Prevalence of Elevated Blood Leads and Exposure to Lead in Construction Trades in Iowa and Illinois

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Background *Despite lowering of the permissible exposure level for lead in construction from 200 to 50 μg/m^3 in 1993, excessive lead exposure continues to be a problem. Relatively little data are available from the Midwestern U.S. on the environmental lead concentrations generated during various construction activities and the potential for worker exposure. This study characterized the prevalence of blood lead concentrations in high-risk construction trades in Iowa/Illinois, and identified risk factors for occupational exposure to lead in these construction workers.*

Methods *A sample of 459 workers was selected from the total population of all union members from trade groups of painters, plumbers/pipefitters, ironworkers, laborers, and electricians. Participants completed an interviewer-administered questionnaire obtaining information on demographics, symptoms, occupational history, work practices, personal protective equipment, and training. Venous blood samples were collected from each participant and analyzed for blood lead (using atomic absorption spectroscopy) and free erythrocyte protoporphyrin levels.*

Results *Blood lead levels (BLLs) of construction workers ranged from 0.1 to 50 μg/dL. Geometric mean blood lead concentrations by trade group were: laborers (7.6 μg/dL, n = 80); painters (5.9 μg/dL, n = 83); ironworkers (5.2 μg/dL, n = 87); plumbers (4.4 μg/dL, n = 82); electricians (2.4 μg/dL, n = 91). Blood lead levels for painters and laborers were significantly higher than other trade groups, and levels for electricians were significantly lower ($p < 0.01$). Participants reported working primarily on commercial and industrial projects including new construction, renovation, and demolition. There were significant differences between the types of projects performed by different trade groups with laborers performing more highway/bridge renovation ($p < 0.01$), and plumbers reporting more residential remodeling ($p = 0.05$), repair of water lines containing lead ($p = 0.04$), or work on lead joints ($p < 0.01$). In addition to trade, elevated blood lead levels were associated with the type of construction project (especially bridge renovation and residential remodeling) and activities that include welding, cutting, rivet busting. The age of the home in which the worker lived, and hobbies such as casting/smelting lead for bullets or sinkers, were also important risk factors. Compliance with OSHA's Construction Lead Standard, and implementation of good occupational health and safety practices in general, was poor.*

Conclusions *Blood lead levels of 459 construction workers differed by the type of trade, type of project and specific job activity owing to differences in the inherent exposure*

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potential of each task. Although the numbers of workers performing lead abatement projects were small, the trend for lower BLL in this group provides evidence that training, implementation of engineering controls, and proper use of personal protective equipment such as respirators is effective in controlling lead poisoning. Am. J. Ind. Med. 36:307–316, 1999. *© 1999 Wiley-Liss, Inc.*

KEY WORDS: lead; blood; lead exposure; construction; occupational health

INTRODUCTION

Lead poisoning is a serious hazard for construction workers. It is estimated that over 900,000 U.S. construction workers are at risk of lead poisoning. [Occupational Safety and Health Administration, 1993]. Exposure assessments reported by the National Institute for Occupational Safety and Health (NIOSH) and the Occupational Safety and Health Administration (OSHA) indicate that construction workers performing certain tasks may be exposed to airborne lead at concentrations hundreds of time greater than accepted limits. At selected construction sites where air monitoring has been performed, 65% of airborne concentrations of lead have exceeded OSHA's pre-1993 Construction Lead Standard of 200 μg/m^3 [Robinson et al., 1990]. Airborne lead concentrations as high as 29,000 μg/m^3 have been reported inside confined areas during abrasive blasting, and lower levels associated with demolition (200–300 μg/m^3), steel cutting and rivet busting (1,500 μg/m^3) still greatly exceed the current OSHA PEL of 50 μg/m^3 [National Institute for Occupational Safety and Health, 1991; Occupational Safety and Health Administration, 1993; Robinson et al., 1990].

While the true extent of lead exposure among trades involved in different types of construction is unknown, reports to date have indicated that construction activities involving lead-based materials can result in severe lead poisoning for workers, their family members, and nearby communities [Centers for Disease Control, 1992; Fischbein et al., 1984; Grandjean and Bach, 1986; Landrigan et al., 1982; National Institute for Occupational Safety and Health, 1991; Occupational Safety and Health Administration, 1993; Piacitelli et al., 1995, 1997; Pollock and Ibels, 1986; Reynolds et al., 1997; Robinson et al., 1990].

