Environmental Research 135 (2014) 21–30

Contents lists available at ScienceDirect

Environmental Research

journal homepage: www.elsevier.com/locate/envres

Associations between blood lead level and substance use and sexually transmitted infection risk among adults in the United States

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ARTICLE INFO

Article history:
Received 18 March 2014
Received in revised form
8 May 2014
Accepted 15 May 2014

Keywords:
Blood lead
Substance use
Sexually transmitted infection
NHANES

ABSTRACT

The effects of low-level lead exposure on neuropsychological status in the United States (US) general adult population have been reported, and the relationship between neuropsychiatric dysfunction and health risk behaviors including substance use and sexual risk taking is well established. However, the potential influence of lead exposure on risk-taking behavior has received little attention. Using the National Health and Nutrition Examination Survey (NHANES) 2005–2010, we estimated multivariable logistic regression models to measure odds ratios (ORs) and 95% confidence intervals (CIs) for the cross-sectional associations between blood lead level and risk behaviors including binge drinking, drug use, and indicator of sexually transmitted infection (STI) risk. STI indicators included past 12 month sexual risk behaviors (age mixing with partners who were at least five years younger or older and multiple partnerships), self-reported STI, and biologically-confirmed herpes simplex virus type 2 (HSV-2) infection. Dose–response like relationships were observed between blood lead and substance use, age mixing with younger and older partners, self-reported STI, and HSV-2. In addition, participants with lead levels in highest quartile versus those with levels in the lowest quartile had over three times the odds of binge drinking and over twice the odds of injection drug or cocaine use in the past 12 months, while being in one of the top two quartiles was significantly associated with 30–70% increased odds of multiple partnerships, sex with older partners, and self-reported and biologically confirmed STI. Results from this study suggested that lead exposure may contribute to substance use, sexual risk-taking, and STI. However, given limitations inherent in the cross-sectional nature of the study, additional studies that use longitudinal data and measure detailed temporal information are warranted.

1. Introduction

Substance use and the subsequent elevated risk of sexually transmitted infections (STI) remain critical public health priorities affecting US communities (CDC, 2012a; 2012b). Substance use and STI cluster in poor communities (Booysen and Summerton, 2011; Kalichman et al., 2006; Madise et al., 2007), which are characterized by multiple, co-occurring social and structural factors that may drive drug and alcohol use, sexual risk-taking, and infection. One factor that is not typically considered when identifying determinants of substance use and STI risk is exposure to environmental toxicants, despite the fact that high levels of pollution and other adverse environmental exposures disproportionately affect the poor communities most commonly impacted by substance use and STI risk (Kearney and Kiros, 2009; Pollock and Vittas, 1995; Rogge and Darkwa, 1996; Stretesky and Hogan, 1998). Environmental exposure to toxicants could work in tandem with other social, economic, and structural factors to drive adverse health outcomes in poor communities.

Lead is a neurotoxic heavy metal that is ubiquitous in the environment. Lead exposure has decreased substantially in the United States (US) since the legislation in the 1980s governing lead use and removal from gasoline (Muntner et al., 2005; Pirkle et al., 1994); atmospheric lead levels decreased by 91% from 1980 to 2012 (EPA, 2013). Meanwhile, the geometric mean blood lead levels also decreased by over 90% from 1970s to 2000s in the United States (Abadin et al., 2007; Meyer et al., 2003). However, several other sources of exposure still remain, including paint, dust, soil, tap water with lead service connection, tobacco smoking (Etchevers et al., 2013), and folk medicines such as the Indian herbal remedies (Ibrahim and Latif, 2011). In contrast to many trace elements, no beneficial effects of lead have been found (Hou et al., 2013), and a "safe" level of lead exposure has not been identified (Bellinger, 2008).

Abbreviations: NHANES, The National Health and Nutrition Examination Survey; STI, Sexually Transmitted Infection; MEC, mobile examination center; ORs, odds ratios; CIs, confidence intervals

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http://dx.doi.org/10.1016/j.envres.2014.05.037
0013-9351/

Lead is transported bound to erythrocytes and accumulates in the blood and the bone with a lead bone half-life of approximately 30 years after being absorbed from the gastrointestinal tract or the respiratory system (Mushak, 1991). The adverse effects of lead exposure on the nervous system have been well documented in both children and adults (Canfield et al., 2003; Schwartz et al., 2000). However, research that assesses the association between nervous system effects of lead exposure and behavioral outcomes in general population is limited (Lane et al., 2008).

Exposures to environmental pollutants with neurotoxic properties influence neuropsychiatric function and potentially could lead to behavior changes, including substance use and sexual risk-taking, by impairing cognitive function, reducing impulse control, and inhibiting emotion regulation (Crockett, 2006; Eddins et al., 2008; Jedrychowski et al., 2006; Magar, 2008; Stacy et al., 2000). Specifically, there is an evidence from cross-sectional and cohort studies that lead exposure impairs intelligence and executive function including impulse control in children (Lanphear et al., 2005), in adults exposed to high levels as a result of occupational exposure (Khalil et al., 2009), and in adults with chronic low levels of exposure surveyed in general-population studies (Bandeen-Roche et al., 2009; van Wijngaarden et al., 2011; Weuve et al., 2009). Executive function is associated with one's ability to monitor and change behavior accordingly (Lezak et al., 2012). Core aspects of executive function include inhibition, working memory, and cognitive flexibility (Diamond, 2013). Impairments in inhibition, including increased impulsivity, predict initiation of drug use, problematic drug use, and inability to abstain from use (deWit, 2009; Nigg et al., 2006; Sher et al., 2000). Deficits in domains of executive function such as impulse control and decision-making are also associated with engagement in sexual risk behavior (Magar, 2008) including initiating sex at an early age, having multiple partnerships, and choosing "high-risk" sex partners such as those who are substantially older (Crockett, 2006) and inconsistent condom use (Stacy et al., 2000). These behaviors are determinants of sexually transmitted infection (STI) (Coul et al., 2013; Doherty et al., 2011; Epstein et al., 2013; Kraut-Becher and Aral, 2006a; Santelli et al., 1998; Shafii et al., 2007; Shiely et al., 2010; Upchurch et al., 2004).

Further, lead-associated disruptions of neuropsychological processes are associated with externalizing and internalizing disorders (Bouchard et al., 2009; Braun et al., 2006; Echeverria et al., 2005; Froehlich et al., 2009; Ha et al., 2009; Maruyama et al., 2012; Nigg et al., 2008; Rajan et al., 2007; Walkowiak et al., 1998; Wang et al., 2008), and internalizing and externalizing factors are associated with increases in substance use and sexual risk-taking (Ellis et al., 1995; Khan et al., 2009; Ramrakha et al., 2000). Specifically, lead exposure is associated with externalizing outcomes including attention deficit hyperactivity disorder (ADHD) (Braun et al., 2006; Froehlich et al., 2009; Ha et al., 2009; Wang et al., 2008), delinquency (Dietrich et al., 2001b; Naicker et al., 2012; Needleman et al., 1996), antisocial personality disorder (Olympio et al., 2010), and criminal justice involvement (Mielke and Zahran, 2012; Needleman et al., 2002; Wright et al., 2008). In a nationally-representative sample of U.S. adults, increasing blood lead levels were associated with higher odds of internalizing disorders, including depression and panic disorder (Bouchard et al., 2009).

