allostatic load (stress-related wear-and-tear). Psychosocial factors (i.e., adverse life events, discrimination, psychological distress) often promote stress and may help explain greater allostatic load in NAs. Moreover, previous research suggests sleep may either mediate or moderate the effects of some psychosocial stressors, like discrimination, on allostatic load. The current study investigated the relationship between adverse life events, discrimination, psychological stress, sleep, and cardiometabolic load.

Methods Using a sample of 302 healthy, chronic pain-free NAs and non-Hispanic White (NHW) participants, bootstrapped mediation analyses were conducted to determine whether the relationship between NA race/ethnicity and cardiometabolic allostatic load (composite score of body mass index, mean arterial pressure, and heart rate variability) was mediated by psychosocial stressors. Models also assessed whether sleep disturbance served as an additional mediator or a moderator to the effects.

Results Consistent with prior research, we found that NAs experienced greater discrimination, adverse life events (potentially traumatic events), and cardiometabolic allostatic load than NHWs. Further, discrimination was associated with increased psychological stress for NAs, but this did not explain why NAs experience higher cardiometabolic allostatic load. A moderating effect of sleep on discrimination was found, such that discrimination partially contributed to the relationship between NA race/ethnicity and cardiometabolic allostatic load, but only for participants reporting greater sleep disturbance.

Implications These findings highlight that good sleep can buffer the effect of psychosocial stress on cardiometabolic allostatic load in Native Americans.

Keywords Allostatic load · Ethnic differences · Discrimination · Adverse life events · Sleep disturbance · Stress

To sustain health and adaptively respond to environmental stressors, our bodies must constantly modulate the degree of activation and deactivation of physiological systems (e.g., glucose regulation, body temperature). This process, known as allostasis, occurs dynamically in response to acute stressors and is integral to an organism's survival [1, 2]. While adaptive in coordinating an individual's physiological response to acute stress, chronic activation of the neural and neuroendocrine systems promoting allostasis can lead to physiological wear-and-tear (i.e., allostatic load) on the body's other regulatory systems[1, 2]. Allostatic load is associated with numerous disease states, including cardiovascular disease and diabetes, as well as heightened risk of mortality [3–5]. Measures of allostatic load typically assess markers of regulatory systems (i.e., metabolic, cardiovascular, neuroendocrine, immune, and parasympathetic) that experience stress-related wear-and-tear [4]. Research has consistently found a relationship between markers of allostatic load (e.g., blood pressure, heart rate, cholesterol level, body mass index, HbA1c, C-reactive protein, IL-6, cortisol, heart rate variability) and negative health outcomes [5–7]. For example, chronic elevations of heart rate and blood pressure can result in an increased risk of stroke and myocardial infarction [8].

Accumulating evidence suggests allostatic load contributes to racial health disparities [9]. This may be particularly true for

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Published online: 28 July 2021

Native Americans, who have high rates of chronic health conditions associated with allostatic load [10–12]. In fact, a theoretical paper by Tiedt and Brown has made a compelling argument for the role of allostatic load for diabetes in US Native Americans; however, the role of allostatic load in Native American health has been understudied [12]. Research investigating the relationship between markers of allostatic load and poor health within Native Americans has focused on psychosocial stressors this population has disproportionately experienced [13, 14]. Specifically, Native Americans have endured generations of extreme psychosocial stressors, including the early history of forced relocation and forced boarding school placement. Additionally, Native Americans have experienced the negative emotional impact of mascot caricatures and the epidemic of missing and murdered indigenous women and girls [15–18]. These experiences of historical trauma and persistent racism are associated with markers of allostatic load (e.g., high blood pressure, neuroendocrine dysfunction) and likely contribute to the increased rates of poor physical health within the Native American community [12, 14, 19–21]. In fact, compared to the general population, Native Americans are at an increased risk of death due to diabetes and heart disease and experience higher rates of obesity, high blood pressure, and several chronic pain conditions [10, 11, 22–25].

Additionally, the experience of discrimination is also heightened within Native Americans. Compared to non-Hispanic Whites, Native Americans report experiencing more discrimination when interacting with healthcare providers and law enforcement officers [26, 27]. These experiences of discrimination have been found to explain some racial disparities in health outcomes [28], and previous studies have documented a relationship between discrimination and allostatic load. For example, research has found a link between experiences of racial discrimination and hypertension [20, 29] as well as discrimination and comprehensive composite measures of allostatic load (e.g., blood pressure, heart rate variability, urinary cortisol, urinary epinephrine and norepinephrine, C-reactive protein, high- and low-density lipoproteins, etc.) [30–32].

Together, these findings suggest that greater and heightened experiences of adversity and discrimination may place Native Americans at higher risk for allostatic load [33], and, consequently, that allostatic load may play an important role in Native American health disparities. Researches completed among First Nations Australians and Indigenous Canadians have demonstrated a link between experiences of adversity and markers of allostatic load (e.g., diastolic blood pressure, fasting glucose, BMI, C-reactive protein, DHEA-S, etc.) [32, 34]. However, to our knowledge, only two studies have directly examined the impact of allostatic load in Indigenous peoples from the USA. Research by Thayer et al. [20] investigated whether early life traumas (e.g., witnessing violence) were related to negative health outcomes (e.g., allostatic load) in adulthood. They found that individuals who experienced early life trauma and then later developed PTSD had elevated neuroendocrine markers of allostatic load (i.e., DHEA-S). Recently, an analysis of data from the Oklahoma Study of Native American Pain Risk (OK-SNAP) found that healthy, pain-free Native Americans experienced higher cardiometabolic allostatic load (defined as a combination of blood pressure, body mass index, and heart rate variability-a marker of autonomic regulation of the heart) than non-Hispanic Whites that in turn increased pronociceptive processes associated with increased chronic pain risk [35]. Specifically, higher cardiometabolic allostatic load was associated with amplified pain signals (i.e., nociception) within the spinal cord and impaired ability of the central nervous system to dampen that amplified spinal nociception. Understanding more about these disparities may assist in explaining the biological causes that result in early mortality and morbidity within this understudied group [36].

Research examining the effects of psychosocial stressors on negative health outcomes has found that sleep disturbance may be a mediating pathway through which discrimination and adversity contribute to negative health outcomes [37, 38]. That is, experiences of discrimination [39] and adversity [40] have been consistently linked to impaired sleep, which in turn predicts markers of allostatic load [41, 42]. Moreover, one recent study with a multiethnic sample found that discrimination was linked to higher inflammatory burden, defined as a sum of five markers (e.g., CRP, IL-6, fibrinogen, E-selectin, ICAM-1) [13], an effect that was partly explained by sleep quality. Alternatively, sleep disturbances have also been found to amplify the effects of psychosocial stressors on markers of allostatic load [43, 44], perhaps via sensitization of the body's stress response. This research implicates healthy sleep as a critical factor in protecting from deleterious physiological consequences of psychosocial stress. Other studies have also observed a direct relationship between discrimination and allostatic load (e.g., cardiovascular risk) [38, 45]. Specific to Native Americans, there appears to be a link between current perceived stress and sleep quality, sleep efficiency and sleep disturbance as well as a relationship between negative life events and sleep disturbance [46]. However, no research has focused on the associations between psychosocial stressors (e.g., adversity, discrimination), perceived stress, sleep quality, and markers of allostatic load within this population.