Worksite evaluations indicate that construction workers in selected trades are experiencing some of the most severe cases of lead poisoning reported. In a study looking at lead exposures in ironworkers, current work on a lead job, rivet busting (removing rivets which hold metal structures together by cutting, shearing or sawing), and cigarette smoking were all found to be significantly associated with elevated blood-lead level in the participating union members [Forst et al., 1997]. Lead poisoning was recently reported among construction workers renovating a previously deleaded bridge [Reynolds et al., 1997]. Renovation released lead that had previously been inaccessible. This study identified several tasks with high potential for exposure to lead: concrete demolition, steel cutting, rivet busting, deck forming, structural repair, and cleanup of debris. Workers did not use engineering controls, respirators, change clothes, wash hands, or shower. Another study found that blood lead levels (BLLs) were significantly higher for construction workers who had ever worked in demolition, ever burned paint and metal and welded on outdoor structures compared to those workers who had done none of these activities [Sokas et al., 1997].

Relatively little data is available regarding environmental lead concentrations generated during various construction activities in the mid- and central U.S., and the potential for worker exposure that might result from these activities. The emphasis of this study is on evaluating lead exposures among various construction trades and project types in the Midwestern U.S. The specific aims of this project are to:

1) Characterize the prevalence of elevated blood lead concentrations and FEP levels in Iowa/Illinois construction workers in selected high-risk trades including painters, ironworkers, plumbers and pipefitters, laborers, and electrical workers.
2) Identify and evaluate risk factors such as work practices, use of engineering controls and personal protective equipment that may contribute to occupational exposure to lead in these construction trades.

METHODS

Selection of Subjects

As a general strategy for subject selection and recruitment, business agents from local unions provided a list of identification numbers for their total memberships, and 100 were randomly selected. The business agents then provided the names, addresses, and phone numbers for these individuals. Recruitment letters (approved by the University of Iowa IRB) were sent and followed up with repeated phone calls to confirm participation and scheduling. Those choosing not to participate were replaced by inviting new subjects through repeated generation of new random numbers. This procedure was strictly followed for electricians, and ironworkers. In other trade groups, this general strategy had to be modified. Painters were recruited at the union hall as they attended meetings, rather than by sending letters and calling. For plumbers, invitations were mailed to all members, with a card that could be returned indicating the member's interest in participating; a confirmatory call was then made. Laborers, who were the most difficult to contact, were recruited in person at the union hall as they arrived in the early morning. To help assess the representativeness of our sample, the business agents provided information on demographics of their total memberships. We also attempted to gather information on the characteristics of individuals who refused to participate in the study.

Questionnaire

A questionnaire was developed based upon several sources: sample questionnaires used by other researchers, review of the literature, consultation with other researchers, interviews with construction workers, and construction site visits, and review of the OSHA Construction Lead Standard. After two rounds of pilot testing by union members (not part of the study population), the questionnaire was sent for further evaluation by peer reviewers including researchers in academic, governmental, and non-governmental organizations.

Questionnaires were administered by an interviewer to small groups of participants. In addition to demographic information, the questionnaire asked for occupational history including information on the construction trade in which the participant currently worked, number of years employed in construction, number of employers in the past 12 months, and description of the work they had done. Information about work projects, work practices, and health was collected including histories of prior lead screening, work-related disease, and safety training. Detailed information regarding recent construction projects, specific tasks, and implementation of control measures during the last 3 months was recorded.

Information was also collected about exposure to lead outside the workplace by asking questions about: residence history, source of water for drinking and cooking, hobbies entailing potential lead exposure, and information about children in the household and whether they were ever tested for lead.

Blood Samples

Venous blood samples were collected from the antecubital vein in the arm or from the back of the hand in two separate 3cc vacuum tubes containing ethylenediamine tetraacetic acid (EDTA) for lead analysis and heparin for free erythrocyte protoporphyrin (FEP) analysis. Blood lead analysis was performed by Graphite Furnace Atomic Absorption (GFAA) following a method recommended by the Centers for Disease Control and Prevention (CDC) for blood lead analysis [New York State Department of Health, 1991]. FEP was determined using front face fluorescence analysis (ESA, Boston, MA).

Statistical Methods

Questionnaire data was entered in an EpiInfo database and analyzed using SAS 6.1. Accuracy of data entry was confirmed by checking more than 10% of all files. Descriptive statistics were used to summarize the distributions of demographic variables and proportions of categorical responses were evaluated over all workers and by construction trades.

