International Journal of Research in Medical Sciences
*Adekola AT et al. Int J Res Med Sci. 2026 Oct;14(10):4230-4237*
www.msjonline.org
pISSN 2320-6071 | eISSN 2320-6012
DOI: https://dx.doi.org/10.18203/2320-6012.ijrms20263488

**Original Research Article**

# The combined effects of blood lead exposure and chronic psychosocial stress on cardiovascular, inflammatory and cardiometabolic biomarkers among U. S. adults: a survey-weighted analysis of NHANES 2013-2014

**Adedayo T. Adekola[1]*, Ekta Kumar[2]**

[1]West Haven, Connecticut, USA
[2]Cape Breton University, Nova Scotia, Canada

**Received:** 20 August 2026
**Revised:** 19 September 2026
**Accepted:** 24 September 2026

***Correspondence:**
Dr. Adedayo T. Adekola,
E-mail: adedayotoluwanimi@gmail.com



## ABSTRACT

**Background:** Lead exposure remains a public health concern, with low-level exposure associated with adverse cardiovascular and inflammatory outcomes. Depressive symptoms may influence cardiovascular responses to environmental toxicants through overlapping biological pathways. This study examined whether depressive symptom burden modified associations between blood lead exposure and cardiovascular, inflammatory, and cardiometabolic biomarkers among U. S. adults.

**Methods:** A cross-sectional analysis was conducted using NHANES 2013-2014 data. The analytic sample included 5,924 adults with available blood lead, patient health questionnaire-9 (PHQ-9), outcome, and covariate data. Survey-weighted multivariable linear regression models accounted for the NHANES complex sampling design and examined interactions between blood lead concentration and PHQ-9 score for mean systolic and diastolic blood pressure (SBP and DBP), pulse rate, white blood cell count, and low-density lipoprotein cholesterol. Models were adjusted for age, sex, race/ethnicity, body mass index (BMI), and poverty-income ratio (PIR).

**Results:** A statistically significant interaction between blood lead concentration and PHQ-9 score was observed for mean SBP ($\beta$=-0.201, p=0.047). No significant interactions were observed for DBP, pulse rate, white blood cell count, or low-density lipoprotein cholesterol (all p>0.05).

**Conclusions:** Depressive symptom burden modified the association between blood lead concentration and SBP but not the other biomarkers examined. These findings support considering environmental and psychosocial factors jointly when evaluating cardiovascular effects of lead exposure. Longitudinal studies are needed to confirm this interaction and clarify its underlying mechanisms.

**Keywords:** Blood lead, Psychosocial stress, PHQ-9, NHANES, Systolic blood pressure, Cardiovascular health

## INTRODUCTION

Lead remains one of the most pervasive environmental toxicants worldwide and continues to pose a significant public health challenge despite substantial reductions in environmental exposure over the past several decades. Historically, lead was widely used in gasoline, paints, plumbing materials, batteries, and numerous industrial processes, resulting in extensive contamination of air, soil, water, and household environments. Although regulatory actions have markedly reduced population blood lead concentrations in the United States, exposure persists through aging housing infrastructure, contaminated drinking water, occupational settings, industrial emissions,

consumer products, and environmental reservoirs. Even at relatively low concentrations, lead has no known physiological benefit and has been associated with adverse health effects across multiple organ systems.[1,2] The cardiovascular consequences of lead exposure have received considerable attention. Experimental and epidemiological studies have demonstrated associations between blood lead concentration and elevated blood pressure and increased risk of cardiovascular disease.[3,4] Lead-related cardiovascular effects have been linked to oxidative stress, inflammation, endothelial dysfunction, and other disturbances in vascular function, providing biological plausibility for its contribution to cardiovascular disease.[5]

Psychosocial stress has likewise emerged as an important determinant of cardiovascular and metabolic health. Chronic psychological stress can activate physiological stress-response systems, including the hypothalamic-pituitary–adrenal axis and sympathetic nervous system, contributing to sustained physiological activation and adverse cardiovascular outcomes.[6] Depression and depressive symptoms have also been associated with increased cardiovascular morbidity and mortality.[7]

