

Impact of federal housing assistance on children's blood Lead Levels, NHANES 1999–2016

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Background: Lead is toxic for children's neurodevelopment, and low-income families face higher exposure. Federal housing assistance has been shown to decrease blood lead levels (BLLs), though its impact on children's BLLs is underexplored. We examined differences in BLLs among assistance-eligible US children aged ≤ 5 years by housing assistance status and program type.

Methods: Using linked 1999–2016 National Health and Nutrition Examination Survey (NHANES) and US Department of Housing and Urban Development records, we compared BLLs of children on housing assistance ($n = 557$) and children who would receive assistance within two years after NHANES participation (pseudo-waitlist; $n = 317$). We estimated geometric mean BLLs and adjusted odds ratios for BLLs ≥ 3.5 $\mu\text{g}/\text{dL}$ —Centers for Disease Control and Prevention blood lead reference value—and assessed effect modification by program type, i.e., project-based (public and multifamily income-restricted housing) versus housing choice vouchers.

Results: Housing-assisted children had lower geometric mean BLLs (1.58 vs. 2.10 $\mu\text{g}/\text{dL}$) and lower prevalence of BLL ≥ 3.5 $\mu\text{g}/\text{dL}$ (12.8% vs 24.9%) than pseudo-waitlisted children ($P \leq 0.001$). In adjusted models, federal housing assistance had a negative but nonstatistically significant association with BLL ≥ 3.5 $\mu\text{g}/\text{dL}$ (adjusted odds ratio = 0.71; 95% confidence interval = 0.48, 1.05). We also observed effect modification by program type ($p_{\text{interaction}} = 0.0024$): project-based housing (0.46 [0.25, 0.86]) versus housing choice vouchers (1.61 [0.78, 3.33]).

Conclusion: Project-based federal housing assistance was associated with lower odds of elevated BLLs among young children, highlighting potential differences in housing quality, management, or enforcement across programs. Strengthening housing quality standards and lead-free enforcement across all federal housing assistance programs is critical to reducing inequities in childhood lead exposure.

Keywords: Blood lead; Children's health; Health disparities; Built environment; Housing security; Public Housing; Housing choice voucher

Introduction

Lead is toxic for children's physical and cognitive development; there is no safe level of lead in children's blood. Children under

6 years of age are especially vulnerable to lead exposure due to rapid neurological development, age-specific behaviors (e.g., hand-to-mouth activity), and higher gastrointestinal absorption compared to adults.¹ Even low levels of lead exposure in early childhood have been linked with reduced IQ and cognitive function,² poor academic performance,³ behavioral issues, and criminality later in life.⁴ Nationally, children's blood lead levels (BLLs) have declined since the late 1970s following the removal of lead from gasoline and paint, among other products. However, millions of low-income and racially minoritized children continue to be disproportionately exposed due to persistent sources like deteriorated lead-paint residues in dust, soil, and around demolition sites of homes built before 1978; drinking water from corroded lead pipes; lead in unregulated cosmetics, toys, and jewelry; living near mining, smelting, or waste incineration sites; or from take-home occupational exposures.^{1,5}

Federal housing assistance, administered by the US Department of Housing and Urban Development (HUD), has been associated with lower BLLs.^{6–8} According to HUD's report of subsidized households (2025), about 4.5 million low-income households receive HUD assistance at any given time. The two major HUD housing portfolios include project-based housing such as public housing and income-restricted multifamily

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This study was funded by the US Department of Housing and Urban Development (DCHHU0054-19). The Funding/Sponsor was not involved in any aspects of the study, including the design and conduct of the study; collection, management, analysis, and interpretation of data; preparation, review, or approval of the manuscript; nor the decision to submit the manuscript for publication.

Due to confidentiality and disclosure policies, the linked NHANES-HUD data is restricted-use data and can only be accessed through the National Center for Health Statistics' Research Data Center.