Research on the role of lead exposure in behavioral risk, including substance use and sexual risk-taking, is limited. There is an evidence that those exposed to metals have elevated substance use levels (Chan, 2003; Grandjean et al., 1981; Rai et al., 2001; Sällsten et al., 1996) and there is an evidence that lead exposure is an independent risk factor for drug and alcohol use when controlling for important confounding factors such as current socioeconomic status, parental intelligence quotient, and the quality of caregiving in the home environment (Dietrich et al., 2001a). Substance use is an important risk factor for sexual risk-taking and STI (Brodbeck et al., 2006; Cavazos-Rehg et al., 2009; Khan et al., 2013; MacArthur et al., 2012; Patrick et al., 2012), hence lead-associated elevations in substance use also may contribute to STI risk. Only one study, to our knowledge, has examined lead exposure as an indicator of sexual risk, focusing on teen pregnancy outcomes (Lane et al., 2008). The study found that childhood lead exposure was associated to 1.59 times the odds of any prior repeated teen pregnancy among 536 teens aged 15–19 years in New York. These extant studies, which suggest an association between lead and risk-taking behavior, highlights a need for additional research on associations among lead exposure, substance use, and sexual risk in a large, nationally-representative data source in which a number of substance use and STI risk outcomes are examined.

The purpose of this study was to use data from the 2005–2010 National Health and Nutrition Examination Survey (NHANES) to measure the cross-sectional associations between exposure to lead and multiple behavioral outcomes. Specifically, substance use (binge drinking and drug use), sexual risk behaviors (adulthood multiple sex partners and having younger/older sex partners), self-reported STIs, and biologically-confirmed HSV-2 were examined in a sample representative of the U.S. adults aged 20–59 years old.

2. Methods

2.1. Study population

The NHANES is a population-based complex survey designed to collect information on the health and nutrition status of the non-institutional civilian U.S. population (CDC, 2013). Since 1999, the survey data are released every 2 years for public use. The data from the most recent three survey-cycles, 2005–2010, were used and analyzed in this study. Blood lead were measured in a subsample of persons aged one year or older in each data-cycle, and a total of 25,466 participants had nonmissing measured blood lead concentrations in NHANES 2005–2010. Information of sexual risk behaviors was collected via interviews among participants aged 20–59 years in 2005–2006, 20–60 years in 2007–2008, and 18–69 years in 2009–2010, and substance use information was collected among participants aged 20 and older. Therefore, this study is limited to adults aged 20–59 years. There were 14,658 adults aged 20–59 years selected for the biannual samples in 2005–2010, 11,335 (77.3%) of those were interviewed, and 11,001 (75.1%) of those underwent a physical examination in a Mobile Examination Center (MEC) (CDC, 2011b). A total of 10,383 adults aged 20–59 years had blood lead tested, and were included in the analyses.

2.2. Measures

2.2.1. Exposure: blood lead level

The laboratory procedure and quality control of blood lead concentrations are described in detail in the NHANES Laboratory/Medical Technologist Procedures Manual (LPM) (CDC, 2013). Briefly, whole blood specimens were processed, frozen and then shipped to National Center for Environmental Health for testing. Blood lead concentrations were measured by inductively coupled plasma mass spectrometry using quadrupole ICP-MS technology (CDC, 2004). There were no changes in equipment, lab methods or lab site, and the coefficient of variations (CVs) ranged from 1.2–4.4% through the study period. The detection limit for lead in blood specimens was based on three times the standard deviation of blood blank run for a minimum of 20 runs (CDC, 2004). The limit of detection of lead was 0.25 μg/dL. As recommended by the NHANES, when the result was below the limit of detection, the value for that variable is the detection limit divided by the square root of two (CDC, 2011a). Blood lead concentrations were categorized into quartiles, and both categorical and log-transformed continuous blood lead were analyzed in this study.

2.2.2. Outcomes: substance use and sexual risk behavior

2.2.2.1. Binge drinking. Participants in the NHANES survey were asked to come to a Mobile Exam Center (MEC) for a variety of physical tests and measurements (Zipf G, 2013). During the MEC interview/examination, NHANES asks all participants aged 20 years or older if they had at least 12 alcoholic drinks in the past year. Those endorsing any prior drinking in the past year were then asked "In the past 12 months, on how many days did you have 5 or more drinks of any alcoholic beverage?" Based on these items, two dichotomous indicators of binge drinking were

coded, including any prior binge drinking in the past year (Yes versus No) and frequent binge drinking, defined as endorsement of 12 or more episodes of binge drinking in the past year (Yes versus No). The past-year frequent binge drinking indicator was chosen to identify respondents who, on an average, engaged in monthly binge drinking. In addition, participants endorsing no prior drinking in the past year were further asked "In your entire life, have you had at least 12 drinks of any type of alcoholic beverage?" Those endorsing any lifetime drinking were then asked "Was there ever a time or times in your life when you drank 5 or more drinks of any kind of alcoholic beverage almost every day?" A dichotomous measure of lifetime frequent binge drinking (Yes versus No) was determined based on this item. Participants with missing data on lifetime ($n=913$) or recent binge drinking ($n=2370$) were further excluded, and no significant difference was observed in the excluded subjects in regard to the covariates we selected.

2.2.2.2. Drug use. During the examination, participants were asked whether they have ever used marijuana, cocaine, heroin, methamphetamine, or whether they had injected drugs. Participants with any previous use of the above drugs were categorized as previous drug users, and those with any previous use of injected drugs were categorized as injection drug users. Participants with missing data on all drugs were excluded from the analyses for previous drug use ($n=1079$), and those with missing data on injected drugs were excluded from the injection drug use analyses ($n=1093$). No significant difference of the covariates we included was found in the excluded subjects.

2.2.2.3. Sexual risk behaviors. During the interview, participants were asked "Of the persons you had any kind of sex with in the past 12 months, how many were five or more years older/younger than you?", and "In the past 12 months, with how many males/females have you had vaginal, anal, or oral sex?" We examined recent sexual risk behaviors (in the year prior to the survey) that are established determinants of increased STI transmission including multiple sexual partners (>1 partners vs. ≤ 1 partner) and indicators of age mixing, including sex partners five years younger (Yes versus No) and sex partners five years older (Yes versus No) (Kraut-Becher and Aral, 2006b). Participants with missing data on multiple sex partners ($n=1762$) were excluded from the multiple partners analyses. Information on age mixing was collected in participants aged 20–59 years old in the 2005–2006 and 2007–2008 data cycles, but only in participants aged 18–29 years old in the 2009–2010 data cycle. Participants with missing data on sex partners five years younger ($n=4939$) or older ($n=4933$) were excluded in the analyses for that specific outcome.

2.2.2.4. Self-reported history of sexual transmitted infection. Participants were also interviewed about the history of diagnosis of STIs. The questionnaires included questions such as "Has a doctor ever told you had genital herpes/genital warts/gonorrhea/chlamydia?" Participants who have endorsed diagnosis with any prior infection were categorized as having a history of STI (Yes versus No). Those with missing data on these variables were excluded ($n=1804$).

2.2.2.5. Biologically-confirmed herpes simplex virus II (HSV-2). The detailed laboratory methodology is described in the NHANES LPM (CDC, 2013). Briefly, serum specimens were processed, stored, and shipped to Emory University, Atlanta, GA for analysis. Enzymatic immunodot assay with purified glycoprotein gG-2, which is specific for HSV-2 as the antigen, was used to assess HSV-2. The results were categorized as positive, negative, and indeterminate. For the analyses, we excluded all participants with indeterminate HSV-2 results ($n=17$) and missing data ($n=2471$).