Although previous studies have reported associations between lead exposure and cardiovascular outcomes and others have examined the independent effects of psychological stress and depression on cardiometabolic health, relatively few investigations have evaluated whether psychosocial factors modify the relationship between blood lead exposure and physiological biomarkers in nationally representative populations. Furthermore, comparatively little evidence is available regarding the combined influence of blood lead concentration and psychosocial factors across multiple biological systems within the U. S. adult population. Evidence examining the combined effects of lead exposure and allostatic load on cardiovascular disease mortality further suggests that interactions between environmental exposures and chronic physiological stress warrant additional investigation.[8]

The National Health and Nutrition Examination Survey (NHANES) provide a unique opportunity to address this knowledge gap because it combines standardized laboratory measurements, comprehensive health examinations, and detailed demographic and health information within a nationally representative sample of the U.S. population. By integrating objective biomarker data with measures of depressive symptoms, NHANES enables the simultaneous evaluation of environmental exposures, psychosocial factors, and clinically relevant health outcomes while accounting for the complex sampling design required to produce nationally representative estimates.

Therefore, the primary objective of this study was to examine the combined effects of blood lead exposure and depressive symptom burden on cardiovascular, inflammatory, and cardiometabolic biomarkers among U.S. adults using NHANES 2013-2014 data. Specifically, we evaluated whether depressive symptom burden, measured using the PHQ-9, modified the association between blood lead concentration and mean SBP, mean DBP, pulse rate, white blood cell count, and low-density lipoprotein cholesterol after adjustment for demographic, socioeconomic, and anthropometric covariates. The PHQ-9 is a validated instrument for assessing depressive symptom severity.[9] We hypothesized that higher depressive symptom burden would modify the association between blood lead exposure and these biomarkers, reflecting the potential combined influence of environmental and psychosocial factors on cardiovascular and systemic health.

## METHODS

### *Study design*

This cross-sectional study used publicly available data from the 2013-2014 NHANES. NHANES is a nationally representative survey conducted by the National Center for Health Statistics (NCHS), Centers for Disease Control and Prevention (CDC), to assess the health and nutritional status of the civilian, non-institutionalized U.S. population. The survey combines household interviews, standardized physical examinations, and laboratory testing using a complex, multistage probability sampling design, described in detail in the NHANES sampling methodology documentation cited below.[10] The present study investigated whether depressive symptom burden modified the association between blood lead exposure and selected cardiovascular, inflammatory, and cardiometabolic biomarkers.

Data were collected across multiple survey locations throughout the United States via Mobile Examination Centers rather than at a single hospital or clinical site: in the 2013-2014 cycle, 14,332 persons were selected for NHANES from 30 different survey locations nationwide, of whom 10,175 completed the interview and 9,813 were examined, consistent with the nationally representative design of NHANES.

### *Data source*

Data were obtained from the publicly available NHANES 2013-2014 cycle. NCHS releases NHANES data in two-year cycles (the present cycle is designated release cycle number 8); exact month-level field start and end dates for this cycle are not published in the publicly available NHANES documentation. Six datasets were downloaded from the CDC NHANES website and merged using the unique participant identifier (SEQN): Demographics, examination, laboratory, questionnaire, dietary and prescription medication.

Only variables required for the objectives of this study were retained for analysis.

### *Study population*

Adults who participated in the mobile examination center (MEC) examination during NHANES 2013-2014 were eligible for inclusion. Participants were included if they had available measurements for blood lead concentration, completed the PHQ-9, and had data available for at least one study outcome and the covariates included in the adjusted regression models.

The merged analytic dataset comprised 5,924 participants. Because individual outcome variables contained different patterns of missing data, survey-weighted regression models were estimated using complete-case analysis for each outcome, consistent with the default behavior of the svyglm() function in R. Consequently, the effective sample size varied slightly across individual regression models.

### *Exposure variable*

*Blood lead concentration*

Blood lead concentration (LBXBPB; µg/dl) was the primary exposure variable.