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Environmental Epidemiology (2026) 10:e503

Received: 15 January 2026; Accepted 27 May 2026

Published online 30 June 2026

DOI: 10.1097/EE9.0000000000000503

What this study adds

Our study reveals heterogeneity in the impact of federal housing assistance on children's BLLs by program type: protective for children in *project-based housing* but not among children in *housing choice voucher* programs. Also, our pseudo-waitlist, quasi-experimental design comparing current recipients with those who would receive assistance within two years reduces selection bias and strengthens causal inference beyond prior studies.

units, and tenant-based housing choice vouchers (HCV) that subsidize private-market rents and comprise over half of HUD's portfolio.⁹ Typically, households in these programs are expected to pay up to 30% of their income towards housing costs, and the government subsidizes the remaining costs.

In addition to affordability requirements, federally assisted housing built before 1978 is subject to lead-based paint regulations. The HUD Lead Safe Housing Rule (24 CFR Part 35) requires inspection, control, and elimination of lead-based paint hazards in pre-1978 federally assisted or owned housing, while Title X requires the disclosure of any lead-based paint hazards in all pre-1978 housing.¹⁰ However, variations in regulatory enforcement and property maintenance across HUD's programs¹¹ may contribute to differences in residential lead exposure. Under 24 CFR Part 35, project-based programs require formal lead hazard control measures (e.g., abatement or interim controls), while HCV units rely on visual inspection-based identification, and subsequent remediation if deficiencies or reported hazards are found.¹² Our prior research among adolescents and adults found variability in BLL exposure by HUD program type, with HCV units being least protective.⁶ However, no study to date has investigated programmatic differences and BLLs among children under 6 years, who are the most susceptible to the neurotoxic effects of lead.

Furthermore, access to federal housing assistance requires household income eligibility, multistage applications, and often long wait times.¹¹ Even for eligible households, the receipt of housing assistance is not randomly assigned due to other characteristics like knowledge of government programs and motivation to participate.¹³ Previous studies evaluating the impact of housing assistance on lead exposure often overlook these selection factors, comparing housing-assisted versus nonassisted groups.^{7,8} In our prior work, we addressed this issue by leveraging a pseudo-waitlist design among *only* assisted participants to isolate the impact of the timing of housing assistance, i.e., current and future recipients, on lead exposure, finding a positive association between federal housing assistance and lower BLLs for adolescents and adults.⁶ The current study extends the line of inquiry to examine associations between federal housing assistance and BLLs among children age ≤ 5 years, overall and by program type, using the same pseudo-waitlist approach.

Methods

We leveraged linked data from the National Health and Nutrition Examination Survey (NHANES) and HUD administrative records conducted by the National Center for Health Statistics to identify children age ≤ 5 years who received assistance during the NHANES 1999–2016 survey cycles. NHANES, a nationally representative household survey of civilian, non-institutionalized US populations, provided sociodemographic, health, and blood lead information for children in our study, while the HUD administrative records provided a history of their enrollment in HUD's housing programs (e.g., public housing, multifamily income-restricted, and HCV), including dates of entry and exit points.¹⁴ Due to confidentiality and disclosure policies, the linked NHANES-HUD data were only accessed in a Federal Statistical Research Data Center. The George Washington University Institutional Review Board (IRB) determined that this study was IRB-exempt.

Our study population was NHANES-HUD linkage-eligible children age ≤ 5 years with a BLL measurement ($N = 874$). In brief, whole blood specimens were collected among participants aged 1 and older by venipuncture at the NHANES mobile examination center, processed and stored frozen before being shipped to the National Center for Environmental Health (Atlanta, GA) for heavy metal assays.¹⁵ We created our housing assistance comparison groups based on the timing of entry into housing assistance and the NHANES interview date: children

with assistance at the time of the NHANES interview (i.e., current recipients, $n = 557$ of 874, 63.7%) and children who would receive assistance within two years after their interview—the national average wait time at the time of our analysis¹¹ (i.e., “pseudo-waitlist” future recipients, $n = 317$ of 874, 36.3%). Our pseudo-waitlist approach ensures comparable groups by restricting the study population to those receiving HUD assistance. Detailed methods have been previously described.⁶