2.2.3. Covariates

All confounding factors were carefully selected as factors potentially associated with both lead exposure and behavioral risk based on review of the extant literature. Demographic information including age (20–29, 30–39, 40–49, or 50–59), gender, and race/ethnicity (Non-Hispanic white, Non-Hispanic black, or Hispanic and others), marital status (married, or not married), poverty income ratio (PIR; <1.0, 1.0–2.0, ≥ 2.0, or missing) and education ($<$ high school, high school, or $>$ high school) were obtained from demographic questionnaire.

2.3. Statistical analysis

Descriptive statistics such as two-sided Student *t*-tests, analysis of variance (ANOVA), and Wald chi-square analysis were performed where appropriate. Blood lead concentrations were log transformed to ensure a normal distribution and make a comparison by the status of covariates. Logistic regression models were used to obtain unadjusted and adjusted odds ratios (ORs) and 95% confidence intervals (CIs) for the associations between exposure to lead and outcomes including substance use (binge drinking and drug use), sexual risk behaviors, self-reported STIs, and HSV-2. Blood lead was analyzed as both continuous and categorical (quartiles) variables in each set of models. Crude adjusted models controlled for age, gender, and race/ethnicity, and confounder adjusted model controlled in addition for education, PIR, and marital status were used. The sample weights, stratification and clustering design variables were incorporated into all SAS survey procedures to ensure the correct estimation of sampling error. A six-year subsample weight was calculated for the combined 2005–2010 data following the NHANES analytic guidelines by assigning one-third of the sub-sample weight for each data cycle (Johnson CL, 2013). This calculated weight was used to analyze the combined six-year data of NHANES 2005–2010.

We also examined the interactions between blood lead and age, gender, or race/ethnicity (since no significant interactions were observed, suggesting that the associations between lead and outcomes did not vary across sub-populations, results were not stratified by these demographic factors). Standard error (SE) was estimated using the Taylor series linearization method. All statistical analyses were performed using SAS 9.3 software (SAS Institute Inc., Cary, NC) survey procedures.

3. Results

Table 1 presents the distribution of selected demographic characteristics and covariates by substance use. Subjects who were male, with lower education level, or unmarried had higher prevalence of both lifetime and recent binge drinking. Subjects with lower PIR had higher prevalence of lifetime and frequent recent binge drinking. In addition, subjects who were younger were more likely to have recent binge drinking, while older subjects were more likely to have lifetime binge drinking. Furthermore, fewer non-Hispanic blacks had recent binge drinking, and subjects who were non-Hispanic white were more likely to have lifetime binge drinking. On the other hand, subjects who were male, non-Hispanic white, or unmarried had higher prevalence of both previous drug use and injection drug use. Subjects who were older, with higher education or PIR were more likely to be previous drug users, while those who were younger, with lower education or PIR were more likely to have injection drug use (all $p<0.05$).

Table 2 presents the distribution of selected demographic characteristics and covariates by sexual risk behaviors, self-reported STIs, and biologically-confirmed HSV-2. Subjects who were non-Hispanic black, unmarried, or had a history of drug use had higher prevalence of self-reported STIs, biologically-confirmed positive HSV-2 results, and all the sexual risk behaviors investigated in this study. In addition, subjects with lower education level or PIR were more likely to have positive HSV-2 results, have sex partners at least five years older, and have multiple sex partners in the past year. Furthermore, males were more likely to have younger sex partners and have multiple sex partners, and less likely to have STIs and have older sex partners. Individuals with younger age had higher prevalence of having older sex partners, multiple sex partners, and self-reported STIs, and lower prevalence of having younger sex partners and positive HSV-2. Subjects with increasing levels of alcohol consumption were more likely to have younger sex partners, multiple sex partners, and self-reported STIs, while less likely to have positive HSV-2 (all $p<0.05$).

The comparison of geometric mean of blood lead concentration by covariates is presented in Table 3. Individuals who were older, who were male, who were Hispanic, who were with lower education level or PIR, who had heavy alcohol consumption, or who had drug use have higher blood lead levels (all $p<0.05$). Among all the participants, 48 (weighted percentage: 0.36%, 95% CI: 0.21–0.52%) had blood lead levels ≥ 10 μg/dL. Of those 48 participants, the highest blood lead level was 43.52 μg/dL.

Table 4 shows the associations between substance use and blood lead. Logistic regression analyses adjusting for age, gender, race/ethnicity, education, PIR, and marital status showed a relationship in a dose–response like fashion between blood lead level and both lifetime and recent binge drinking, previous drug use and injection drug use, and use of marijuana. Individuals with blood lead levels in the highest quartile had 2.69 times the odds of lifetime frequent binge drinking (95% CI, 2.04–3.55). Persons with blood lead levels in the highest quartile had 3.21 times (95% CI, 2.76–3.74) the odds of recent binge drinking and 3.85 times (95%

Table 1
Distribution of selected demographic characteristics and covariates by substance use in NHANES 2005–2010.