According to NHANES laboratory protocols, whole blood lead concentrations were measured using inductively coupled plasma mass spectrometry (ICP-MS) under standardized quality-control procedures established by CDC.

Blood lead concentration was analyzed as a continuous variable in all regression models. Quartiles of blood lead concentration were generated during data preparation for descriptive purposes but were not used in the primary multivariable analyses.

### *Assessment of depressive symptom burden*

Depressive symptom burden was assessed using the PHQ-9, a nine-item screening instrument validated for assessing depressive symptoms experienced during the previous two weeks, as established in the original validation study cited below.[9]

Each item is scored from 0 ("not at all") to 3 ("nearly every day"), producing a total score ranging from 0-27, with higher scores indicating greater depressive symptom severity.

Although the PHQ-9 does not directly measure psychosocial stress, depressive symptoms are closely related to chronic psychological distress and have been widely used in epidemiological studies as an indicator of psychological burden.

Therefore, PHQ-9 score was used as the modifier variable in the interaction analyses.

### *Outcome variables*

Five biomarkers representing cardiovascular, inflammatory, and cardiometabolic health were evaluated.

### *Cardiovascular biomarkers*

Mean SBP was calculated as the average of all available SBP measurements recorded during the standardized NHANES examination.

Mean DBP was calculated as the average of all available DBP measurements. Resting pulse rate (BPXPLS), measured during the physical examination, was included as an additional cardiovascular biomarker.

### *Inflammatory biomarker*

White blood cell count (LBXWBCSI) was included as an indicator of systemic inflammation.

### *Cardiometabolic biomarker*

Low-density lipoprotein cholesterol (LBDLDL) was included as a cardiometabolic biomarker because of its established role in cardiovascular risk assessment.

### *Covariates*

Potential confounding variables were selected a priori based on established evidence linking them to both lead exposure and cardiovascular health. The following variables were included in all adjusted models: Age (years; continuous), sex (male/female), race/ethnicity, PIR and BMI (kg/m$^2$). Age, BMI, and PIR were analyzed as continuous variables. Sex and race/ethnicity were included as categorical variables.

### *Data management and variable construction*

Data management and statistical analyses were performed using R statistical software (Version 4.x).

Individual NHANES datasets were merged using participant identification no. (SEQN). Prior to analysis, variables were reviewed for completeness, coding consistency, implausible values, and missing observations.

The following derived variables were created: Mean SBP (SBP_MEAN), mean DBP (DBP_MEAN), total PHQ-9 score, body mass index category (descriptive analyses only) and blood lead quartiles (descriptive analyses only).

Continuous variables were retained in their original scale for regression analyses to maximize statistical efficiency and minimize information loss.

### *Statistical analysis*

All analyses accounted for the complex NHANES sampling design.

Survey-weighted analyses incorporated: Mobile examination center examination weights (WTMEC2YR), sampling strata (SDMVSTRA), and primary sampling units (SDMVPSU).

The survey design object was created using the survey package in R.

Separate survey-weighted multivariable linear regression models were fitted for each outcome variable: Mean SBP, mean DBP, resting pulse rate, white blood cell count and low-density lipoprotein cholesterol.

Each model included blood lead concentration, PHQ-9 score, and a multiplicative interaction term (Blood Lead × PHQ-9) to evaluate whether depressive symptom burden modified the association between blood lead exposure and each biomarker.

All models were adjusted for age, sex, race/ethnicity, PIR, and body mass index.

Regression coefficients (β), standard errors (SE), 95% confidence intervals (CI), and two-sided p values were reported. Statistical significance was defined as a two-sided $p<0.05$.

This study followed the Strengthening the Reporting of Observational Studies in Epidemiology (STROBE) guidelines for the reporting of cross-sectional studies.

### *Ethical considerations*

NHANES protocols were approved by the NCHS Research Ethics Review Board, and written informed consent was obtained from all participants before data collection. The present study analyzed publicly available, de-identified data and therefore did not require additional institutional ethics approval.