Our analyses compared BLL geometric means (GM) for current versus pseudo-waitlist children. We estimated odds ratios (OR) for BLLs ≥ 3.5 $\mu\text{g/dL}$ (the US national blood lead reference value) and the percent difference in least squares geometric means (LGSM) by HUD assistance status, and their corresponding 95% confidence intervals, adjusting for covariates. Covariates were selected *a priori* based on literature documenting their associations with HUD assistance and/or BLL, without being on the causal pathway. We considered age, gender, race and ethnicity, family income-to-poverty ratio, household education, nativity status, US Census region (masked), and NHANES survey cycle. The final model did not adjust for family income-to-poverty ratio due to a higher percentage of missing values (7%), and nativity status due to limited variability (98% were US-born) and to preserve degrees of freedom. The distribution of these characteristics was statistically similar by HUD assistance status (Table 1) and BLLs (Table S1 <https://links.lww.com/EE/A441>). We also categorized program assistance based on the first program recorded in the study period (i.e., HCV [$n = 441$], public housing [$n = 224$], multifamily income-restricted [$n = 209$]) and examined effect modification of HUD assistance and BLLs by program type. Our analyses used the R *survey* package in R Studio¹⁶ (version 2024.12.1 Build 563) and NHANES-HUD linkage-eligible weights.¹⁴ We used Wald tests to construct pairwise *P*-values and 95% confidence intervals based on the *t*-distribution.

Results

Children who received federal housing assistance between 1999 and 2016 were predominantly US-born (98.9%), lived below the federal poverty level (72.1%), and were from urban areas (92.2%). About half were in the HCV program (50.5%), two-thirds were Black or African American non-Hispanic (61.4%), and 17.2% had BLLs ≥ 3.5 $\mu\text{g/dL}$. By timing of federal assistance, compared to children waiting for assistance, current recipients had lower GM BLLs (1.58 [geometric standard error: 1.05] vs. 2.10 [1.06] $\mu\text{g/dL}$) ($P < 0.001$), lower prevalence of BLLs ≥ 3.5 $\mu\text{g/dL}$ (12.8% vs. 24.9%) ($P = 0.001$), and a higher prevalence of children aged 3–5 years. The distribution of other sociodemographic characteristics was similar by time of housing assistance (Table 1). In adjusted models, we found that being on federal housing assistance had a negative but nonstatistically significant association with elevated BLLs ≥ 3.5 $\mu\text{g/dL}$ (adjusted odds ratio [aOR]: 0.71 [95% confidence interval (CI): 0.48, 1.05]) and percent difference in LGSM BLL (−2.4% [95% CI: −12.2%, 8.3%]). The associations between timing of HUD assistance and BLLs were significantly modified by program type (Table 2). For elevated BLLs ≥ 3.5 $\mu\text{g/dL}$, the negative association was observed only among children in project-based housing (aOR: 0.46 [95% CI: 0.25, 0.86]) versus HCV units (aOR: 1.61 [0.78, 3.33]) ($P_{\text{interaction}} = 0.0024$) (Figure 1 and Table 2).

Discussion

Reducing childhood lead exposure is a national public health priority.^{1,6,7} Under the US Lead Safe Housing Rule, federally assisted and owned housing built before 1978 and renting to families with children under six must undergo lead-based paint evaluations, rehabilitation, stabilization, and appropriate response if elevated BLLs are found.¹⁰ In our study using a pseudo-waitlist

Table 1.
Distribution of blood lead level (BLL) and major baseline characteristics by timing of HUD housing assistance, NHANES-HUD linked data 1999–2016 (N = 874).