The current study is an ancillary analysis of healthy, pain-free participants (153 Native Americans, 149 non-Hispanic Whites) from OK-SNAP [47]. As noted above, we have previously reported that Native Americans in OK-SNAP experienced higher cardiometabolic allostatic load [35]. The present study attempts to identify variables that mediate this relationship. Thus, bootstrapped mediation analyses were used to test whether adverse life events (i.e., potentially traumatic events, like physical/sexual assault, accidents, disasters), discrimination, and psychological stress are significant mediators of the

relationship between Native American race/ethnicity and cardiometabolic allostatic load. We hypothesized that adverse life events and discrimination would lead to increased psychological stress and that these variables would mediate the relationship between Native American race/ethnicity and cardiometabolic allostatic load. Given prior evidence that sleep disturbance may mediate or moderate the relationships between these psychological stressors and allostatic load, competing models were constructed for the current study (see Figure 1): one model includes sleep disturbance as a mediator linking discrimination, adversity, and psychological stress to cardiometabolic allostatic load, whereas the second model tests whether sleep disturbance moderates relationships between discrimination, adversity, psychological stress, and cardiometabolic allostatic load.

Methods

Brief Overview of Procedures

A full description of OK-SNAP procedures is reported elsewhere [47]. Participants were tested over a 2-day period (4–6 h/day). One day focused primarily on assessment of psychophysical pain tests (e.g., pain threshold/tolerance), whereas the other day focused primarily on neurophysiological pain tests (e.g., physiological responses to pain). Order of testing days was randomized but blocked by race and sex. Tests within each day were partly randomized to avoid order effects. Informed consent and inclusion/exclusion screening were conducted on the first day, followed by assessment of body mass index and mean arterial pressure. Questionnaires to

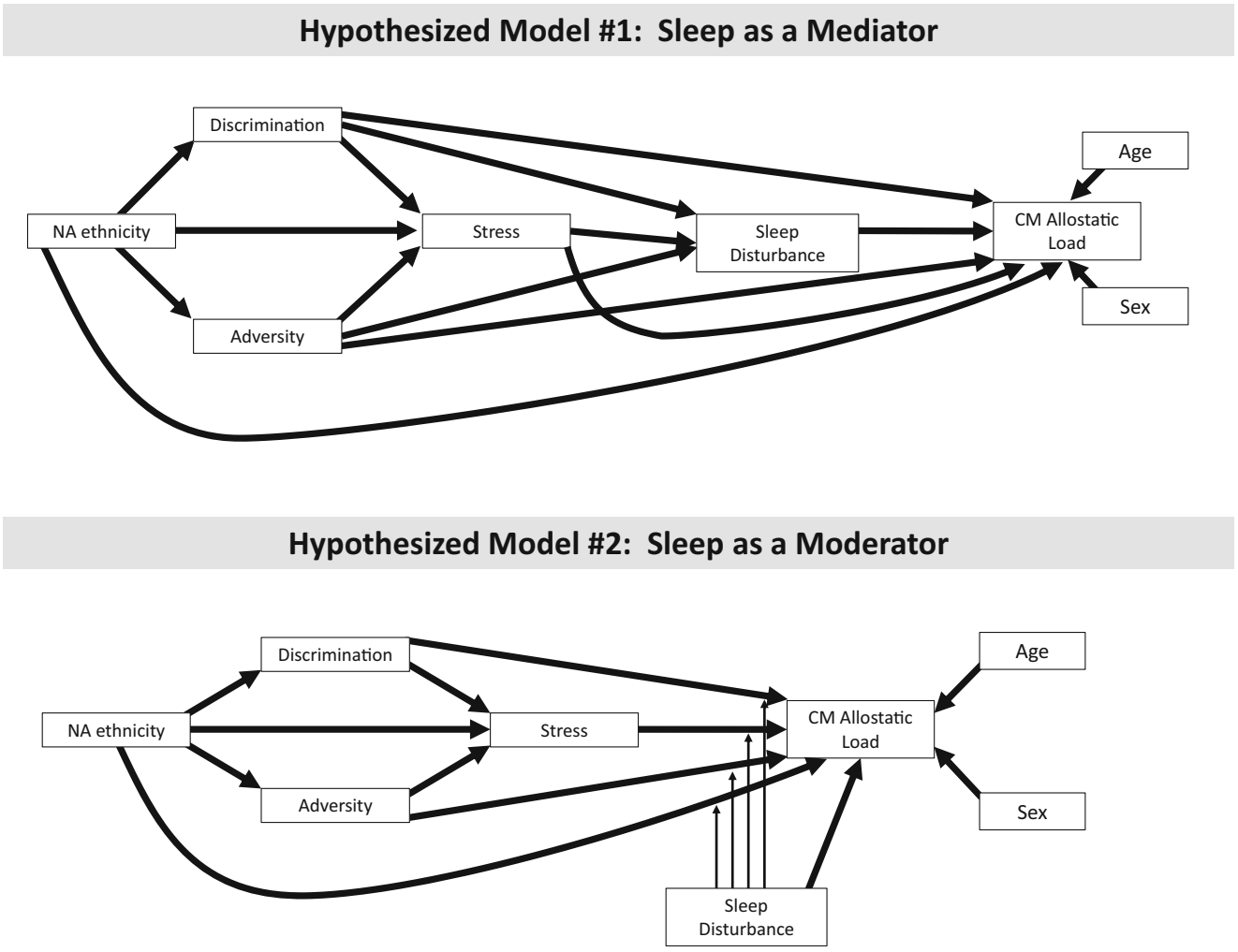


Figure 1. Hypothesized mediation models linking ethnicity (coded 0=non-Hispanic White [NHW], 1=Native American [NA]) to cardiometabolic allostatic load. The first model proposes that NAs experience more adverse life events and discrimination, which in turn leads to greater psychological distress. These three variables, along with sleep disturbance, are thought to promote allostatic load. In turn, sleep disturbance is proposed to mediate the relationships between these three mediators and cardiometabolic allostatic load. Age and biological sex (coded 0=male, 1=female) are included as controls. The second model tests whether sleep disturbance moderates the relationships between these three mediators (discrimination, adverse life events, psychological stress) and cardiometabolic allostatic load. In the second model, better sleep is predicted to act as a buffer against the negative effects of discrimination, adversity, and psychological stress. Age and biological sex (coded 0=male, 1=female) are included as controls

assess adverse life events, discrimination, and psychological stress were always administered on the first testing day, whereas sleep questionnaires were always administered on the second testing day. Heart rate variability was assessed on the neurophysiology testing day. Although OK-SNAP has a longitudinal component to determine if participants develop chronic pain, data used for the present analyses were collected during the initial 2-day assessment following study enrollment and are thus cross-sectional.

Participants

The primary goal of OK-SNAP was to assess the risks associated with chronic pain before it develops. Thus, in order to ensure that any observed effects were not due to disparities in pain condition or etiology or disease severity or treatment of pain, OK-SNAP participants were healthy and pain-free at the time of testing. Recruitment efforts were widespread and included advertisements in tribal and non-tribal newspapers, fliers in local community spaces, personal communications with Native American groups, email announcements at area universities, online platforms (e.g., Indian Healthcare and laboratory Facebook pages), and word of mouth. Initial phone screens were conducted and those deemed eligible were invited to attend a laboratory testing day. The testing day began with a more thorough review of inclusion/exclusion criteria. Data collection occurred between March 2014 and October 2018.

Participants were excluded for (1) <18 years old; (2) history of self-reported cardiovascular, neuroendocrine, musculoskeletal, and neurological disorders; (3) self-reported chronic pain or current acute pain; (4) BMI≥35 (due to difficulties recording electromyogram for neurophysiological pain tests); (5) current/recent use of antidepressants, anxiolytic, analgesic, stimulant, or anti-hypertensive medication; (6) current psychotic symptoms (assessed by Psychosis Screening Questionnaire [48]) or substance use problems; and/or (7) an inability to read and speak English. A Certificate of Degree of Indian Blood (CDIB) or tribal membership card was provided to verify Native American status. Native American participants represented tribal nations predominantly from the Southern Plains and eastern Oklahoma tribes. Participants were given an overview of the study's procedures and were informed that they could withdraw at any time. All participants provided verbal and written informed consent. At the completion of each testing day, participants received a $100 honorarium. The study was approved by IRBs of The University of Tulsa, Cherokee Nation, and the Indian Health Service Oklahoma City Area Office.