## RESULTS

### *Study population characteristics*

The final analytic sample comprised 5,924 U.S. adults from the NHANES 2013-2014 cycle. The weighted mean age was 47.48 years, mean BMI was 28.89 kg/m², and mean waist circumference was 98.91 cm. Mean blood lead concentration was 1.25 µg/d, and the mean PHQ-9 score was 2.99. Weighted mean SBP and DBP were 120.87 mmHg and 68.32 mmHg, respectively. Mean resting pulse rate was 71.57 beats/min, WBC count was 6.94×10⁹/L, and LDL cholesterol was 112.17 mg/dl.

The weighted sample was 48.1% male and 51.9% female, with non-Hispanic White participants representing the largest racial/ethnic group (65.5%). Detailed characteristics are presented in Table 1.

**Table 1: Weighted baseline characteristics of U. S. adults included in the NHANES 2013-2014 analytic sample, (n=5,924).**

| Characteristics | Weighted estimate |
|---|---|
| **Study population** | 5,924 |
| Age (in years), mean±SE | 47.48±0.77 |
| **Sex** | |
| Male | 48.12% |
| Female | 51.88% |
| **Race/ethnicity** | |
| Mexican American | 9.38% |
| Other Hispanic | 5.55% |
| Non-Hispanic white | 65.53% |
| Non-Hispanic black | 11.48% |
| Other race/multiracial | 8.06% |
| PIR, mean±SE | 2.91±0.11 |
| BMI (kg/m²), mean±SE | 28.89±0.31 |
| Waist circumference (cm), mean±SE | 98.91±0.77 |
| Blood lead (µg/dl), mean±SE | 1.25±0.06 |
| PHQ-9 score, mean±SE | 2.99±0.11 |
| Mean SBP (mmHg), mean±SE | 120.87±0.76 |
| Mean DBP (mmHg), mean±SE | 68.32±0.49 |
| Resting pulse rate (beats/min), mean±SE | 71.57±0.75 |
| White blood cell Count (×10⁹/l), mean±SE | 6.94±0.08 |
| LDL cholesterol (mg/dl), mean±SE | 112.17±1.30 |

*LDL, low-density lipoprotein cholesterol; SE, standard error.

### *Survey-weighted multivariable regression analyses*

Survey-weighted multivariable linear regression models were used to examine the associations of blood lead concentration, PHQ-9 score, and their interaction with SBP, DBP, resting pulse rate, WBC count, and LDL cholesterol. Models accounted for the NHANES complex survey design using the MEC examination weight (WTMEC2YR), masked variance strata (SDMVSTRA), and masked variance pseudo-PSUs (SDMVPSU), consistent with CDC NHANES analytic guidance.

### *SBP*

A statistically significant interaction was observed between blood lead concentration and PHQ-9 score for mean SBP (β=-0.201, SE=0.071, 95% CI: -0.397 to -0.005, p=0.047). This indicates that the estimated association between blood lead concentration and SBP varied according to depressive symptom burden.

Neither blood lead concentration (β=0.972, 95% CI: -0.333 to 2.278, p=0.108) nor PHQ-9 score (β=0.137, 95% CI: -0.271 to 0.545, p=0.404) was independently associated with SBP after adjustment. Among the covariates, older age (β=0.397, p<0.001), female sex (β=-4.271, p=0.004), and higher BMI (β=0.396, p=0.002) were significantly associated with SBP.

### *DBP*

No statistically significant interaction between blood lead concentration and PHQ-9 score was observed for mean DBP (β=-0.105, SE=0.064, 95% CI: -0.283 to 0.073, p=0.176). Neither blood lead concentration nor PHQ-9 score was independently associated with DBP. Female participants had lower DBP than males (β=-1.843, p=0.025), while PIR (β=0.603, p=0.030) and BMI (β=0.317, p<0.001) were positively associated with DBP.