	All children (sample N = 874)	Current recipients (n = 557)	Future recipients (n = 317)	P value ^c
Blood lead level, geometric mean (geometric standard error), µg/dL	1.75 (1.05)	1.58 (1.05)	2.10 (1.06)	<0.001
Blood lead reference level, count (%)				
BLL < 3.5 µg/dL	724 (82.8%)	87.2%	75.1%	0.001
BLL ≥ 3.5 µg/dL	150 (17.2%)	12.8%	24.9%	
HUD Assistance program, %				
Housing choice vouchers	441 (50.5%)	52.1%	46.7%	0.245
Public housing	224 (25.6%)	22.4%	30.2%	
Multifamily income restricted	209 (23.9%)	25.5%	23.1%	
Age, count (%)				
1–2 years old	397 (45.4%)	33.6%	46.5%	<0.001
3–5 years old	477 (54.6%)	66.4%	53.5%	
Gender, count (%)				
Male	471 (53.9%)	52.9%	55.0%	0.583
Female	403 (46.1%)	47.2%	45.0%	
Nativity status, %				
Foreign-born	10 (1.1%)	0.9%	3.5%	0.237
US-born	864 (98.9%)	99.1%	96.5%	
Educational attainment of householder ^a , %				
Up to high school	349 (39.9%)	39.2%	33.6%	0.424
High school degree or some college	483 (55.3%)	58.4%	64.1%	
College graduate	17 (1.9%)	2.4%	2.3%	
Income-to-poverty threshold ^b , %				
<50%	358 (41.0%)	42.6%	35.4%	0.165
50%–99%	272 (31.1%)	39.1%	34.6%	
100%–199%	142 (16.2%)	14.3%	22.6%	
200+%	42 (4.8%)	4.0%	7.4%	
Urbanicity				
Urban	806 (92.2%)	90.6%	88.0%	0.307
Rural	37 (4.2%)	6.6%	5.4%	
Unknown	31 (3.5%)	2.8%	6.6%	
Race and ethnicity, %				
Black or African American	537 (61.4%)	48.5%	53.1%	0.397
White non-Hispanic	109 (12.5%)	23.2%	23.0%	
Another race/ethnicity (e.g., Asian, other Hispanic/Latinx, Multiracial)	129 (14.8%)	19.5%	13.6%	
Mexican American	99 (11.3%)	8.8%	10.3%	

Percentages may not add up to 100% due to rounding.

^aEducation attainment of the householder was missing from 25 participants and excluded from percentage calculations (N = 849).

^bIncome-to-poverty threshold was missing from 60 participants and excluded from percentage calculations (N = 814).

^cP-values were calculated from *t* tests for continuous BLL, and Chi-square test of proportions for categorical predictors.

BLL indicates blood lead level; N, sample size; NHANES, National Health and Nutrition Examination Survey; HUD, US Department of Housing and Urban Development.

approach, we found that children under six who received federal project-based housing assistance had lower odds of elevated BLLs compared to children awaiting assistance. We did not observe this protective association among children in the tenant-based HCV program. These findings are consistent with our previous study of adolescents and adults,⁶ as well as a prior study of children's BLLs and federal housing assistance that found lower BLLs among assisted versus nonassisted children.⁷ However, our study expands prior work on children's BLLs by implementing a quasi-experimental pseudo-waitlist study design that minimizes selection biases and by assessing effect modification of program type.^{7,8} Altogether, our study and prior work highlight the importance of federal housing assistance in providing access to affordable and safe, lead-free housing to very low-income families.

Observed differences in BLLs by type of federal housing assistance program may reflect systematic variations in housing quality, regulatory compliance, inspection rigor, and/or lead enforcement across programs. HUD's public housing program provides approximately 0.8 million affordable units nationally (as of 2025)⁹ overseen by local housing authorities. These project-based units require routine inspections and interim controls for lead abatement when hazards are identified. In contrast, the tenant-based HCV program provides over 2.36 million affordable units (as of 2025)⁹ owned by private landlords. They

only require a visual inspection and lead paint stabilization if lead is found (i.e., reactive management).^{6,7,9,11,17} Local housing authorities may also be more responsive than private landlords at addressing tenants' housing concerns. Moreover, given its magnitude, tenant-based HCV units are more varied in age and physical quality, which may explain our observed null findings.