	Binge drinking in the past 12 months (n=8013)					Frequent binge drinking in the past 12 months (n=8013)					Lifetime frequent binge drinking (n=9470)				
	Yes (n=3204)		No (n=4809)		p[c]	Yes (n=1769)		No (n=6244)		p[c]	Yes (n=1485)		No (n=7985)		p[c]
	N[a]	Percent(95% CI)[b]	N[a]	Percent(95% CI)[b]		N[a]	Percent(95% CI)[b]	N[a]	Percent(95% CI)[b]		N[a]	Percent(95% CI)[b]	N[a]	Percent(95% CI)[b]	
Age															
20–29 years	1095	34.1(31.9–36.4)	1156	20.2(18.7–21.7)	<0.001	645	38.7(35.5–42.0)	1606	22.4(20.9–24.0)	<0.001	260	18.2(15.9–20.5)	2203	25.3(23.8–26.8)	<0.001
30–39 years	856	26.2(23.7–28.6)	1211	23.4(21.8–24.9)		457	24.9(21.8–28.0)	1610	24.4(22.8–26.0)		330	21.9(19.1–24.7)	2035	24.2(22.7–25.7)	
40–49 years	769	25.0(22.6–27.3)	1253	27.7(26.0–29.5)		407	23.1(20.1–26.1)	1615	27.6(25.9–29.2)		463	32.5(29.6–35.4)	1998	26.4(25.1–27.8)	
50–59 years	484	14.7(12.4–17.0)	1189	28.7(26.7–30.8)		260	13.3(11.1–15.5)	1413	25.6(23.7–27.4)		432	27.5(24.0–30.9)	1749	24.0(22.4–25.7)	
Gender															
Male	2186	67.8(66.1–69.6)	1719	37.3(35.8–38.9)	<0.001	1361	77.3(75.2–79.4)	2544	42.4(41.2–43.7)	<0.001	1072	73.2(71.1–75.3)	3511	45.6(44.4–46.8)	<0.001
Female	1018	32.2(30.4–33.9)	3090	62.7(61.1–64.2)		408	22.7(20.6–24.8)	3700	57.6(56.3–58.8)		413	26.8(24.7–28.9)	4474	54.4(53.2–55.6)	
Race/ethnicity															
Non-Hispanic white	1668	73.7(70.1–77.3)	1974	64.4(60.0–68.8)	<0.001	864	70.9(66.4–75.4)	2778	67.5(63.6–71.5)	<0.001	778	72.7(68.9–76.5)	3518	67.0(62.9–71.2)	<0.001
Non-Hispanic black	435	7.2(6.0–8.4)	1134	13.9(11.4–16.4)		260	8.1(6.7–9.5)	1309	12.0(9.9–14.0)		258	9.9(7.9–11.8)	1600	11.5(9.5–13.6)	
Hispanic and others	1101	19.1(15.8–22.4)	1701	21.7(18.5–24.9)		645	21.0(16.7–25.3)	2157	20.5(17.6–23.4)		449	17.4(14.2–20.6)	2867	21.4(18.2–24.6)	
Education															
<High school	279	4.5(3.7–5.3)	398	4.2(3.5–4.9)	0.005	182	5.8(4.5–7.0)	495	3.9(3.3–4.6)	<0.001	178	7.3(5.8–8.8)	688	4.5(3.7–5.2)	<0.001
High school	555	12.7(10.9–14.4)	692	10.3(8.9–11.7)		353	14.2(11.9–16.6)	894	10.5(9.1–11.9)		330	17.3(14.9–19.7)	1208	11.0(9.6–12.3)	
>High school	2367	82.8(80.8–84.9)	3715	85.5(84.0–87.0)		1234	80.0(77.6–82.4)	4848	85.6(84.0–87.2)		977	75.4(72.5–78.3)	6081	84.6(82.9–86.3)	
PIR															
<1.0	663	13.7(12.2–15.1)	912	12.1(10.9–13.4)	0.149	408	15.9(14.1–17.7)	1167	11.9(10.7–13.1)	0.002	409	19.2(168–21.6)	1525	12.2(11.0–13.4)	<0.001
1.0–2.0	703	15.7(14.1–17.4)	1070	16.6(15.0–18.2)		418	17.3(15.2–19.4)	1355	15.9(14.5–17.4)		390	20.7(18.0–23.4)	1799	16.5(15.0–17.9)	
≥1.0	1637	65.8(53.2–68.5)	2494	66.2(63.7–68.7)		835	62.2(58.9–65.4)	3296	67.1(64.8–69.5)		598	55.7(52.4–59.0)	4122	66.3(63.9–68.7)	
Missing	201	4.8(3.7–5.8)	333	5.1(4.0–6.1)		108	4.6(3.5–5.8)	426	5.0(4.0–6.0)		88	4.4(3.2–5.6)	539	5.0(4.1–6.0)	
Marital status															
Married	1423	47.5(44.5–50.5)	2645	60.2(58.0–62.4)	<0.001	693	40.4(36.5–44.4)	3375	58.9(56.9–61.0)	<0.001	701	50.0(46.9–53.1)	4198	57.0(55.0–59.1)	<0.001
Not married	1779	52.5(49.5–55.5)	2161	39.8(37.6–42.0)		1075	59.6(55.6–63.5)	2865	41.1(39.0–43.1)		782	50.0(46.9–53.1)	3783	43.0(40.9–45.0)	

	Previous drug use (n=9304)					Injection drug use (n=9290)				
	Yes (n=5197)		No (n=4107)		p[c]	Yes (n=235)		No (n=9055)		p[c]
	N[a]	Percent(95% CI)[b]	N[a]	Percent(95% CI)[b]		N[a]	Percent(95% CI)[b]	N[a]	Percent(95% CI)[b]	
Age										
20–29 years	1469	25.8(24.2–27.3)	968	22.3(20.2–24.4)	<0.001	41	21.1(15.3–26.9)	2393	24.5(23.2–25.8)	0.068
30–39 years	1275	23.2(21.3–25.0)	1057	25.2(23.3–27.1)		44	17.1(10.6–23.6)	2285	24.1(22.8–25.5)	
40–49 years	1370	28.5(26.7–30.1)	1052	25.4(23.6–27.2)		80	34.5(25.7–43.3)	2339	27.1(25.8–28.4)	
50–59 years	1083	22.6(20.7–24.5)	1030	27.0(24.5–29.5)		70	27.3(19.9–34.7)	2038	24.2(22.7–25.8)	
Gender										
Male	2839	54.4(53.1–55.8)	1670	42.6(41.0–44.3)	<0.001	151	65.4(58.6–72.2)	4352	49.4(48.4–50.4)	<0.001
Female	2358	45.6(44.2–46.9)	2437	57.4(55.7–59.0)		84	34.6(27.8–41.4)	4703	50.6(49.6–51.6)	
Race/ethnicity										
Non-Hispanic white	2864	75.7(72.7–78.8)	1394	57.2(51.7–62.7)	<0.001	152	77.5(71.1–83.4)	4104	68.3(64.3–72.2)	0.057
Non-Hispanic black	1120	11.2(9.4–13.1)	706	11.2(8.9–13.6)		36	8.2(4.3–12.1)	1786	11.3(9.4–13.3)	
Hispanic and others	1213	13.0(10.9–15.2)	2007	31.6(26.9–36.2)		47	14.3(9.3–19.3)	3165	20.4(17.3–23.5)	
Education										
<High school	208	2.4(1.8–2.9)	592	7.9(6.4–9.4)	<0.001	19	7.3(2.8–11.9)	780	4.4(3.7–5.2)	0.096
High school	885	12.6(10.9–14.3)	630	10.7(9.4–12.0)		42	15.6(9.4–21.8)	1466	11.7(10.4–13.0)	
>High school	4102	85.0(83.1–86.9)	2879	81.4(79.4–83.5)		174	77.1(70.5–83.7)	6801	83.8(82.2–85.5)	

PIR					< 0.001					< 0.001
< 1.0	1028	13.0(11.7–14.2)	840	13.0(11.3–14.8)		77	24.8(18.0–31.5)	1789	12.7(11.5–13.8)	
1.0–2.0	1127	15.8(14.2–17.4)	1019	18.7(17.0–20.5)		70	22.3(14.8–29.9)	2070	16.8(15.4–18.1)	
≥ 1.0	2781	67.3(65.0–69.6)	1898	61.9(58.9–64.9)		80	50.0(40.1–59.9)	4595	65.6(63.4–67.8)	
Missing	261	4.0(3.1–4.8)	350	6.3(5.1–7.6)		8	3.0(0.5–5.4)	601	4.9(4.1–5.8)	
Marital status					< 0.001					< 0.001
Married	2394	51.5(49.2–53.8)	2419	62.8(60.5–65.0)		74	35.6(28.2–43.0)	4734	56.5(54.5–58.4)	
Not married	2799	48.5(46.2–50.8)	1686	37.2(35.0–39.5)		161	64.4(57.0–71.8)	4315	43.5(41.6–45.5)	

[a] Unweighted *N*.
[b] Weighted percent with 95% confidence interval.
[c] *p*-Value was obtained from Wald chi-square test.

CI, 3.12–4.76) the odds of at least 1 episode of binge drinking per month over the past year. In addition, subjects with blood lead levels in the highest quartile also had 2.08, 2.96, and 2.02 times the odds of previous drug use (95% CI, 1.74–2.49), injection drug use (95% CI, 1.91–4.58), and use of marijuana (95% CI, 1.70–2.41) respectively (all p for trend < 0.05). No statistically significant results were found of the interactions between blood lead and age, gender, or race/ethnicity.