The parent study targeted a total sample size of 240 (120 Native Americans, 120 non-Hispanic Whites) with completed data. Prior papers have reported on the racial/ethnic group differences associated with the main study findings [47] and the effect of allostatic load on pain processing outcomes [35].

Of the 329 participants found eligible, 247 completed both testing days, 41 completed 1 day, and 39 completed partial tasks during 1 testing day. Two participants' data were lost due to a computer malfunction, 22 participants were non-NA minorities and thus were excluded from analyses, and 3 were excluded for having type 1 or type 2 diabetes. Thus, a total of 302 participants (153 Native American and 149 non-Hispanic Whites) were available for analysis in the current study (Table 1).

Testing Environment and Apparatus

During testing, participants were seated in a comfortable reclining chair (Perfect Chair Zero Gravity Recliner, Human Touch, Long Beach, CA) in a sound-attenuated and electrically shielded room. The experimenter sat in an adjacent room and monitored testing using audio and video equipment. Questionnaires were presented by a computer. Custom-built software (LabVIEW; National Instruments, Austin, TX) was used to control most experimental procedures and administer questionnaires electronically.

Cardiometabolic Allostatic Load

Allostatic load represents wear-and-tear that can occur on systems (cardiovascular, metabolic, immune, neuroendocrine, parasympathetic) responsible for maintaining allostasis. Researchers typically assess markers from multiple systems to create an index of overall allostatic load [4]. Oftentimes, this index is created by first calculating quartiles of each marker and then a count is created from the number of markers that fall into the high risk quartile (typically the upper quartile) [4]. A limitation of this approach is that it does not consider the full continuum of risk for each marker, because it assumes that only the upper quartile confers risk. Thus, other approaches have been used to account for the full range of risk. For example, the z-score allostatic load index [49] first converts each variable to a z-score based on the sample's distribution and then a linear combination of the z-scores is created by summing them to get a total score. We took a similar approach and created a variable (see below) to model the shared variance across 3 markers of allostatic load that were collected in OK-SNAP (body mass index [metabolic], blood pressure/mean arterial pressure [cardiovascular], and heart rate variability [parasympathetic control of heart]). This allowed us to create a measure of cardiometabolic allostatic load that accounts for the full continuum of risk. Using this method, we have shown that cardiometabolic allostatic load confers risk for chronic pain by amplifying pain signals and impairing inhibitory processes within the spinal cord [35], both of which increase chronic pain risk.

Table 1. Ethnic differences on background variables

	Native American (*N*=153)			Non-Hispanic White (*N*=149)			Inferential statistics		
Continuous variables	*N*	*M*	*SD*	*N*	*M*	*SD*	Cohen's d	*t* test	*p* value
Age (y)	153	30.60	12.67	149	28.56	13.53	0.21	−1.84	0.067
Body mass index (BMI; kg/m^2)	149	25.90	4.48	148	24.15	3.80	0.42	−3.62	<0.001
Mean arterial blood pressure (mmHg)	147	88.07	9.27	147	83.07	7.95	0.58	−4.96	<0.001
Heart rate variability (RMSSD, ms)	122	50.97	40.02	129	51.74	37.13	0.06	0.46	0.645
Subjective sleep quality subscale (PSQI; 0–3)	115	1.26	0.85	117	0.96	0.64	0.41	−3.08	0.002
Insomnia severity (ISI; 0–28)	115	7.68	5.46	116	5.78	4.58	0.38	−2.87	0.005
Fatigue (FSS; 9–63)	115	29.32	10.69	117	25.35	9.58	0.39	−2.98	0.003
Perceived stress (PSS; 0–40)	147	14.54	6.04	146	13.10	6.00	0.24	−2.04	0.042
Psychological distress (GSI; 0–4)	147	0.42	0.40	146	0.32	0.32	0.30	−2.54	0.012
Adverse life events (LEC; 0–5)	152	2.10	1.56	148	1.74	1.50	0.23	−2.01	0.045
Discrimination (EDS; 1–6)	147	2.01	0.82	146	1.69	0.68	0.43	−3.65	<0.001
Categorical variables		N	%	N	%			X^2	*p* value
Female sex		89	58.2%	74	49.7%			2.20	0.138
Marital status								9.04	0.029
Single		93	62.0%	111	74.5%				
Married		31	20.7%	24	16.1%				
Separated/divorced/widowed		15	10.0%	12	8.1%				
Cohabitating		11	7.3%	2	1.3%				
Education								11.11	0.025
<High school		8	5.3%	3	2.0%				
High school diploma		25	16.4%	21	14.2%				
Partial college		64	42.1%	75	50.7%				
College grad		43	28.3%	38	25.7%				
Grad/prof training		12	7.9%	11	7.4%				
Income								7.74	0.356
<$9999		40	27.0%	56	38.4%				
$10K–14999		18	12.2%	18	12.3%				
$15K–24999		18	12.2%	17	11.6%				
$25–34999		16	10.8%	11	7.5%				
$35K–49999		25	16.9%	14	9.6%				
$50K–74999		12	8.1%	8	5.5%				
$75K–99999		8	5.4%	9	6.2%				
>=$100K		11	7.4%	13	8.9%				
Basis of discrimination (EDS)									
Ancestry/national origin		21	14.3%	3	2.1%			14.57	<0.001
Gender		39	26.5%	25	17.1%			3.80	0.051
Race		30	20.4%	8	5.5%			14.46	<0.001
Age		38	25.9%	31	21.2%			0.87	0.352
Religion		5	3.4%	10	6.8%			1.79	0.181
Height		11	7.5%	11	7.5%			0.00	0.987
Weight		10	6.8%	9	6.2%			0.05	0.824
Other physical		35	23.8%	27	18.5%			1.24	0.265
Sexual orientation		3	2.0%	4	2.7%			0.15	0.695
Socioeconomic status		43	29.3%	27	18.5%			4.66	0.031

Note. Bold variables had significant group differences. Age, heart rate variability, and psychological distress were log10 transformed prior to conducting *t* tests or computing Cohen's *d* values, but for ease of interpretation the untransformed means and SDs are reported in the table

RMSSD root mean square of the successive differences, *PSQI* Pittsburgh Sleep Quality Index, *ISI* Insomnia Severity Index, *FSS* Fatigue Severity Scale, *PSS* Perceived Stress Scale, *GSI* Global Severity Index of the SCL-90, *LEC* Life Events Checklist, *EDS* Everyday Discrimination Scale

Body mass index (BMI) was assessed from weight and height determined from a medical scale. Higher BMI is associated with greater allostatic load. Blood pressure was assessed from mean arterial blood pressure (MAP) that was measured 3 times (3 min inter-test interval) at rest on the first testing day (Dinamap; Tampa, FL) before any pain assessment occurred. Participants sat still in a chair with their arm on the armrest. Higher BP is associated with greater allostatic load. Heart rate variability (HRV) assesses changes in the heart's beat-to-beat intervals that are primarily driven by parasympathetic (vagus) control of the heart. HRV was assessed from two 5-min rest periods that occurred during extended breaks on the neurophysiological assessment day. During each HRV assessment, participants were seated in a reclining chair and

told to get into a comfortable position, relax, and not move while baseline physiology was recorded for 5 min. The recording began only after they pressed a button to indicate that they were ready. Electrocardiogram (ECG) was measured using a Grass Technologies (West Warwick, RI) Model 15LT amplifier (with AC Module 15A54). One active electrode was placed near the right clavicle bone and the other electrode was placed on the lower left abdomen. ECG was sampled at 1000 Hz. RR intervals were identified offline by an experimenter using custom-built LabVIEW software. In the event of an ectopic beat, the R-spike was estimated to be equally spaced between the adjacent R-spikes. In addition, 30-s intervals were trimmed from the beginning and end of each record to control for task acclimation using HRV analysis software [50]. After trimming, the root mean square of successive differences (RMSSD) between RR intervals was calculated using the trimmed RR interval records. RMSSD from the two resting periods was averaged to create our HRV measure. RMSSD is a measure of respiratory sinus arrhythmia, which reflects parasympathetic control of the heart. Less parasympathetic control (i.e., lower HRV) is associated with increased allostatic load.