### *Resting pulse rate*

The interaction between blood lead concentration and PHQ-9 score was not statistically significant for resting pulse rate (β=-0.004, 95% CI: -0.175 to 0.168, p=0.956). Blood lead concentration was not associated with pulse rate (β=0.059, p=0.860), while PHQ-9 score showed a positive but non-significant association (β=0.215, p=0.074). Older age was associated with lower pulse rate (β=-0.141, p<0.001), whereas female sex (β=1.973, p=0.043) and BMI (β=0.147, p=0.045) were positively associated with pulse rate.

### *White blood cell count*

No statistically significant interaction was observed between blood lead concentration and PHQ-9 score for WBC count (β=0.018, 95% CI: -0.009 to 0.045, p=0.140). Neither blood lead concentration nor PHQ-9 score was independently associated with WBC count. Older age was associated with lower WBC count (β=-0.019, p=0.004), whereas BMI was positively associated with WBC count (β=0.066, p<0.001).

### *LDL cholesterol*

Neither blood lead concentration (β=0.946, 95% CI: -2.365 to 4.257, p=0.472), PHQ-9 score (β=-0.519, 95% CI: -1.460 to 0.422, p=0.200), nor their interaction (β=0.167, 95% CI: -0.460 to 0.794, p=0.500) was significantly associated with LDL cholesterol after multivariable adjustment.

Overall, the interaction between blood lead concentration and depressive symptom burden was statistically significant only for SBP, with no significant interactions observed for DBP, resting pulse rate, WBC count, or LDL cholesterol. The complete regression estimates are presented in Table 2.

**Table 2: Survey-weighted multivariable linear regression examining the association between blood lead concentration, depressive symptom burden, and cardiovascular, inflammatory, and cardiometabolic biomarkers among U. S. Adults, NHANES 2013-2014.**

| Outcomes | Predictor | β | SE | 95% CI | P value |
|---|---|---|---|---|---|
| **Mean SBP** | Blood lead | 0.972 | 0.470 | -0.333 to 2.278 | 0.108 |
| | PHQ-9 score | 0.137 | 0.147 | -0.271 to 0.545 | 0.404 |
| | Blood lead × PHQ-9 | -0.201 | 0.071 | -0.397 to -0.005 | 0.047 |
| | Age (in years) | 0.397 | 0.034 | 0.304 to 0.491 | <0.001 |
| | Female (vs male) | -4.271 | 0.734 | -6.309 to -2.233 | 0.004 |
| | PIR | -0.572 | 0.260 | -1.294 to 0.149 | 0.092 |
| | BMI | 0.396 | 0.052 | 0.251 to 0.541 | 0.002 |
| **Mean DBP** | Blood lead | 0.377 | 0.209 | -0.202 to 0.956 | 0.145 |
| | PHQ-9 score | 0.023 | 0.091 | -0.231 to 0.276 | 0.815 |
| | Blood lead × PHQ-9 | -0.105 | 0.064 | -0.283 to 0.073 | 0.176 |
| | Age (in years) | 0.005 | 0.025 | -0.064 to 0.074 | 0.858 |
| | Female (vs Male) | -1.843 | 0.525 | -3.300 to -0.386 | 0.025 |
| | PIR | 0.603 | 0.183 | 0.094 to 1.110 | 0.030 |
| | BMI | 0.317 | 0.034 | 0.222 to 0.412 | <0.001 |

Continued.