Table 5 shows the associations between blood lead and sexual risk behaviors, self-reported STIs, and biologically-confirmed HSV-2. After adjusting for age, gender, race/ethnicity, education, PIR, and marital status, logistic regression and linear trend tests using orthogonal polynomial contrasts demonstrated that increasing blood lead level was associated in a dose–response like fashion with age mixing with younger partners ($p < 0.01$) and older partners ($p < 0.01$), self-reported STI ($p < 0.04$), and HSV-2 ($p < 0.01$). Higher blood lead level was significantly associated with age mixing with younger sex partners (OR for the highest quartile: 1.57, 95% CI, 1.05–2.34), older sex partners (OR for the highest quartile: 1.77, 95% CI, 1.27–2.46), and positive HSV-2 results (OR for the highest quartile: 1.25, 95% CI, 1.00–1.56). Marginal associations were also observed for multiple sex partners (OR for the highest quartile: 1.22, 95% CI, 0.93–1.60).

4. Discussion

To our knowledge, this study is the first to link blood lead to multiple risk-taking behaviors and to STI. Using a large nationally-representative sample, we found that higher blood lead levels were associated with increased odds of substance use, sexual risk behaviors, and STIs in the U.S. general population of adults aged 20–59 years old. The observed associations appeared to remain independent of the confounding effects of demographic characteristics and socioeconomic status. These results, with previous reports of the association between blood lead and neurocognitive dysfunction (Bandeen-Roche et al., 2009; Khalil et al., 2009; Lanphear et al., 2005; van Wijngaarden et al., 2011; Weuve et al., 2009), support our hypothesis that lead exposure may contribute to substance use and STI risk by impairing neuropsychiatric function. The results highlight the need for research in additional samples using longitudinal data to more rigorously evaluate the association. If findings of the current study are upheld, results would provide further evidence of the adverse effects of lead exposure on physical and social wellbeing and would further highlight the critical need for programs and interventions to reduce environmental lead exposure in the US and globally.

Lead may influence substance use, sexual risk behaviors, and STI risk by impairing executive functioning. Numerous studies document the association between lead exposure and impaired cognition (Bandeen-Roche et al., 2009; Khalil et al., 2009; Lanphear et al., 2005; van Wijngaarden et al., 2011; Walkowiak et al., 1998; Weuve et al., 2009). There is an evidence from longitudinal studies suggesting that lead has persistent effects across multiple domains of cognitive function including spatial ability, learning, and memory (Bandeen-Roche et al., 2009; Khalil et al., 2009). Reductions in brain volume are thought to underlie the association between lead and reduced cognitive function (Schwartz et al., 2007). Specifically, lead is associated with decreases in total brain volume, white matter degeneration, and reductions in gray matter, with reduced volumes in the prefrontal cortex and anterior cingulated cortex, the areas of the brain that regulate emotion, judgment, arousal, and behavioral inhibition, particularly striking (Cecil et al., 2008).

Lead also may influence substance use, sexual risk behaviors, and STI risk by increasing the externalizing and internalizing disorders that result in part from impairments in executive

Table 2
Distribution of selected demographic characteristics and covariates by sexual risk behaviors, self-reported STIs, and biologically-confirmed HSV-2 in NHANES 2005–2010.

	Multiple sex partner ($n=8621$)					Sex partners five years younger ($n=5444$)					Sex partners five years older ($n=5450$)				
	Yes ($n=1534$)		No ($n=7087$)		p[c]	Yes ($n=1180$)		No ($n=4264$)		p[c]	Yes ($n=1339$)		No ($n=4111$)		p[c]
	N[a]	Percent(95% CI)[b]	N[a]	Percent(95% CI)[b]		N[a]	Percent(95% CI)[b]	N[a]	Percent(95% CI)[b]		N[a]	Percent(95% CI)[b]	N[a]	Percent(95% CI)[b]	
Age															
20–29 years	661	45.7(42.6–48.9)	1605	20.2(19.1–21.3)	< 0.001	260	19.5(16.8–22.1)	1825	37.4(35.1–39.7)	< 0.001	613	39.9(36.0–43.8)	1471	32.0(29.7–34.3)	< 0.001
30–39 years	386	24.3(21.7–26.8)	1807	24.1(22.7–25.5)		308	25.4(21.9–28.9)	999	22.5(20.8–24.3)		334	24.6(21.1–28.2)	975	22.7(20.5–24.8)	
40–49 years	299	18.9(16.2–21.6)	1946	28.9(27.6–30.3)		349	31.5(28.4–34.7)	823	22.7(20.7–24.6)		251	22.1(19.0–25.2)	923	25.2(23.0–27.3)	
50–59 years	188	11.1(9.1–13.0)	1729	26.7(25.0–28.5)		263	23.6(20.6–26.6)	617	17.4(15.4–19.4)		141	13.4(10.8–15.9)	742	20.2(17.6–22.7)	
Gender															
Male	897	58.2(54.6–61.7)	3160	47.1(46.1–48.2)	< 0.001	821	72.6(70.0–75.2)	1693	42.8(41.0–44.6)	< 0.001	433	32.2(29.4–35.0)	2090	53.7(52.2–55.2)	< 0.001
Female	637	41.8(38.3–45.4)	3927	52.9(51.8–53.9)		359	27.4(24.8–30.0)	2571	57.2(55.4–59.0)		906	67.8(65.0–70.6)	2021	46.3(44.8–47.8)	
Race/ethnicity															
Non-Hispanic white	585	59.4(55.2–63.6)	3513	71.9(68.2–75.7)	< 0.001	489	64.5(59.1–69.9)	2107	72.2(68.4–76.0)	< 0.001	564	66.0(61.0–70.9)	2030	71.9(68.2–75.7)	< 0.001
Non-Hispanic black	479	20.0(17.0–23.0)	1179	9.2(7.5–10.9)		282	13.8(10.4–17.1)	790	9.8(7.7–11.9)		339	14.9(11.7–18.1)	740	9.5(7.4–11.6)	
Hispanic and others	470	20.6(17.6–23.7)	2395	18.9(15.9–21.9)		409	21.7(17.7–25.7)	1367	18.0(15.5–20.5)		436	19.2(16.4–21.9)	1341	18.6(15.9–21.3)	
Education															
< High school	100	4.3(2.9–5.6)	536	3.7(3.1–4.4)	< 0.001	82	3.8(2.8–4.8)	225	3.1(2.4–3.7)	0.480	78	3.6(2.8–4.5)	227	3.0(2.3–3.7)	< 0.001
High school	301	14.8(12.6–17.0)	1064	10.8(9.5–12.1)		188	11.7(9.7–13.7)	689	10.6(9.2–13.3)		266	14.7(12.3–17.0)	613	10.5(8.4–12.5)	
> High school	1333	80.9(77.9–83.9)	5480	85.4(83.8–87.1)		909	84.5(82.6–86.5)	3349	70.8(83.2–88.1)		995	81.7(79.0–84.4)	3269	86.6(84.3–88.9)	
PIR															
< 1.0	386	19.7(17.4–21.9)	1286	11.0(9.8–12.3)	< 0.001	239	13.2(11.3–15.1)	824	12.8(11.3–14.4)	0.241	328	17.7(15.2–20.2)	735	11.5(10.0–13.0)	< 0.001
1.0–2.0	360	19.1(16.8–21.4)	1591	15.9(14.6–17.2)		269	17.9(15.4–20.4)	907	15.6(13.8–17.4)		301	17.5(15.1–20.0)	877	15.6(13.9–17.4)	
≥ 1.0	679	55.3(51.8–58.8)	3763	68.4(66.2–70.6)		610	64.6(61.3–67.8)	2303	67.7(65.0–70.4)		627	60.1(56.4–63.8)	2290	69.1(66.4–71.7)	
Missing	109	5.9(4.6–7.3)	447	4.7(3.7–5.6)		62	4.4(2.9–5.8)	230	3.9(2.9–4.8)		83	4.7(3.2–6.1)	209	3.8(2.8–4.7)	
Marital status															
Married	278	16.2(13.6–18.7)	4213	64.1(62.3–65.9)	< 0.001	513	46.7(42.5–50.9)	2377	60.6(57.5–63.7)	< 0.001	546	43.9(39.6–48.1)	2344	61.8(58.6–65.1)	< 0.001
Not married	1255	83.8(81.3–86.4)	2869	35.9(34.1–37.7)		666	53.3(49.1–57.5)	1886	39.4(36.3–42.5)		792	56.1(51.9–60.4)	1766	38.2(34.9–41.4)	
Alcohol consumption															
None	141	7.5(5.7–9.3)	1139	16.2(14.4–17.9)	< 0.001	163	14.1(11.1–17.2)	550	12.7(10.9–14.5)	0.001	165	12.0(9.1–15.0)	552	13.3(11.4–15.3)	0.135
Light	671	44.1(40.8–47.5)	3414	54.2(52.3–56.0)		542	47.0(43.4–50.6)	2126	55.3(53.3–57.2)		632	52.0(48.2–55.8)	2031	53.9(51.9–55.9)	
Moderate	400	29.1(25.6–32.6)	1174	20.8(19.6–22.0)		262	24.9(21.8–28.0)	742	21.8(20.1–23.6)		250	22.0(18.8–25.2)	761	22.7(21.1–24.3)	
Heavy	247	19.3(16.8–21.8)	527	8.9(7.9–10.0)		142	13.9(11.4–16.5)	358	10.2(8.8–11.5)		156	14.0(10.7–17.2)	345	10.1(8.9–11.4)	