Our study has several limitations. The cross-sectional and nationally representative nature of the NHANES data precluded assessment of longitudinal and subnational trends, respectively. We also lacked information about the duration of HUD assistance and season of blood sampling, both of which could influence BLLs. However, BLL is usually a measure of acute exposure with a half-life in children of 1–4 weeks.¹⁸ In spite of these limitations, our study has notable strengths. We used a quasi-experimental, pseudo-waitlist approach that facilitated the construction of comparable groups and minimized potential selection biases based on HUD eligibility and entry factors. Data sources on HUD housing assistance and BLL were also routinely collected and not subjected to recall biases.

Policy Implications

Our study is the first to identify the effect modification of federal housing assistance program type on children's BLLs, with

Table 2.

Adjusted odds ratio of BLL ≥ 3.5 $\mu\text{g/dL}$, percent difference in least squares geometric mean BLL, and corresponding 95% confidence intervals comparing current versus future (reference group) HUD recipients, overall and by program type strata, NHANES-HUD linked data 1999–2016 (N = 874).

	Adjusted odds ratio ^a (95% confidence limits)	Percent difference in LSGM BLL (95% confidence limits) ^b
All programs	0.71 (0.48, 1.05)	−2.4% (−12.2%, 8.3%)
By program type strata		
Project-based housing (public housing and multifamily income-restricted 8) (n = 433)	0.46 (0.25, 0.86)	−8.8% (−22.0%, 6.7%)
Public housing (n = 224)	0.34 (0.10, 1.09)	−12.4% (−30.4%, 10.2%)
Multifamily income-restricted (n = 209)	0.74 (0.14, 3.85)	0.74% (−29.7%, 44.4%)
Housing choice voucher [HCV] (n = 441)	1.61 (0.78, 3.33)	8.4% (−5.1%, 23.8%)
Pairwise $P_{\text{interaction}}$: HUD assistance timing $\times$ Program type	0.0024	0.0418

All models adjusted for gender, age category, race and ethnicity, educational attainment of householder, US Census region, and NHANES survey cycle. For all strata, the reference group is future recipients. 95% confidence intervals constructed using Wald tests based on the t-distribution.

^aOdds ratios were estimated based on the multivariable logistic regression models for BLL ≥ 3.5 $\mu\text{g/dL}$ taking the form: $\text{logit}(p) = \text{logp } 1 - p = \beta_0 + \beta_1 H + \beta_{XX}$, where p is probability of the BLL outcome ≥ 3.5 $\mu\text{g/dL}$; H is housing assistance status (current, pseudo-waitlist); and X is a vector of covariates.

^bPercent differences were based on the multivariable linear regression model to estimate the least square mean BLL after adjustment for covariates: $\text{logy}_i = \beta_0 + \beta_1 H + \beta_{XX} + e_i$, where $e_i \sim N(0, \sigma^2)$ is a normally distributed error term, y_i is the BLL outcome for individual i ; H is housing assistance status (current, pseudo-waitlist); and X is a vector of covariates. We then calculated the percent difference in LSGM by HUD assistance status as $(e\beta - 1) \times 100\%$ and estimated the 95% confidence intervals as $(e\beta \pm 1.96 \times \text{standard error} - 1) \times 100\%$.

BLL indicates blood lead level; N, sample size; NHANES, National Health and Nutrition Examination Survey; HUD, US Department of Housing and Urban Development; LSGM, Least squares geometric mean.