| Outcomes | Predictor | β | SE | 95% CI | P value |
|---|---|---|---|---|---|
| **Pulse rate** | Blood lead | 0.059 | 0.314 | -0.813 to 0.932 | 0.860 |
| | PHQ-9 score | 0.215 | 0.089 | -0.033 to 0.462 | 0.074 |
| | Blood lead × PHQ-9 | -0.004 | 0.062 | -0.175 to 0.168 | 0.956 |
| | Age (in years) | -0.141 | 0.010 | -0.170 to -0.112 | <0.001 |
| | Female (vs Male) | 1.972 | 0.673 | 0.105 to 3.840 | 0.043 |
| | PIR | -0.338 | 0.196 | -0.881 to 0.206 | 0.160 |
| | BMI | 0.147 | 0.051 | 0.005 to 0.289 | 0.045 |
| **White blood cell count** | Blood lead | 0.004 | 0.055 | -0.149 to 0.157 | 0.941 |
| | PHQ-9 score | 0.013 | 0.024 | -0.053 to 0.078 | 0.614 |
| | Blood lead × PHQ-9 | 0.018 | 0.010 | -0.009 to 0.045 | 0.140 |
| | Age (in years) | -0.019 | 0.003 | -0.028 to -0.010 | 0.004 |
| | Female vs male | 0.105 | 0.148 | -0.306 to 0.516 | 0.517 |
| | PIR | -0.154 | 0.029 | -0.233 to -0.075 | 0.006 |
| | BMI | 0.066 | 0.007 | 0.047 to 0.085 | <0.001 |
| **LDL cholesterol** | Blood lead | 0.946 | 1.193 | -2.370 to 4.262 | 0.472 |
| | PHQ-9 score | -0.519 | 0.339 | -1.460 to 0.422 | 0.200 |
| | Blood lead × PHQ-9 | 0.167 | 0.226 | -0.460 to 0.794 | 0.500 |
| | Age (in years) | 0.151 | 0.084 | -0.083 to 0.385 | 0.147 |
| | Female vs male | 0.045 | 2.789 | -7.690 to 7.780 | 0.988 |
| | PIR | 1.093 | 0.866 | -1.310 to 3.500 | 0.276 |
| | BMI | 0.338 | 0.194 | -0.201 to 0.876 | 0.157 |

*CI, confidence interval; LDL, low-density lipoprotein cholesterol; standard error.

### *Model adjustment*

All models were adjusted for age, sex, race/ethnicity, PIR, and body mass index using the NHANES 2013-2014 complex survey design (WTMEC2YR, SDMVSTRA, and SDMVPSU).

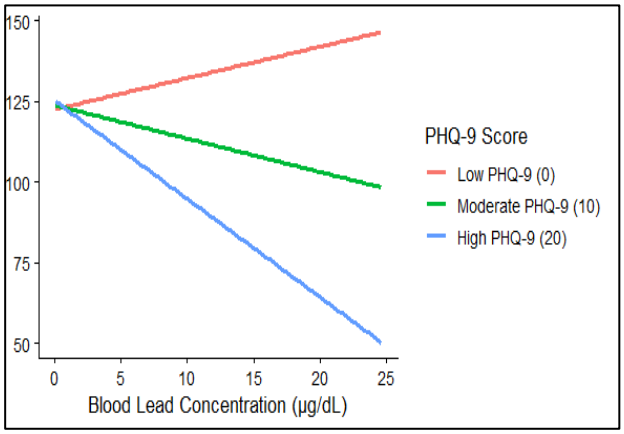


**Figure 1: Predicted mean SBP according to blood lead concentration at low, moderate, and high depressive symptom burden among U. S. adults, NHANES 2013-2014.**

## DISCUSSION

This nationally representative cross-sectional study examined whether depressive symptom burden modified the association between blood lead concentration and cardiovascular, inflammatory, and cardiometabolic biomarkers among U.S. adults using NHANES 2013-2014 data. After accounting for the complex survey design and adjusting for demographic and socioeconomic factors, a statistically significant interaction was observed between blood lead concentration and depressive symptom burden in relation to mean SBP. Specifically, the positive association between blood lead concentration and SBP became weaker as PHQ-9 scores increased. No statistically significant interactions were observed for DBP, resting pulse rate, white blood cell count, or LDL cholesterol. These findings suggest that depressive symptom burden may modify the relationship between lead exposure and SBP, although this effect was not evident across the other outcomes examined.