	Self-reported sexual transmitted infection ($n=8579$)					Herpes simplex virus II ($n=7895$)				
	Positive ($n=729$)		Negative ($n=7850$)		p[c]	Positive ($n=1761$)		Negative ($n=6134$)		p[c]
	N[a]	Percent(95% CI)[b]	N[a]	Percent(95% CI)[b]		N[a]	Percent(95% CI)[b]	N[a]	Percent(95% CI)[b]	
Age										
20–29 years	187	21.8(18.1–25.6)	2025	23.9(22.6–25.2)	0.026	339	17.0(15.0–19.1)	2313	35.4(33.4–37.4)	< 0.001
30–39 years	206	28.6(24.6–32.6)	1991	23.8(22.5–25.1)		606	33.1(29.8–36.4)	1973	31.6(30.0–33.2)	
40–49 years	196	29.8(25.9–33.7)	2058	27.4(26.2–28.7)		816	49.8(46.4–53.2)	1848	33.0(31.4–34.7)	
50–59 years	140	19.7(15.5–24.0)	1776	24.8(23.3–26.5)		–	–	–	–	
Gender										
Male	243	32.2(28.3–36.2)	3787	50.4(49.3–51.4)	< 0.001	604	34.7(32.3–37.0)	3085	52.7(51.5–53.9)	< 0.001
Female	486	67.8(63.8–71.7)	4063	49.6(48.6–50.7)		1157	65.3(63.0–67.7)	3049	47.3(46.1–48.5)	
Race/ethnicity										
Non-Hispanic white	367	71.9(67.2–76.5)	3714	69.9(66.1–73.7)	< 0.001	528	48.7(43.4–54.0)	2925	68.4(64.2–72.5)	< 0.001
Non-Hispanic black	198	15.1(11.7–18.5)	1468	10.5(8.7–12.4)		733	30.5(26.2–34.9)	802	7.5(6.1–8.9)	

Hispanic and others	164	13.1(10.1–16.0)	2668	19.6(16.6–22.6)		500	20.8(16.7–24.8)	2407	24.1(20.5–27.7)	
Education										
< High School	28	2.3(1.3–3.4)	595	3.9(3.3–4.6)	0.003	139	5.9(4.3–7.5)	539	4.9(4.1–5.7)	0.002
High School	96	8.8(6.3–11.3)	1276	11.8(10.4–13.2)		366	16.9(14.1–19.7)	964	11.6(10.1–13.1)	
> High School	605	88.8(86.1–91.5)	5973	84.3(82.6–86.0)		1256	77.2(73.8–80.6)	4624	83.5(81.7–85.3)	
PIR										
< 1.0	129	11.2(8.8–13.6)	1518	12.4(11.1–13.7)	0.477	460	19.9(17.7–22.2)	1299	14.2(12.5–15.8)	< 0.001
1.0–2.0	163	15.2(12.3–18.2)	1785	16.5(15.1–17.9)		488	23.6(20.1–27.2)	1432	17.8(16.2–19.5)	
≥ 1.0	402	69.7(65.1–74.4)	4035	66.2(64.0–68.4)		697	50.8(46.7–55.0)	2986	62.7(60.1–65.2)	
Missing	35	3.9(2.1–5.6)	512	4.9(3.9–5.8)		116	5.6(4.2–7.0)	417	5.4(4.4–6.3)	
Marital status										
Married	306	48.2(43.0–53.3)	4203	58.0(56.0–60.0)	< 0.001	725	45.8(42.9–48.7)	3184	54.6(52.5–56.8)	< 0.001
Not married	423	51.8(46.7–57.0)	3641	42.0(40.0–44.0)		1036	54.2(51.3–57.1)	2948	45.4(43.2–47.5)	
Alcohol consumption										
None	95	10.7(7.8–13.6)	1189	15.2(13.6–16.8)	< 0.001	265	17.2(14.8–19.7)	661	12.1(10.4–13.8)	< 0.001
Light	355	51.0(47.1–55.0)	3714	52.4(50.6–54.3)		776	54.1(50.5–57.6)	2648	53.3(51.5–55.0)	
Moderate	144	23.0(19.1–27.0)	1425	22.1(21.0–23.1)		242	17.2(14.5–19.9)	1077	23.8(22.0–25.5)	
Heavy	92	15.2(12.3–18.1)	693	10.3(9.2–11.4)		153	11.5(9.0–14.0)	503	10.9(9.9–12.0)	

[a] Unweighted *N*.
[b] Weighted percent with 95% confidence interval.
[c] *p*-Value was obtained from Wald chi-square test.

Table 3
Blood lead level by covariates among all participants aged 20–59 years in NHANES 2005–2010 ($n=10,383$).