Descriptive statistics were used to evaluate the distributions of the data. Skewed data were normalized by log transformation for parametric analyses. Non-parametric tests were used since log-transformations did not result in normal distributions for BLLs and FEPs. Proportions of categorical responses were evaluated over all workers and by construction trade for demographics and for most sections of the questionnaire. Differences in proportions among trades were evaluated using Fisher Exact tests. Kruskal–Wallis χ^2 test and Wilcoxon Rank Sum Scores were used to test for differences in BLLs and FEPs among all trades and between individual trades, and by season. T-Tests or Paired Signed Rank Tests (nonparametric T-Test) were used to test for differences in blood lead and FEP measures over time for a subset of data from Bridge workers, and T-Tests were used to test for differences in blood lead and FEP for cases reporting symptoms compared to non-cases. Spearman correlations were calculated to evaluate relationships between BLLs or FEPs and potential predictor variables. Then stepwise multiple linear regression was used to evaluate the relationships between the significant ($p = 0.05$) multiple predictor variables and BLL or FEPs.

Human subjects

The research protocol was approved by the University of Iowa IRB, and informed consent was obtained for all subjects.

RESULTS

Demographics

Data collection began in August 1994 and concluded in August 1996. A total of 45 sampling sessions were conducted. A total of 459 construction workers participated in the study including: 102 painters, 82 plumbers, 80 laborers, 88 ironworkers, 93 electricians, and 14 in other

TABLE I. Summary of Demographics for Participants Completing a Questionnaire in a Study of Randomly Selected Lead Exposed Construction Workers in Iowa and Illinois, 1994–1996

Parameter	All	Trade: Painters	Plumbers	Laborers	Ironworkers	Electricians	Other	Fisher exact p-value
N	450	88	79	62	89	92	12	
Age								
Mean	42	39	46	38	43	41	42	$p < 0.01$
SD	11	11	9	9	10	11	11	
Range	19–74	19–74	25–69	20–60	21–66	20–62	23–60	
Gender								
Male	410	83	78	60	88	89	12	$p < 0.01$
	97%	94%	99%	97%	99%	97%	100%	
Female	12	5	1	2	1	3	0	
	3%	6%	1%	3%	1%	3%	0%	
Race								
White	400	79	78	57	84	92	10	$p = 0.02$
	94.8%	90%	99%	92%	94%	100%	83%	
Black	6	2	0	3	1	0	0	
	1.4%	2%	0%	5%	1%	0%	0%	
Hispanic	8	4	0	1	2	0	1	
	1.9%	5%	0%	2%	2%	0%	8%	
Nat. Am.	7	3	1	1	1	0	1	
	1.7%	3%	1%	2%	1%	0%	8%	
Other	1	0	0	0	1	0	0	
	0.2%	0%	0%	0%	1%	0%	0%	
Education								
Grade school	11	4	0	1	5	0	1	$p < 0.01$
	2.6%	5%	0%	2%	6%	0%	8%	
Some high School	30	11	1	8	6	2	2	
	7.1%	13%	1%	13%	7%	2%	17%	
High school	116	34	13	25	29	12	3	
	27.6%	39%	16%	40%	33%	13%	25%	
Some college	109	21	16	17	20	32	3	
	25.9%	24%	21%	27%	23%	35%	25%	
College	21	2	3	4	5	5	2	
	5.0%	2%	4%	6%	6%	5%	17%	
Other/trade school	134	16	46	7	23	41	1	
	31.8%	18%	58%	11%	26%	45%	8%	
Trade N	450	88	79	62	89	92	12	
		20.9%	18.7%	14.7%	21.1%	21.8%	2.8%	
Current apprentice	54	11	6	7	10	19	1	$p = 0.06$
	13.2%	13%	8%	12%	12%	21	9%	
Years employed in construction								
Mean	18.8	16.4	23.6	15.5	19.3	18.8	22.0	
SD	10.7	10.6	8.8	9.7	10.8	11.6	11.2	
Range	<1–49	1–42	2–42	<1–39	1–49	1–45	8–45	
Number of employers in the past 12 Months								
Mean	2.2	1.4	1.9	3.2	3.2	1.7	1.8	
SD	1.8	0.9	1.4	2.3	2.3	1.3	1.0	
Range	0–12	0–5	0–6	0–10	0–12	0–6	0–3	

trades such as carpenter, operator, engineer, safety professional. These other trades were present at the sampling sessions and were analyzed separately from the target trade groups. Not all participants completed both questionnaires and blood sampling.