To combine BMI, MAP, and HRV into a single measure, a principal components analysis was conducted. Results indicated a single component explained 52% of the variance in the three measures. Component loadings were MAP = 0.805, BMI = 0.705, and HRV = −0.640. Next, a regression-based approach was used to generate standardized component scores for each participant, which was used in the analyses. Higher scores on this component represent greater cardiometabolic allostatic load.

Discrimination

Experiences of discrimination were assessed from the Everyday Discrimination Scale (EDS). The EDS is a 9-item measure that assesses the frequency of chronic, routine, and relatively minor experiences of unfair treatment in day-to-day experiences [51]. The instructions ask: "In your day to day life, how often do any of the following things happen to you?" Participants respond using a 6-point scale ranging from 1="Almost every day" to 6="Never." If the participant responds to any question with a frequency of "A few times a year" or more, then 10 yes/no items assess what they believe the source of the discrimination is: ancestry or national origins, gender, race, age, religion, height, weight, some other aspects of physical appearance, sexual orientation, or socioeconomic status (education, income). Items were reverse coded and then averaged to generate a total score that ranges from 1 to 6, with higher scores indicating higher levels of perceived discrimination. The frequencies of the bases of discrimination were also computed and reported.

Adverse Life Events (ALEs)

For the present study, ALEs were defined as major life stressors that could potentially qualify as psychological trauma. To assess ALEs, the Life Events Checklist (LEC) for the Diagnostic and Statistical Manual of Mental Disorders, 4th edition, Text Revision, was used [52]. The LEC is a 17-item self-report instrument that asks participants whether they have experienced, witnessed, or learned about various ALEs in their lifetime (e.g., natural disaster, transportation accidents, physical/sexual assault, combat exposure, life threatening injury, human suffering, violent death). Each item assesses a single potentially traumatic event. For the current study, ALEs were operationally defined as having experienced (answering "happened to me") to any items on the LEC. Items were summed, with a possible range of 0–17. Because there was significant positive skew due to outliers on the LEC total score, outliers were winsorized. This resulted in scores ranging from 0 to 5 (5 represents ALEs≥5), with higher scores indicating higher adversity.

Sleep Disturbance

Sleep disturbance was assessed from three measures. Self-reported sleep quality was assessed from the 1-item subscale of the Pittsburgh Sleep Quality Index (PSQI) [53] that asks "During the past month, how would you rate your sleep quality overall?" Responses are made using a 4-point scale ranging from 0 = "very good" to 3 = "very bad." Thus, higher scores indicate worse sleep quality.

Insomnia severity was assessed from the Insomnia Severity Index (ISI) [54, 55]. The ISI is a 7-item scale that measures the severity of sleep onset and sleep maintenance difficulties, satisfaction with current sleep pattern, interference with daily functioning, impairment attributed to the sleep problem, and degree of concern caused by the sleep problem. Each item is rated on a 0–4 scale based on problems over the last 2 weeks, and the total score ranges from 0 to 28. Higher scores indicate greater insomnia severity.

Fatigue was assessed from the Fatigue Severity Scale (FSS). The FSS is a 9-item measure that measures the severity of fatigue and how it interferes with daily activities [56] are made on a 7-point scale (1, strongly disagree; 7; strongly agree) based on fatigue symptoms from the last week. Items are summed to create a total score ranging from 9 to 63. Higher scores indicate a greater severity of fatigue symptoms. Although the FSS was originally developed to assess fatigue related to neurological and medical conditions [56], people with sleep-wake disorders consistently score higher on the FSS than healthy controls [57, 58]. Given that OK-SNAP participants were healthy and chronic pain-free, the FSS was used to assess daytime fatigue related to sleep disturbance, rather than chronic illness. Notably, daytime fatigue is a

prominent symptom of insomnia disorder [59], so including the FSS as an indicator of sleep disturbance assesses functioning related to impaired sleep.

To combine responses from the Sleep Quality Index, ISI, and FSS into a single measure of sleep disturbance, a principal components analysis was conducted. Results indicated a single component explained 74% of the variance in the three scales. Component loadings were sleep Q=0.884, ISI=0.924, and FSS=0.770. Next, a regression-based approach was used to generate standardized component scores for each participant, which was used in the analyses. Higher scores on this component represent greater sleep disturbance.

Psychological Stress

Psychological stress was assessed from two questionnaires. The Perceived Stress Scale (PSS) was used to assess stress over the past month [60]. The PSS includes 10 items that measure the degree to which situations in a participant's life are experienced as stressful. Responses are made on a 5-point scale ranging from 0 "never" to 4 "very often." Total scores range from 0 to 40, with higher scores indicating greater perceived stress.

The Symptom Checklist-90-Revised (SCL-90-R) was administered to assess psychological distress [61]. The scale consists of 90 items that assess various psychological symptoms (e.g., somatization, obsessive-compulsive, depression, phobic anxiety, paranoia). Responses are made on a 5-point scale ranging from 0 "not at all" to 4 "extremely." The Global Severity Index (GSI) of the SCL-90-R was calculated to assess overall psychological distress. Total GSI scores range from 0 to 4 with higher scores indicating greater distress.

To combine responses from the PSS and GSI into a single measure, a principal components analysis was conducted. Results indicated a single component explained 85% of the variance in the two scales. Component loadings were PSS = 0.923 and GSI = 0.923. Next, a regression-based approach was used to generate standardized component scores for each participant, which was used in analyses. Higher scores on this component represent greater psychological stress.

Control Variables

Age and biological sex were added as control variables in the prediction of allostatic load due to research indicating that allostatic load increases with age [62, 63] and is higher in men [64].

Data Analysis

The Statistical Package for the Social Sciences v25 (SPSS; IBM Corp) was used for all analyses. Ethnic differences on continuous outcomes were assessed using independent samples *t* tests, whereas categorical outcomes were assessed using chi-squared tests. Significance was set at $p<0.05$ (2-tailed) for these analyses.

Three principal component analyses (PCA) were conducted separately on allostatic load variables, sleep variables, and stress variables to reduce them into three separate components to be used in primary analyses (results reported in the "Methods" section).

Primary analyses were conducted using custom models within the PROCESS macro for SPSS [65]. PROCESS was chosen over structural equation modeling (SEM) due to the challenges of modeling and interpreting moderation effects in SEM (Little et al., 2006). These were custom models that examined whether ALEs, discrimination, and psychological distress mediated the relationship between Native American race/ethnicity and cardiometabolic allostatic load. Sleep disturbance was modeled as a mediator (model 1) and moderator (model 2) of these mediated paths (Fig. 1). PROCESS analyses allow researchers to compute bootstrapped confidence intervals for all coefficients, including (1) the paths (unstandardized regression slopes) linking the independent variable (ethnicity) to mediators, (2) the paths linking the mediators to the dependent variable (allostatic load), (3) the indirect (mediated) pathways, and (4) the "index" for tests of moderated mediation. In all cases, 5000 bootstrapped samples were generated, and the 95% confidence interval was created from these observed samples. The path coefficients are the average of these 5000 bootstrapped samples. The indirect paths are a result of the product (via multiplication) of all of the unstandardized coefficients that make up the indirect (mediated) path linking one variable to another. Rather than using traditional tests of significance (i.e., *p* values), significance for coefficients in these models is determined from the bootstrapped 95% confidence interval. If the interval contains zero, then that coefficient is not statistically different from zero (i.e., the null hypothesis is not rejected).