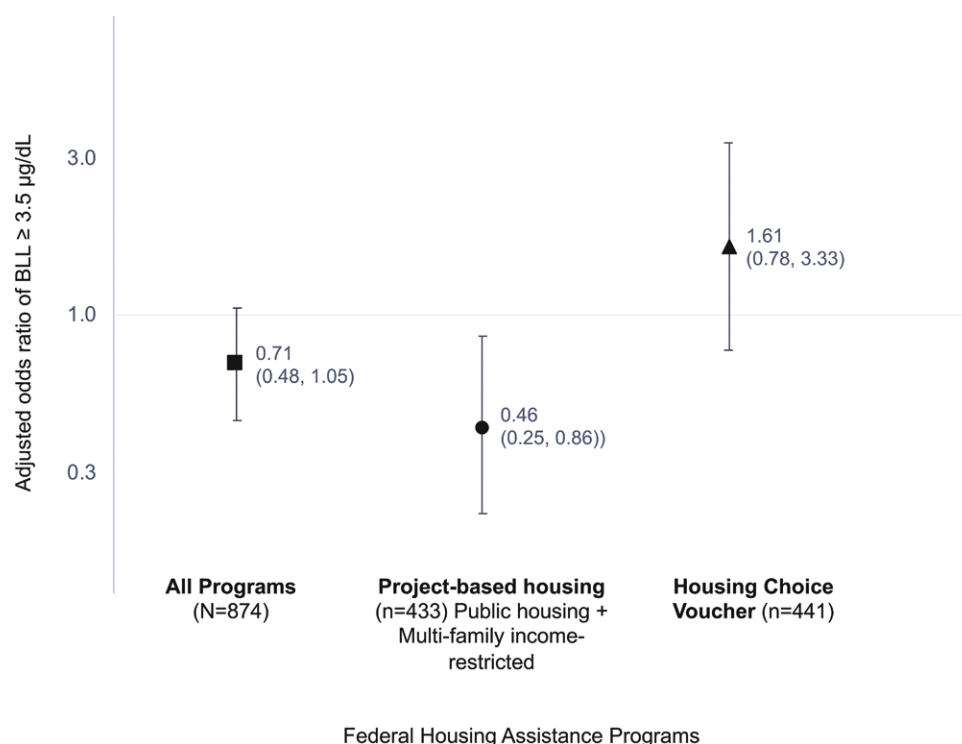


Figure 1. Adjusted odds ratio of blood lead levels (BLL) ≥ 3.5 $\mu\text{g/dL}$ and corresponding 95% confidence intervals comparing current versus future federal housing assistance recipients, overall and by program type, NHANES-HUD linked data 1999–2016 (N = 874). All models adjusted for gender, age category, race and ethnicity, educational attainment of householder; US Census region (masked); and NHANES survey cycle. For all strata, the reference group is future HUD housing assistance recipients. 95% confidence intervals constructed using Wald tests based on the t-distribution. The reference group is the pseudo-waitlist future housing assistance group. BLL indicates blood lead level; HUD, US Department of Housing and Urban Development; NHANES, National Health and Nutrition Examination Survey.

a protective association observed for project-based housing recipients. Our findings underscore the importance of federal housing assistance programs overall as a social-structural safety net to protect low-income families from environmental health hazards such as lead. Continued investments should be made to increase HUD's project-based housing portfolios, which may offer families more systematic protections from lead exposure than tenant-based HCV units. However, given that tenant-based HCVs are HUD's largest assistance program serving

over 2 million low-income families, HUD should strengthen its lead prevention standards and enforcement in this program to ensure that all families with children are adequately protected from lead hazards.

Conflicts of interest statement

The authors declare that they have no conflicts of interest with regard to the content of this report.

ACKNOWLEDGMENTS

The authors thank participants of the National Health and Nutrition Examination Survey (NHANES) and the US Department of Housing and Urban Development (HUD) housing assistance recipients, without whom this analysis would not have been possible. We also thank the Office of Analysis and Epidemiology in the National Center for Health Statistics and the Federal Statistical Data Research Centers for data access support. The findings and conclusions in this paper are those of the author(s) and do not necessarily represent the views of the Federal Research Data Center, National Center for Health Statistics, or the Centers for Disease Control and Prevention.

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