Based on the data obtained with the questionnaire, the overall age of participants ranged from 19 to 74 years with a mean of 42 years. The majority of those who answered the questionnaire were white (94.8%) and male (97%). Most had either a high school education, some college, or trade school. The number of years employed in construction ranged from less than 1–49 years, with a mean of 18.8 years. Participants had worked for an average of 2.2 different employers in the previous year. Table I presents demographic results by trade. There were statistically significant differences between trades for age (painters and laborers were younger), gender (there were more female painters), race (painters were slightly more diverse), education (more electricians and plumbers reporting some college or trade school), and fewer current apprentices among plumbers. A comparison of these figures to the demographics reported by the Union Local Business Agents (not shown in the table) indicated that these participants were representative of the racial and gender characteristics of the full union membership. Detailed information on non-participants was collected primarily for plumbers and electrical workers and indicated that these refusals were slightly younger (mean age of 37 years) than participants and that more (29.7%) were apprentices. Of those who refused, most were simply not interested, too busy, or averse to giving blood.

Blood Lead and FEP

Table II summarizes blood lead measurements overall and by trade. Both arithmetic and geometric means are reported since BLLs are often lognormally distributed in populations. No samples clotted or were lost. All blanks submitted were below detectable levels.

The overall geometric mean (GM) BLL was 4.7 μg/dL, slightly higher than the U.S. national average of 3 μg/dL reported in NHANES III [National Center for Health Statistics, 1984]. Laborers had the highest BLL (GM = 7.6 μg/dL), while electricians had the lowest (GM = 2.4 μg/dL); see Figure 1. Twenty four (30%) laborers had blood leads exceeding 10 μg/dL and 12 individuals (15%) had levels exceeding 20 μg/dL, the level recently recommended by the American Conference of Governmental Industrial Hygienists (ACGIH) to prevent adverse reproductive effects [ACGIH, 1993]. Overall the differences between trades (Npairways ANOVA—Kruskall Wallace) were significant ($p = 0.0001$). Free Erythrocyte Protoporphyrin, expressed as μg FEP/gram HB, was very similar among the five trades targeted (GM = 1.4–1.5). Blood lead levels were not correlated with FEPs.

Wilcoxon Rank Sum Scores comparisons between individual trades, and Kruskall Wallace comparisons for overall trade groups were calculated. Overall, there were statistically significant differences in BLL and FEP among the trade groups. For BLL, laborers has significantly higher values than plumbers and electricians, but not painters, ironworkers, or other trades. Painters had statistically significantly higher BLL than plumbers and electricians, but not ironworkers, laborers or other trades. A different pattern was seen for FEPs, with no significant differences between trades, except for 'other' trades being significantly lower.

Although not all trades were sampled in all four seasons, there were statistically significant differences in BLL values by season for the plumbers, ironworkers, and the overall trade groups. The overall geometric mean BLL during fall was 6.4 μg/dL, followed by winter (4.6μg/dL), spring (4.1 μg/dL), and summer (3.7 μg/dL). Similarly, the seasonal differences in FEPs were statistically significant in overall trade groups and each individual trade group except the painters. The overall geometric mean FEP was highest during winter (1.8 μg/gmHB), followed by summer (1.6 μg/gmHB), spring (1.3 μg/gmHB), and fall (1.1 μg/gmHB). We

TABLE II. Blood Lead Results (μg/dL) by Trade Group for Randomly Selected Lead Exposed Construction Workers in Iowa and Illinois, 1994–1996

Trade Group	N	GM	Arithm. mean	SD	Range	Number (%) >10 μg/dL	Number (%) >20 μg/dL
All Groups	437	4.7	6.5	6.4	0.1–50.0	55(12.6%)	16 (3.7%)
Painters	83	5.9	7.0	4.7	1.5–26.3	12 (14.5%)	2 (2.4%)
Plumbers	82	4.4	5.1	3.4	1.4–27.0	5 (6.1%)	1 (1.2%)
Laborers	80	7.6	11.2	11.4	1.2–50.0	24 (30.0%)	12 (15.0%)
Ironworkers	87	5.2	6.1	3.9	0.9–23.2	10 (11.5%)	1 (1.5%)
Electricians	91	2.4	3.4	2.4	0.1–13.3	1 (1.1%)	0
Other	14	5.9	6.7	3.7	3.1–13.7	3 (21.4%)	0

Kruskal–Wallis χ^2 test ($p = 0.0001$)