Prior to analyses, SPSS Explore was used to assess the distributional characteristics of all variables. In the event of skewness, it was corrected. Age, HRV (RMSSD), and GSI were log10 transformed. Next, outliers were identified using Wilcox's MAD-median procedure using a cutoff of 2.24 and then winsorized to the next nearest non-outlier value [66]. The following variables were winsorized: adverse life events (ALEs), blood pressure (MAP), perceived stress (PSS), psychological distress (GSI), HRV (RMSSD), insomnia severity (ISI), and discrimination (EDS). Given that PROCESS uses listwise deletion, missing values were first imputed using the expectation maximization algorithm in LISREL v8.8 [67]. This helped maintain the whole sample of 302 participants in the mediation analyses to improve statistical power. Table 1 reports the N's for all study variables and thus illustrates the amount of missingness for each variable. Most missingness was due to participants not attending the second

day of testing in the parent study. Fortunately, there were no differences between completers and non-completers on study variables, with the exception that completers achieved a higher education level (more completers reported some college) and reported lower insomnia severity (M=6.59 vs. M=11.00).

Results

Sample Characteristics

Table 1 presents participant characteristics for the 153 Native Americans (58% female) and 149 non-Hispanic Whites (50% female). As seen, compared to non-Hispanic Whites, Native Americans reported worse sleep quality (higher score), and had higher BMI, MAP, insomnia severity, fatigue severity, perceived stress, psychological distress, exposure to ALEs, and experiences of discrimination. Native Americans were also less likely to report achieving partial college at the time of their participation. There were three reported ethnic differences in the reasons for discrimination; Native Americans were more likely than non-Hispanic Whites to report discrimination due to ancestry, race, and socioeconomic status.

Predictors of Cardiometabolic Allostatic Load in Native Americans: Sleep as a Mediator

Correlations among all primary study variables are reported in Table 2. Figure 2 illustrates the results of the serial mediation model linking Native American ethnicity to cardiometabolic allostatic load through psychosocial stressors and sleep disturbance. As shown, Native Americans reported experiencing more discrimination and ALEs, and higher experienced discrimination was associated with higher psychological stress. However, none of the paths linking discrimination, ALEs, stress, or sleep disturbance with cardiometabolic allostatic load were statistically significant. But, there were significant paths between Native American ethnicity and cardiometabolic allostatic load, age and cardiometabolic allostatic load (older participants had higher cardiometabolic allostatic load), and sex and cardiometabolic allostatic load (men had higher cardiometabolic allostatic load). Consistent with these findings, none of the indirect (mediated) paths were statistically significant (Table 3).

Predictors of Cardiometabolic Allostatic Load in Native Americans: Sleep as a Moderator

Figure 3 depicts the results of the moderated mediation model linking Native American ethnicity to cardiometabolic allostatic load, with sleep disturbance as the moderator. The same paths were significant in this model as the last model: (1) Native Americans reported more discrimination and ALEs, (2) higher experienced discrimination was associated with higher psychological stress, (3) Native American experienced more cardiometabolic allostatic load, (4) older participants had higher cardiometabolic allostatic load), and (5) men had higher cardiometabolic allostatic load. Moreover, there were no significant *unmoderated* indirect (mediated) paths linking

Table 2. Means, standard deviations, and Pearson's correlations for imputed variables used in moderated mediation model (N=302)

Variable	M	SD	NA	Sex	Age	Discrim	ALEs	Stress	Psych	SleepQ	Insomn	Fatigue	MAP	BMI
NA ethnicity	-	-	1											
Sex	-	-	0.085	1										
Age (log)	1.437	0.165	0.106	0.045	1									
Discrim	1.849	0.761	0.210*	−0.073	−0.048	1								
ALEs	1.921	1.534	0.117*	−0.035	0.296*	0.213*	1							
Stress	13.844	5.969	0.122*	−0.013	−0.201*	0.477*	0.122*	1						
Psych (log)	0.122	0.087	0.146*	−0.022	−0.083	0.595*	0.235*	0.705*	1					
Sleep Q	1.133	0.712	0.202*	−0.052	−0.094	0.288*	0.119*	0.346*	0.434*	1				
Insomn	6.758	4.728	0.198*	−0.037	0.019	0.360*	0.196*	0.406*	0.545*	0.784*	1			
Fatigue	27.371	9.559	0.221*	−0.085	−0.024	0.258*	0.138*	0.463*	0.504*	0.470*	0.575*	1		
MAP	85.661	8.896	0.283*	−0.192*	0.433*	0.144*	0.188*	−0.034	0.056	0.107	0.127*	0.136*	1	
BMI	25.017	4.209	0.204*	−0.081	0.347*	0.146*	0.158*	0.001	0.040	0.020	0.084	0.059	0.359*	1
HRV (log)	1.612	0.262	−0.068	−0.129*	−0.449*	0.045	−0.202*	0.030	0.021	0.064	0.017	−0.069	−0.302*	−0.159*

Note. Means, standard deviations, and intercorrelations were generated from transformed, winsorized, and imputed variables

Discrim discrimination, *ALEs* adverse life events, *Psych* psychological distress, *Sleep* Q self-reported sleep quality, *Insomn* insomnia severity index, *MAP* mean arterial pressure, *BMI* body mass index, *HRV* heart rate variability

*p<0.05 (2-tailed)

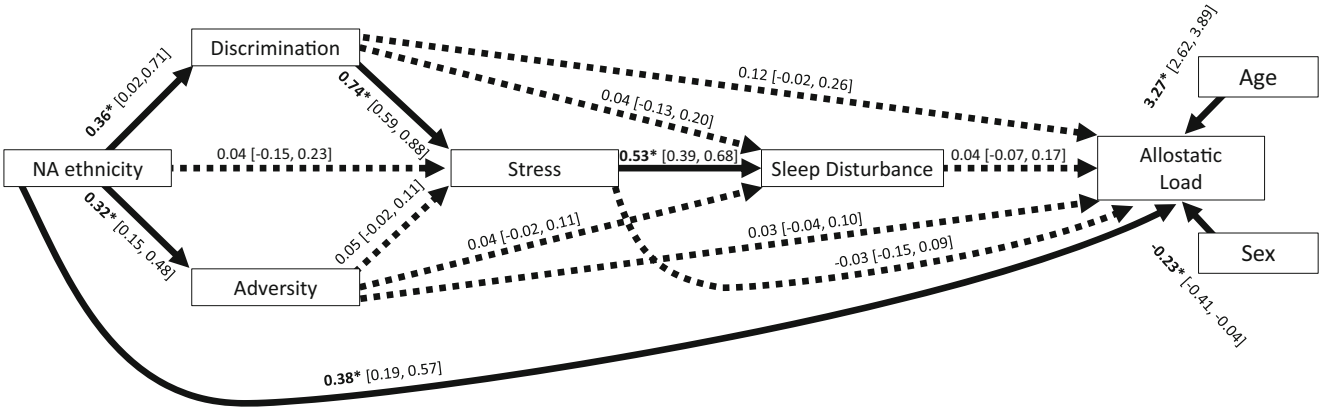


Figure 2. Results of the full mediation model predicting cardiometabolic allostatic load. Coefficients reported alongside paths are the result of 5000 bootstrapped samples. The 95% bootstrapped confidence interval is reported in brackets next to each coefficient. If the interval contains zero, then the path is nonsignificant (path represented by dotted arrows), but if the interval does not contain zero, then it is significant (solid arrows). Native Americans (NAs) experienced greater discrimination and adverse life events, and discrimination was associated with greater psychological distress. None of these variables, including sleep disturbance, had a direct effect on cardiometabolic allostatic load. Only Native American ethnicity, older age, and male sex were associated with higher cardiometabolic allostatic load. Results of the fully mediated model indicate that sleep disturbance did not significantly mediate the relationship between discrimination, adverse life events, or psychological distress