Notably, neither blood lead concentration nor PHQ-9 score was independently associated with SBP after multivariable adjustment, whereas their interaction remained statistically significant. The interaction plot showed that SBP increased with increasing blood lead concentration among individuals with lower depressive symptom burden, while this association was attenuated at higher PHQ-9 scores. This should not be interpreted as evidence that depressive symptoms protect against the cardiovascular effects of lead. Rather, it indicates heterogeneity in the estimated lead–SBP relationship across levels of depressive symptoms. Previous epidemiological evidence has documented associations between lead exposure and blood pressure, although findings have not been entirely consistent at low exposure levels. Unmeasured factors such as medication use, healthcare utilization, lifestyle behaviors, or other clinical characteristics may contribute to the observed pattern.

The findings are broadly consistent with evidence linking lead exposure to adverse cardiovascular effects, including elevated blood pressure. Previous systematic reviews and meta-analyses have reported associations between lead exposure and cardiovascular disease and blood-pressure outcomes.[11] Lead-related oxidative stress, endothelial dysfunction, impaired nitric oxide availability, vascular remodeling, and altered renal or neuroendocrine regulation may contribute to blood-pressure changes.[5,22] Experimental and epidemiological evidence also indicates that lead exposure may affect inflammatory and vascular processes that contribute to cardiovascular dysfunction.[13] Depressive symptoms may influence cardiovascular regulation through sympathetic nervous system activation, hypothalamic-pituitary-adrenal axis dysregulation, inflammation, and behavioral factors.[14] The overlap between these pathways provides biological plausibility for an interaction; however, the observed attenuation cannot establish a specific mechanism. The lack of significant interactions for the other outcomes may indicate outcome-specific effects or insufficient power to detect smaller associations.

Several covariates showed expected associations with cardiovascular and inflammatory outcomes. Older age and higher BMI were associated with several measures of cardiovascular risk, while sex and PIR were also related to selected outcomes. These findings reinforce the importance of accounting for demographic and socioeconomic characteristics when evaluating environmental health relationships. The study has important strengths, including the use of nationally representative NHANES data, standardized blood lead measurements, the validated PHQ-9 instrument, and appropriate accounting for the complex survey design. However, the cross-sectional design prevents conclusions regarding temporality or causality. Residual confounding from smoking, alcohol use, physical activity, diet, occupational exposure, medication use, and chronic disease may remain. In addition, blood lead primarily reflects relatively recent exposure and may not capture cumulative lifetime exposure. This distinction is important because previous research has demonstrated that cumulative lead burden, including bone lead concentrations, may provide information about longer-term exposure that is not captured by blood lead alone.[15]

Overall, these findings suggest that depressive symptom burden may contribute to variation in the association between lead exposure and SBP. Because the interaction was observed for only one outcome, the finding should be considered hypothesis-generating and requires confirmation in longitudinal studies with repeated exposure and biomarker measurements. In addition, interaction terms were tested across five separate outcome models without correction for multiple comparisons; given this, and the borderline p value for the single significant interaction (p=0.047), this result should be interpreted cautiously and treated as exploratory rather than confirmatory. Future research should also investigate whether cumulative lead exposure, chronic psychosocial stress, inflammatory pathways, and cardiovascular risk factors jointly explain differences in the lead-blood pressure relationship.

## CONCLUSION

This study identified a statistically significant interaction between blood lead concentration and depressive symptom burden in relation to mean SBP among U.S. adults using nationally representative NHANES 2013-2014 data. The association between blood lead concentration and SBP varied across levels of depressive symptoms, suggesting that psychological health may contribute to differences in cardiovascular responses to environmental lead exposure. However, no statistically significant interactions were observed for DBP, resting pulse rate, white blood cell count, or LDL cholesterol. Given the cross-sectional design, these findings cannot establish temporal or causal relationships and should therefore be considered hypothesis-generating. Longitudinal studies incorporating repeated assessments of lead exposure, depressive symptoms, and cardiovascular biomarkers are needed to determine whether the observed interaction is reproducible and to clarify the mechanisms underlying this association. Nevertheless, the findings support the importance of considering environmental exposures and psychosocial factors jointly when investigating cardiovascular health, particularly in populations exposed to low levels of lead.