	Blood lead (μg/Dl)		
	N	Geometric Mean ± SE[a]	*p*[b]
Age			
20–29 years	2704	0.92 ± 1.01	< 0.001
30–39 years	2635	1.05 ± 1.02	
40–49 years	2707	1.30 ± 1.02	
50–59 years	2337	1.67 ± 1.02	
Gender			
Male	4943	1.49 ± 1.02	< 0.001
Female	5440	0.99 ± 1.01	
Race/ethnicity			
Non-Hispanic white	4623	1.16 ± 1.02	< 0.001
Non-Hispanic black	2073	1.29 ± 1.02	
Hispanic and others	3687	1.33 ± 1.02	
Education			
< High school	994	1.66 ± 1.03	< 0.001
High school	1698	1.42 ± 1.02	
> High school	7680	1.15 ± 1.01	
PIR			
< 1.0	2164	1.31 ± 1.03	< 0.001
1.0–2.0	2424	1.22 ± 1.02	
≥ 1.0	5094	1.17 ± 1.02	
Missing	746	1.38 ± 1.03	
Marital status			
Not married	5371	1.22 ± 1.02	0.101
Married	5005	1.19 ± 1.02	
Alcohol consumption			
None	1436	1.25 ± 1.03	< 0.001
Light	4394	1.08 ± 1.02	
Moderate	1697	1.37 ± 1.02	
Heavy	843	1.72 ± 1.03	
Drug use			
Yes	5197	1.25 ± 1.02	< 0.001
No	4107	1.12 ± 1.02	

[a] Weighted geometric mean with standard error.
[b] *p*-Value was obtained by Student's *t*-test and ANOVA.

functioning and neuropsychological function. Specifically, lead is associated with externalizing outcomes (Braun et al., 2006; Dietrich et al., 2001b; Froehlich et al., 2009; Ha et al., 2009; Mielke and Zahran, 2012; Naicker et al., 2012; Needleman et al., 2002; Needleman et al., 1996; Olympio et al., 2010; Wang et al., 2008; Wright et al., 2008); externalizing factors are co-morbid with substance use and are linked to sexual risk-taking (Ellis et al., 1995; Stacy et al., 2000) Lead exposure also is associated with internalizing factors including depression, panic disorder, and distress (Bouchard et al., 2009; Rajan et al., 2007), correlates of sexual risk behaviors and STI (Khan et al., 2009; Ramrakha et al., 2000). Lead-associated loss of gray matter in the prefrontal cortex and anterior cingulated cortex, areas are known to be regulating hubs of mood, with lead-associated perturbation of neurotransmission processes including synapse formation that may lead to reductions in serotonin and dopamine activity (Dunlop, 2007; Lidsky and Schneider, 2003) may underlie associations between lead and psychopathology.

An alternative explanation for the observed strong associations between lead exposure and alcohol and drug use in this study may be that substance use can partially lead to the increased blood lead levels. For example, studies have documented an association between alcohol consumption and blood lead (Falq et al., 2011; HENSE et al., 1992; Shaper et al., 1982; Taylor et al., 2013). Although the biological mechanism between the associations is still unclear, one hypothesized pathway is that alcohol use may increase the absorption of lead (Newton et al., 1992) by decreasing

Table 4
ORs of substance use associated with blood lead in NHANES 2005–2010.

	Crude model[a] OR (95% CI)	Confounder-adjusted model[b] OR (95% CI)
Binge drinking in the past 12 months		
Continuous[c]	1.96(1.77–2.16)*	1.91(1.73–2.11)*
Categorical		
Quartile 1 (< 0.78 μg/dL)	1.00	1.00
Quartile 2 (0.78–1.19 μg/dL)	1.66(1.43–1.92)*	1.65(1.43–1.92)*
Quartile 3 (1.19–1.82 μg/dL)	2.10(1.72–2.56)*	2.05(1.69–2.49)*
Quartile 4 (≥ 1.82 μg/dL)	3.34(2.86–3.90)*	3.21(2.76–3.74)*
p for trend	< 0.001	< 0.001
Frequent binge drinking in the past 12 months		
Continuous[c]	2.10(1.86–2.36)*	1.99(1.77–2.25)*
Categorical		
Quartile 1 (< 0.78 μg/dL)	1.00	1.00
Quartile 2 (0.78–1.19 μg/dL)	1.76(1.44–2.14)*	1.75(1.44–2.12)*
Quartile 3 (1.19–1.82 μg/dL)	2.45(2.00–3.00)*	2.34(1.91–2.86)*
Quartile 4 (≥ 1.82 μg/dL)	4.17(3.38–5.14)*	3.85(3.12–4.76)*
p for trend	< 0.001	< 0.001
Lifetime frequent binge drinking		
Continuous[c]	2.00(1.76–2.26)*	1.79(1.58–2.03)*
Categorical		
Quartile 1 (< 0.78 μg/dL)	1.00	1.00
Quartile 2 (0.78–1.19 μg/dL)	1.37(1.03–1.82)*	1.33(0.99–1.77)
Quartile 3 (1.19–1.85 μg/dL)	2.19(1.71–2.80)*	1.99(1.56–2.55)*
Quartile 4 (≥ 1.85 μg/dL)	3.22(2.47–4.21)*	2.69(2.04–3.55)*
p for trend	< 0.001	< 0.001
Previous drug use		
Continuous[c]	1.55(1.41–1.70)*	1.55(1.41–1.71)*
Categorical		
Quartile 1 (< 0.78 μg/dL)	1.00	1.00
Quartile 2 (0.78–1.19 μg/dL)	1.38(1.18–1.62)*	1.38(1.18–1.62)*
Quartile 3 (1.19–1.84 μg/dL)	1.74(1.50–2.02)*	1.73(1.49–2.01)*
Quartile 4 (≥ 1.84 μg/dL)	2.10(1.77–2.50)*	2.08(1.74–2.49)*
p for trend	< 0.001	< 0.001
Injection drug use		
Continuous[c]	2.10(1.79–2.46)*	1.84(1.54–2.18)*
Categorical		
Quartile 1 (< 0.78 μg/dL)	1.00	1.00
Quartile 2 (0.78–1.19 μg/dL)	1.13(0.65–1.97)	1.09(0.63–1.90)
Quartile 3 (1.19–1.83 μg/dL)	1.91(1.17–3.11)*	1.67(1.02–2.74)*
Quartile 4 (≥ 1.83 μg/dL)	3.75(2.46–5.70)*	2.96(1.91–4.58)*
p for trend	< 0.001	< 0.001
Use of marijuana		
Continuous[c]	1.52(1.39–1.66)*	1.53(1.39–1.68)*
Categorical		
Quartile 1 (< 0.78 μg/dL)	1.00	1.00
Quartile 2 (0.78–1.19 μg/dL)	1.36(1.16–1.60)*	1.37(1.16–1.60)*
Quartile 3 (1.19–1.83 μg/dL)	1.71(1.47–1.99)*	1.71(1.47–1.98)*
Quartile 4 (≥ 1.83 μg/dL)	2.02(1.71–2.40)*	2.02(1.70–2.41)*
p for trend	< 0.001	< 0.001
Use of cocaine		
Continuous[c]	0.82(0.55–1.21)	0.90(0.60–1.35)
Categorical		
Quartile 1 (< 0.97 μg/dL)	1.00	1.00
Quartile 2 (0.97–1.48 μg/dL)	2.38(1.01–5.59)*	2.33(1.02–5.30)*
Quartile 3 (1.48–2.19 μg/dL)	0.89(0.43–1.86)	0.96(0.49–1.87)
Quartile 4 (≥ 2.19 μg/dL)	0.78(0.40–1.53)	0.86(0.41–1.82)
p for trend	0.143	0.079
Use of heroin		
Continuous[c]	1.41(1.09–1.83)*	1.27(0.97–1.66)
Categorical		
Quartile 1 (< 0.97 μg/dL)	1.00	1.00
Quartile 2 (0.97–1.47 μg/dL)	0.82(0.54–1.25)	0.78(0.50–1.21)
Quartile 3 (1.47–2.19 μg/dL)	1.48(0.97–2.27)	1.31(0.85–2.03)
Quartile 4 (≥ 2.19 μg/dL)	1.35(0.83–2.20)	1.12(0.68–1.85)
p for trend	0.0733	0.403
Use of methamphetamine		
Continuous[c]	1.13(0.90–1.41)	1.09(0.87–1.37)
Categorical		
Quartile 1 (< 0.97 μg/dL)	1.00	1.00
Quartile 2 (0.97–1.48 μg/dL)	1.08(0.73–1.59)	1.10(0.75–1.62)
Quartile 3 (1.48–2.19 μg/dL)	1.59(1.05–2.41)*	1.58(1.04–2.38)*
Quartile 4 (≥ 2.19 μg/dL)	1.31(0.87–1.96)	1.28(0.85–1.92)
p for trend	0.055	0.995