Native American ethnicity to cardiometabolic allostatic load. However, as Figure 3 shows, there was a significant interaction between discrimination and sleep problems in the prediction of cardiometabolic allostatic load. Figure 4 depicts this interaction and the results of simple relationships at low (16th percentile), moderate (median), and high (84th percentile) levels of sleep disturbance. The relationship between discrimination and cardiometabolic allostatic load was significant for those reporting high levels of sleep disturbance but was nonsignificant for those reporting less sleep disturbance. Thus, better sleep appears to buffer the relationship between discrimination and allostatic load.

Given the significant interaction between discrimination and cardiometabolic allostatic load, this means there could be significant conditional indirect (mediated) paths: (e.g., NA ➔ discrimination ➔ cardiometabolic allostatic load) for some participants depending on their level of sleep problems. Table 4 reports the results from the bootstrapped moderated mediation analyses and the conditional indirect tests (these are analogous to simple effects tests that are conducted following a significant interaction). As suggested by the significant interaction reported above, results of the tests of moderated mediation in Table 4 indicate that the NA ethnicity➔ discrimination➔ cardiometabolic allostatic

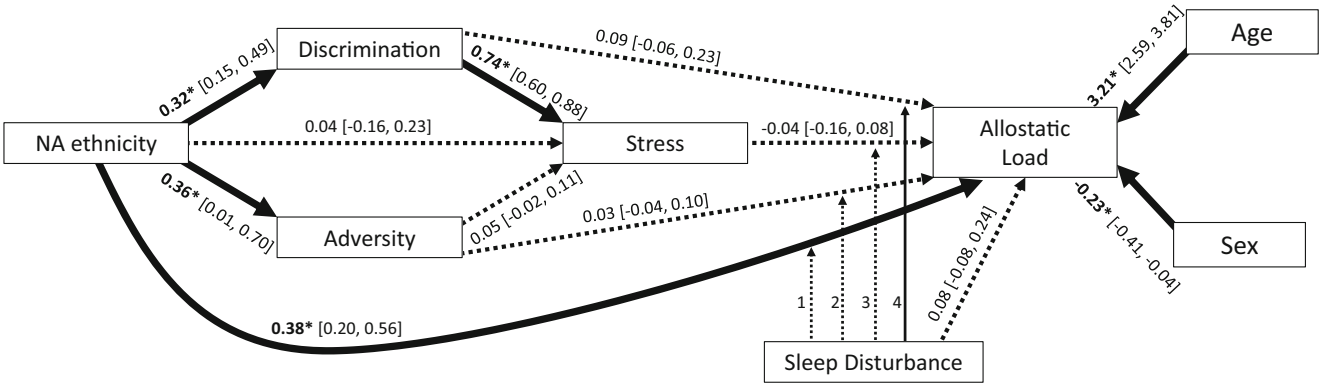
Table 3 Results of indirect (mediated) paths linking Native American ethnicity to cardiometabolic allostatic load in the model with sleep disturbance as a mediator

			Bootstrp	95% CI
Indirect effect	**Effect**	**Boot SE**	**Lower**	**Upper**
NA➔ALEs➔allostatic load	0.0105	0.0154	−0.0136	0.0485
NA➔Discrim➔allostatic load	0.0386	0.0268	−0.0064	0.0989
NA➔Stress➔allostatic load	−0.0010	0.0067	−0.0174	0.0114
NA➔ALEs➔stress➔allostatic load	−0.0005	0.0016	−0.0042	0.0023
NA➔ALEs➔sleep➔allostatic load	0.0007	0.0016	−0.0018	0.0049
NA➔Discrim➔stress➔allostatic load	−0.0064	0.0152	−0.0408	0.0214
NA➔Discrim➔sleep➔allostatic load	0.0005	0.0024	−0.0027	0.0074
NA➔Stress➔sleep➔allostatic load	0.0008	0.0041	−0.0061	0.0110
NA➔ALEs➔stress➔sleep➔allostatic load	0.0004	0.0009	−0.0010	0.0026
NA➔Discrim➔stress➔sleep➔allostatic load	0.0052	0.0082	−0.0091	0.0241

Note. Bold effects/indices are significant

NA Native American, *ALEs* adverse life events, *Discrim* discrimination, *Boot* bootstrapped parameter estimate

If the 95% bootstrapped confidence interval for the index contains zero, then there is no evidence mediation. As noted, no indirect effect was significant



#	Interaction Name	Boot Effect	95% CI Boot Lower	Boot Upper
1	NA Race x Sleep Dis	-0.01	-0.20	0.19
2	Adversity x Sleep Dis	-0.01	-0.08	0.06
3	Stress x Sleep Dis	-0.12	-0.23	0.00
4	Discrimination x Sleep Dis	0.20*	0.03	0.36

Figure 3. Results of the moderated mediation model predicting cardiometabolic allostatic load. Coefficients reported alongside paths are the result of 5000 bootstrapped samples. The 95% bootstrapped confidence interval is reported in brackets next to each coefficient. If the interval contains zero, then the path is nonsignificant (path represented by dotted arrows), but if the interval does not contain zero, then it is significant (solid arrows). Native Americans (NAs) experienced greater discrimination and adverse life events and discrimination was associated with greater psychological distress. However, none of these variables, including sleep disturbance, had a direct effect on cardiometabolic allostatic load. Only Native American ethnicity, older age, and male sex was associated with higher cardiometabolic allostatic load. Results of the interactions with sleep disturbance are also reported and indicate that there was a significant discrimination × sleep disturbance interaction. The tests of moderated mediation indicated that there was a significant mediated pathway (i.e., NA ethnicity➔ discrimination➔ cardiometabolic allostatic load) for those with greater sleep disturbance

load pathway was the only mediated path with significant moderation by sleep disturbance. Results of the conditional indirect effects in Table 4 indicate that there was a significant indirect (mediated) pathway for persons reporting a high level of sleep problems (those at the 84th percentile for sleep problems), but the indirect (mediated) effects were not significant for those at the median or 16th percentile for sleep problems. Together, this suggests that discrimination promotes cardiometabolic allostatic load in Native Americans, but only in those who experience greater sleep disturbance.