## ACKNOWLEDGEMENTS

Authors would like to thank to the National Center for Health Statistics (NCHS) and the Centers for Disease Control and Prevention (CDC) for making the National Health and Nutrition Examination Survey (NHANES) data publicly available. The author also acknowledges the NHANES participants whose involvement made this research possible.

*Funding: No funding sources*
*Conflict of interest: None declared*
*Ethical approval: The study was approved by the Institutional Ethics Committee*

## REFERENCES

1. Alissa EM, Ferns GA. Heavy metal poisoning and cardiovascular disease. J Toxicol. 2011;2011:870125.
2. Chowdhury R, Ramond A, O'Keeffe LM, Shahzad S, Kunutsor SK, Muka T, et al. Environmental toxic metal contaminants and risk of cardiovascular disease: systematic review and meta-analysis. BMJ. 2018;362:k3310.
3. Navas-Acien A, Guallar E, Silbergeld EK, Rothenberg SJ. Lead exposure and cardiovascular disease-a systematic review. Environ Health Perspect. 2007;115(3):472-82.
4. Navas-Acien A, Schwartz BS, Rothenberg SJ, Hu H, Silbergeld EK, Guallar E. Bone lead levels and blood

pressure endpoints: a meta-analysis. Epidemiology. 2008;19(3):496-504.
5. He P, Yang C, He D, Zhao S, Xie Y, Wang H, et al. Blood lead, systemic inflammation, and blood pressure: exploring associations and mediation effects in workers exposed to lead. Biol Trace Elem Res. 2021;199(7):2573-81.
6. Gasperin D, Netuveli G, Dias-da-Costa JS, Pattussi MP. Effect of psychological stress on blood pressure increase: a meta-analysis of cohort studies. Cad Saude Publica. 2009;25(4):715-26.
7. Hare DL, Toukhsati SR, Johansson P, Jaarsma T. Depression and cardiovascular disease: a clinical review. Eur Heart J. 2014;35(21):1365-72.
8. Obeng-Gyasi E, Ferguson AC, Stamatakis KA, Province MA. Combined effect of lead exposure and allostatic load on cardiovascular disease mortality-a preliminary study. Int J Environ Res Public Health. 2021;18(13):6879.
9. Kroenke K, Spitzer RL, Williams JB. The PHQ-9: validity of a brief depression severity measure. J Gen Intern Med. 2001;16(9):606-13.
10. Centers for Disease Control and Prevention (CDC), National Center for Health Statistics (NCHS). National Health and Nutrition Examination Survey, 2013-2014. Hyattsville (MD): U.S. Department of Health and Human Services. 2015. Available at: https://wwwn.cdc.gov/nchs/nhanes/continuousnhanes/. Accessed on 02 August 2026.
11. Wang L, Wang C, Liu T, Xuan H, Li X, Shi X, et al. Association of low-level lead exposure with all-cause and cardiovascular disease mortality in US adults with hypertension: evidence from the National Health and Nutrition Examination Survey 2003-2010. Arch Public Health. 2023;81:146.
12. Staessen JA, Roels H, Lauwerys RR, Amery A. Low-level lead exposure and blood pressure. J Hum Hypertens. 1995;9(5):303-28.
13. Mishra KP. Lead exposure and its impact on immune system: a review. Toxicol In Vitro. 2009;23(6):969-72.
14. Lichtman JH, Froelicher ES, Blumenthal JA, Carney RM, Doering LV, Frasure-Smith N, et al. Depression as a risk factor for poor prognosis among patients with acute coronary syndrome: systematic review and recommendations: a scientific statement from the American Heart Association. Circulation. 2014;129(12):1350-69.
15. Pirkle JL, Schwartz J, Landis JR, Harlan WR. The relationship between blood lead levels and blood pressure and its cardiovascular risk implications. Am J Epidemiol. 1985;121(2):246-58.

**Cite this article as:** Adekola AT, Kumar E. The combined effects of blood lead exposure and chronic psychosocial stress on cardiovascular, inflammatory, and cardiometabolic biomarkers among U. S. adults: a survey-weighted analysis of NHANES 2013-2014. Int J Res Med Sci 2026;14:4230-7.