* $p < 0.05$
[a] Adjusted for gender, age, and race/ethnicity.
[b] Adjusted for gender, age, race/ethnicity, marital status, education, and PIR.
[c] Concentrations of blood lead were log-transformed.

Table 5
ORs of risk sexual behaviors associated with blood lead in NHANES 2005–2010.

	Crude model[a] OR (95% CI)	Confounder-adjusted model[b] OR (95% CI)
Multiple sex partner		
Continuous[c]	1.28(1.13–1.45)*	1.14(0.99–1.31)
Categorical		
Quartile 1 (< 0.77 μg/dL)	1.00	1.00
Quartile 2 (0.77–1.16 μg/dL)	1.18(0.97–1.44)	1.17(0.94–1.47)
Quartile 3 (1.16–1.78 μg/dL)	1.51(1.17–1.95)*	1.37(1.05–1.78)*
Quartile 4 (≥ 1.78 μg/dL)	1.48(1.16–1.88)*	1.22(0.93–1.60)
p for trend	< 0.001	0.214
Sex partner five years younger		
Continuous[c]	1.27(1.09–1.49)*	1.19(1.00–1.42)*
Categorical		
Quartile 1 (< 0.75 μg/dL)	1.00	1.00
Quartile 2 (0.75–1.11 μg/dL)	1.34(0.95–1.89)	1.34(0.94–1.91)
Quartile 3 (1.11–1.71 μg/dL)	1.45(1.08–1.97)*	1.39(1.02–1.88)*
Quartile 4 (≥ 1.71 μg/dL)	1.75(1.22–2.53)*	1.57(1.05–2.34)*
p for trend	0.002	0.003
Sex partner five years older		
Continuous[c]	1.62(1.35–1.94)*	1.52(1.26–1.82)*
Categorical		
Quartile 1 (< 0.75 μg/dL)	1.00	1.00
Quartile 2 (0.75–1.11 μg/dL)	1.22(0.94–1.59)	1.21(0.93–1.57)
Quartile 3 (1.11–1.71 μg/dL)	1.89(1.41–2.55)*	1.79(1.32–2.42)*
Quartile 4 (≥ 1.71 μg/dL)	1.97(1.42–2.73)*	1.77(1.27–2.46)*
p for trend	< 0.001	< 0.001
Self-reported sexual transmitted infection		
Continuous[c]	1.16(0.98–1.37)	1.17(0.98–1.39)
Categorical		
Quartile 1 (< 0.77 μg/dL)	1.00	1.00
Quartile 2 (0.77–1.17 μg/dL)	0.97(0.76–1.22)	0.97(0.76–1.23)
Quartile 3 (1.17–1.80 μg/dL)	1.32(0.98–1.78)	1.32(0.98–1.78)
Quartile 4 (≥ 1.80 μg/dL)	1.32(0.94–1.86)	1.34(0.95–1.90)
p for trend	0.044	0.294
Herpes simplex virus II		
Continuous[c]	1.28(1.13–1.46)*	1.17(1.02–1.33)*
Categorical		
Quartile 1 (< 0.71 μg/dL)	1.00	1.00
Quartile 2 (0.71–1.05 μg/dL)	1.06(0.84–1.35)	1.05(0.93–1.33)
Quartile 3 (1.05–1.62 μg/dL)	1.29(1.02–1.64)*	1.20(0.94–1.53)
Quartile 4 (≥ 1.62 μg/dL)	1.45(1.16–1.81)*	1.25(1.00–1.56)*
p for trend	< 0.001	0.026

* $p < 0.05$
[a] Adjusted for gender, age, and race/ethnicity.
[b] Adjusted for gender, age, race/ethnicity, marital status, education, and PIR.
[c] Concentrations of blood lead were log-transformed.

hepcidin, the molecule that regulates iron metabolism (Harrison-Findik, 2009). Reduced hepcidin production will lead to increased iron absorption (Crist et al.) and, since iron and lead share a common transporter within the body, increased lead absorption. However, even if alcohol and drug use may increase exposure to lead, it is possible that there is a mutually reinforcing feedback loop between blood lead levels and substance use. There is a need

for longitudinal studies with frequent measurements to better understand the interplay between substance use and lead levels.

In addition to the important concern about reverse causality, several additional limitations in this study should be considered when interpreting our results. First, given the cross-sectional nature of the NHANES data, we cannot explore the temporal relationship between lead exposure and risk behaviors. Second, although the half-life of lead in human blood is estimated from 28 days to 36 days (Griffin et al., 1975; Rabinowitz et al., 1976), they represent a mixture of recent exposure as well as the metal from deeper physiological stores such as bone lead (Korrick et al., 2002). With the continuing decrease in environmental heavy metal levels in the U.S., physiological stores of heavy metal may comprise the major source of circulating heavy metal in the body (Hu et al., 1996). In addition, although we hypothesized substance use as mediator in our study, we cannot totally rule out its confounding effects due to alcohol or illicit drug-induced increases of heavy metal absorption (Newton et al., 1992). Furthermore, although several important potential confounding factors were included in our study, other unselected potential social, psychological, physical confounders such as occupation and pre-/postnatal exposure to other environmental factors may also explain some of the difference. Since the development of risk-taking behavior and psychopathology is a result of complex interactions between many factors, studies in future with longitudinal design are warranted to further investigate the magnitude and direction of the actual pathway between risk behaviors and lead as well as other environmental exposure.

Our study has several strengths. The NHANES survey data offers a unique opportunity to examine the associations between lead exposure and risk behaviors in a large nationally-representative sample of U.S. adults. In addition, we were able to adjust for many potential confounders including demographic characteristics, socioeconomic status, alcohol consumption, and drug use. Furthermore, we also conducted sensitivity analysis by using models with different covariates, and the consistent results obtained from these different models suggest that the findings are unlikely observed by chance.

5. Conclusion

In summary, our study found that higher blood lead levels were significantly associated with increased odds of substance use, sexual risk behaviors, and STI. Considering the limitations of our study, further studies with longitudinal data and detailed temporal information are necessary to determine the direction of the association. As both lead and risk behaviors have adverse health effects on the population, the results of this study may raise more attention on the potential adverse effects of lead exposure on health.

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