Discussion

The current study investigated the relationship between adverse life events (i.e., potentially traumatic events), discrimination, psychological stress, sleep disturbance, and cardiometabolic allostatic load (e.g., blood pressure, BMI, heart rate variability) in Native Americans and non-Hispanic Whites from OK-SNAP. We hypothesized that experiences of adversity and discrimination would lead to psychological stress which would predict higher cardiometabolic allostatic load. Additionally, we compared whether sleep disturbance

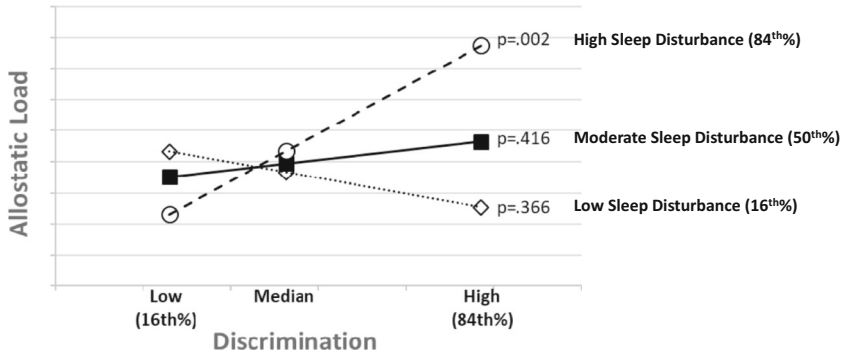


Figure 4. The interaction of discrimination and sleep disturbance in the prediction of cardiometabolic allostatic load. The relationship between discrimination and cardiometabolic allostatic load was significant for those reporting relatively higher levels of sleep disturbance (those at the 84th percentile); but, the relationship was not significant at lower levels of sleep disturbance (at the median or 16th percentile). This suggests that adequate sleep may buffer the negative effects of discrimination on cardiometabolic allostatic load

Table 4. Results of moderated indirect (mediated) paths linking Native American ethnicity to cardiometabolic allostatic load in the model with sleep disturbance as a moderator

	Tests of conditional indirect effects				Tests of moderated mediation			
			Bootstrp	95% CI			Bootstrp	95% CI
Model/conditional indirect effect	**Effect**	**Boot SE**	**Boot lower**	**Boot upper**	**Index**	**Boot SE**	**Boot lower**	**Boot upper**
NA➔ALEs➔allostatic load					−0.006	0.014	−0.035	0.023
Low sleep disturbance (16th%)	0.018	0.023	−0.024	0.072				
Mod sleep disturbance (median)	0.013	0.017	−0.014	0.052				
High sleep disturbance (84th%)	0.006	0.019	−0.026	0.051				
NA➔Discrim➔allostatic load					**0.063***	**0.032**	**0.009**	**0.135**
Low sleep disturbance (16th%)	−0.032	0.041	−0.117	0.047				
Mod sleep disturbance (median)	0.020	0.026	−0.027	0.078				
High sleep disturbance (84th%)*	**0.097**	**0.043**	**0.021**	**0.192**				
NA➔stress-->allostatic load					−0.004	0.013	−0.034	0.021
Low sleep disturbance (16th%)	0.003	0.011	−0.018	0.029				
Mod sleep disturbance (median)	−0.001	0.007	−0.017	0.012				
High sleep disturbance (84th%)	−0.006	0.018	−0.048	0.028				
NA➔ALESs➔stress➔allostatic load					−0.002	0.002	−0.008	0.001
Low sleep disturbance (16th%)	0.001	0.002	−0.002	0.007				
Mod sleep disturbance (median)	0.000	0.002	−0.004	0.002				
High sleep disturbance (84th%)	−0.003	0.003	−0.012	0.001				
NA➔Discrim➔stress➔allostatic load					−0.027	0.016	−0.064	0.001
Low sleep disturbance (16th%)	0.017	0.021	−0.025	0.060				
Mod sleep disturbance (median)	−0.005	0.015	−0.039	0.023				
High sleep disturbance (84th%)	−0.037	0.024	−0.093	0.002				

Note. Bold effects/indices are significant

NA Native American, *ALEs* adverse life events, *Discrim* discrimination, *Boot* bootstrapped parameter estimate

Tests of moderated mediation are on the right-hand side of the table. If the 95% bootstrapped confidence interval for the index contains zero, then there is no evidence for moderation of the mediated effect. Thus, only the indirect pathway with discrimination (i.e., NA➔discrimination➔allostatic load) was significantly moderated. Tests of conditional indirect effects are analogous to simple effects tests that are examined at low (16th percentile), moderate (median), and high (84th percentile) values of the moderator (sleep disturbance). These tests show that discrimination mediated the relationship between NA ethnicity and allostatic load only when participants experienced high levels of sleep problems

*Statistically significant based on 95% bootstrapped confidence interval

mediated or moderated the relationships between cardiometabolic allostatic load and adversity, discrimination, and psychological stress. We found evidence for the moderating effect of sleep on discrimination, such that discrimination partially contributed to the higher levels of cardiometabolic allostatic load in Native Americans in participants who reported higher levels of sleep disturbance. However, we did not find a link between adversity or psychological stress and cardiometabolic allostatic load. Additionally, sleep disturbance was not found to mediate any these relationships.

The main finding of the current study implies that sleep may act as a buffer between the effects of experiences of discrimination and higher cardiometabolic allostatic load. Sleep serves a restorative function and getting adequate sleep is linked to multiple positive health outcomes. Therefore, it is important to understand the relationship between sleep disturbance and variables that increase cardiometabolic risk factors among ethnic minorities [68]. Indeed, high blood pressure, insulin resistance, and hormonal changes are just a few of the consequences of poor sleep [68]. Evidence for shorter sleep duration has been found within Native Americans [69]. That study found relationships between substance abuse, mood disorders, and sleep but did not assess experiences of discrimination or other negative health outcomes. Research with Native Americans has found relationships between poor sleep and higher occurrence of CVD [70, 71]. Similar effects of sleep have been noted with other ethnic minorities. For example, research suggests that, compared to non-Hispanic

Whites, African Americans report their sleep duration is shorter [72] and longer [42], and being on either of the extreme ends of sleep duration has been found to contribute to CVD and diabetes risk [68, 73]. Thus, minorities may be particularly vulnerable to the health consequences of disrupted sleep.

While prior studies observed a direct effect of sleep on various health conditions associated with allostatic load, the current study found that sleep moderated the effects of discrimination on cardiometabolic allostatic load; this divergence in findings, however, may be attributable to differences in inclusion/exclusion criteria. Whereas the aforementioned studies did not utilize stringent exclusion criteria and may therefore be more representative of the general population, the current study excluded all potential participants with chronic pain or other conditions indicative of chronic disease (and thus extreme levels of allostatic load). Consistent with the current study, research investigating sleep within a chronic illness-free African American youth sample found that sleep duration moderated the association between discrimination and mental health, in that shorter sleep duration strengthened the relationship between the experience of discrimination and increased externalizing behaviors [74]. Recent research within a Native American college population found an association between experiences of stress, a sense of belonging, and sleep quality. Specifically, less perceived stress and a sense of belonging to the university were related to better subjective and objective (e.g., actigraphy) sleep outcomes [46]. Interventions targeted to improve sleep quality and decrease the negative physiological and psychological responses that are often linked to poor sleep may help reduce allostatic load.

Similar to other studies, the current study found a relationship between discrimination and cardiometabolic allostatic load, bolstering the body of evidence suggesting that discrimination may contribute to higher allostatic load in racial/ethnic minorities [20, 28, 29, 45]. In addition to our findings, research on Latino day laborers found a link between reports of discrimination and allostatic load [75], and a review specifically addresses how race-based discrimination within African Americans can increase risk of allostatic load [76]. Furthermore, a review of the research on discrimination and racial health disparities [28] highlighted the role of discrimination in negative health outcomes (e.g., elevated blood pressure, cardiovascular disease) via prolonged and repeated activation of the stress response. Perhaps the daily difficulties of heightened stress due to discrimination and the frequency of discriminatory experiences can change the ability of bodily systems to function normally [77]. Interestingly, the current study did not find a direct relationship between psychological distress and cardiometabolic allostatic load. This suggests that discrimination increases cardiometabolic allostatic load via mechanisms that do not involve the psychological experience of stress.

McEwen's model [78] on allostatic load has hypothesized how the stress response can result in negative health outcomes (e.g., heart attack, stroke). Research with Native Americans has also found links between chronic stress and negative health outcomes [49]; however, research on allostatic load within Native Americans is lacking. In fact, recent research by our laboratory [35] and work by Thayer et al. [20] are the only two studies we found that investigated allostatic load within Native Americans. Research published from the Strong Heart Study, a study on cardiovascular disease in Native Americans, has measured markers of allostatic load (e.g., obesity, hypertension) and their relationship with higher rates of cardiovascular disease but have not characterized their effects within the allostatic load framework [79]. Due to the clear relationship between negative health outcomes and allostatic load, the lack of research within the area is of significant concern. Until the forces that promote discrimination against Native Americans undergo fundamental changes (i.e., structural racism), interventions aimed at mitigating the negative consequences of discrimination may be beneficial in decreasing the risk for allostatic load.

In addition to heightened experiences of discrimination, Native Americans in this sample reported more adverse life events, defined as endorsing potentially traumatic events by answering "happened to me" on LEC items. Research has shown that these adverse life events contribute to negative health outcomes [80] and that anticipated stress or memories of stress lead to long-term physiological changes that contribute to allostatic load [1, 81]. The research on adverse childhood events and allostatic load suggests that early history of maltreatment can modify the adaptive maturation of allostatic systems and contribute to maladaptive physiological responses that endure into adulthood [80]. Interestingly, the current study did not find direct or indirect paths between adverse life events and cardiometabolic allostatic load. Although research is quite conclusive on how adverse life events can negatively impact health, many factors contribute to this maladaptive development. For example, the nature of the adverse childhood event, including frequency, duration, and type, as well as individual characteristics of resilience are related to how adverse childhood events impact allostatic systems [80]. Our Native American sample consists of healthy, pain-free individuals and thus may represent a more resilient segment of the population. Nonetheless, compared to non-Hispanic Whites, Native Americans in our sample reported significantly more adverse life events; thus, they are most likely at risk for having future negative health outcomes to which these events contribute. In fact, preliminary results from longitudinal assessments of OK-SNAP participants suggest that Native Americans develop chronic pain (defined as pain lasting >3 months with an intensity rated ≥3 out of 10) at ~3× the rate of non-Hispanic Whites [82].

In addition to the direct pathways linking discrimination and adverse life events to cardiometabolic allostatic load, we also hypothesized that discrimination and adverse life events would result in increased psychological distress, which would in turn predict cardiometabolic allostatic load. Although Native Americans experienced more discrimination and adverse life events, and discrimination was associated with psychological stress, no psychosocial variable had a direct effect on cardiometabolic allostatic load. Thus, our fully mediated model was not supported. Surprisingly, adverse life events were not associated with greater stress in our models, but did have a significant zero-order correlation with stress in Table 2. This implies that discrimination had a stronger relationship with experienced stress than adversity in our sample. These results highlight the importance of considering what other variables could contribute to high cardiometabolic allostatic load in this Native American sample. Native Americans have endured generations of chronic stress including forced relocation and forced boarding school placements, referred to as historical trauma. Research has shown that these factors increase risk for negative health outcomes [12, 14, 19, 79]. The current study did not measure historical trauma; thus, future research should determine if it contributes to allostatic load in Native Americans.

Epigenetic research, which focuses on understanding how gene expression is influenced by social and physical environments, has demonstrated that diet and activity level early in life are determinants of diabetes risk [83]. Longitudinal research within the Pima Nation has found that offspring of mothers with diabetes during pregnancy developed diabetes earlier in life compared to mothers without diabetes during their pregnancies [84, 85]. More epigenetic research, done with tribal engagement and consent, would be helpful to aid our understanding of how these variables may contribute to other negative health outcomes, such as high allostatic load, particularly in Native Americans.

As mentioned throughout the manuscript, allostatic load is associated with numerous health complications including cardiovascular disease and diabetes [7, 86]. Our recent findings suggest that cardiometabolic allostatic load could also contribute to chronic pain risk [35]. Given the negative effects of lifetime experiences of adversity and discrimination as well as allostatic load on psychological and physical health, amelioration of ongoing structural, institutional, and interpersonal discrimination of Native Americans is necessary to reduce the disproportionality at which Native Americans experience health outcomes related to allostatic load. Until such structural changes are made, however, specific interventions aimed at reducing the effects of these experiences within the Native American community will be important to develop and assess for effectiveness.

While this study was able to identify a novel moderated pathway that contributes to greater allostatic load in Native Americans, it also faced limitations. First, the current study only included healthy, pain-free participants in order to identify early markers of pain and health risk. Therefore, this sample excluded people who had already developed conditions associated with allostatic load, likely restricting the range of cardiometabolic allostatic load measured (e.g., BMI, blood pressure, HRV). Although a robust sample of Native Americans was collected, the sample size might have limited the power needed to fully investigate some mediational relationships. Additionally, the findings may not generalize to people with chronic pain or other conditions associated with allostatic load and the cross-sectional data prevented the ability to investigate the sequential order of variables that were involved in the mediational analyses and eliminated the ability to make any causal conclusions. Furthermore, the sample used in this study consisted only of Native Americans and non-Hispanic Whites and may not generalize to other racial/ethnic groups. Given that some participants who enrolled in OK-SNAP did not complete both days, generalizability may be reduced further due to attrition effects; however, previous analyses of this sample have found few group differences between completers and non-completers [47]. Nonetheless, we did find that non-completers experienced higher insomnia severity, so this could have impacted our ability to observe other effects of sleep disturbance. Also, our assessment of ALEs was limited to potentially traumatic events on the LEC-4. Other types of ALEs (e.g., homelessness, poverty, unemployment) may also play an important role in allostatic load and should be considered in future studies. Of note, this study did not measure immune and neuroendocrine markers which may have prevented us from assessing the full scope of allostatic load in our analyses. Finally, the statistical models used in the study only controlled for age and biological sex in the prediction of cardiometabolic allostatic load, such that the influence of other variables related to cardiometabolic allostatic load (e.g., diet, tobacco use) could not be accounted for.

In summary, the current study found that discrimination was associated with increased cardiometabolic allostatic load in Native Americans who also experienced sleep disturbance. Since allostatic load is associated with a multitude of negative health outcomes and likely contributes to health disparities across racial/ethnic groups, this finding is important because it identifies sleep, a modifiable health behavior, as a preventative and proximate target for intervention. Because sleep problems may stem from the effects of adversity and discrimination, however, systematic efforts aiming to reduce structural racism and improve overall conditions of Native Americans are needed. Future studies that investigate the relationship between historical trauma, adverse life events, discrimination, and allostatic load are important and will aid in our ability to better understand and decrease health disparities in ethnic/racial minorities.

Data and Materials Availability Means, standard deviations, and intercorrelations necessary to replicate the analyses are provided in the manuscript. Deidentified raw data are available upon request.

Author Contribution J.O.S. served as one of the primary investigators, designed the study, and wrote most of the manuscript. P.A.K. helped write the manuscript. T.A.T., F.A.H., B.L.K., E.W.L., N.H., C.A.S., and E.N.R. collected data and provided revisions to the manuscript. J.L.R. served as the primary investigator, designed the study, analyzed the data, and helped write the manuscript. All authors read and approved the final manuscript.

Funding This research was supported by the National Institute on Minority Health and Health Disparities of the National Institute of Health under award number R01MD007807. Edward Lannon was supported by a National Science Foundation Graduate Research Fellowship Program.

Declarations

Ethics Approval The study was approved by IRBs of The University of Tulsa, Cherokee Nation, and the Indian Health Service Oklahoma City Area Office.

Conflicts of Interest The authors declare no competing interests.

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