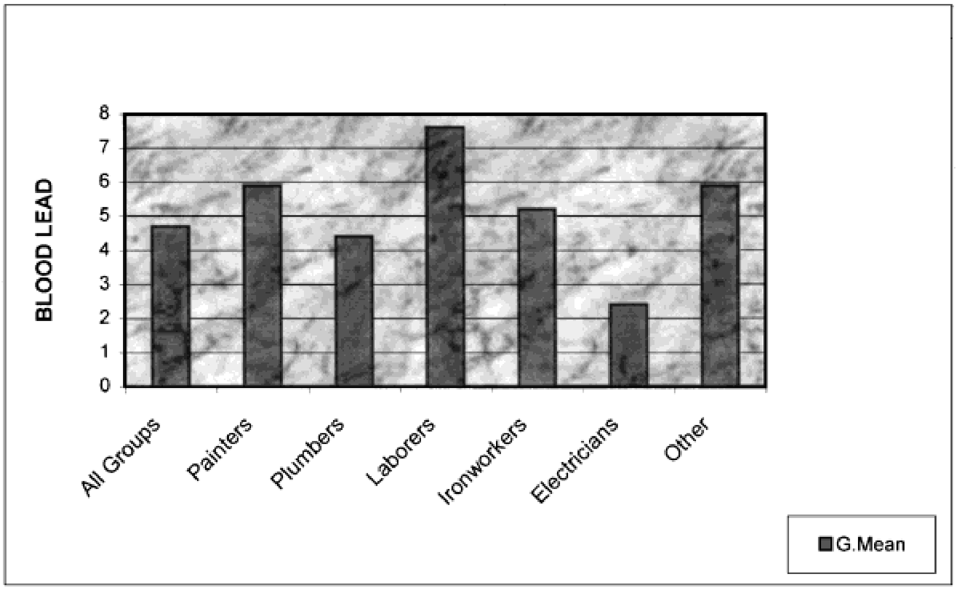

FIGURE 1. Blood Lead (mcg/dL) results by trade group for Iowa-Illinois construction workers, 1994–1996.

observed a trend in the BLL values, which were highest in the fall season for all trades, while no such trend was seen for FEPs and the pattern of seasonal differences in FEPs varied depending on the trade.

Project Information and Work Habits

Detailed information on their most recent jobs was ascertained from participants. Although there were statistically significant differences between trades for both the type of construction and the type of project, most worked in commercial or industrial settings on new construction or renovation/remodeling. Painters worked primarily in commercial (60%) and industrial (24%) settings with 46% involved in new construction and 34% in remodeling. Plumbers worked mostly in commercial (44%), industrial (41%), and residential (15%) settings, with 45% involved in new construction and 37% in remodeling. Laborers worked in commercial (34%), industrial (22%), highways/streets (18%), and bridge (14%) settings with 43% involved in new construction and 30% in remodeling. Ironworkers worked mostly in commercial (47%) and industrial (47%) settings with 74% involved in new construction and 17% in remodeling. Electricians worked primarily in commercial (49%) and industrial (47%) settings with 52% involved in new construction and 44% in remodeling/renovation. Overall 13% of construction workers reported that lead dust or fumes were generated in their work on this job; 55% did not know.

Compliance with regulatory requirements was poor. Only thirty-three percent of workers on projects with potential for lead exposure had received training or written information concerning lead hazards or regulations. While 88% of workers on all projects reporting, using a respirator on their most recent job, only 65% had ever been fit tested, 76% had been trained in respirator use, and 49% had been examined by a physician. Of those receiving medical examinations, only 4% underwent pulmonary function testing. On jobs with potential lead exposure, only 20% of those using respirators had been fit tested. Coveralls or protective clothing were reportedly used by 19%; controls such as clothes changing facilities (19%), water for washing hands/face (61%), showers (15%), and separate eating facilities (39%) were often not available. Regular washing of hands before eating, drinking, or smoking was low (8–64%), 36% reported smoking at work, 25% bit their fingernails, and 10% chewed on plastic-coated wires. Extraction of lead from the plastic coating on wires into saliva during chewing has been described [Franco et al. 1994; Kelley et al. 1993]. Air monitoring was conducted on 13% of these projects and environmental (bulk/surface) monitoring for lead was conducted on only 7% of the sites.

In addition to job activities, information about potential risk factors off the job was also collected. Seventy-seven percent of the participants completing the questionnaire owned their homes, 81% of which were single family dwellings. Of the 391 participants answering questions about the age of their home, 327 lived in homes built before 1980. A large number (187) reported remodeling which included paint removal (88), plumbing (120), soldering/welding (98); 156 had done the work themselves. A few workers engaged in hobbies at home with potential for exposure to lead such as stained glass (15), riflery/shooting (86), and casting or smelting lead (17).

Symptoms Reported

The questionnaire was used to gather information on symptoms that workers had experienced for more than one week during the previous three months. The most commonly reported symptoms during this study were joint pain (27%), muscle aches/pains (24%), headache (16 %), numbness of hands and feet (12%), excessive tiredness (11%), inability to sleep (11%), forgetfulness (10%), irritability (10%), and trouble conceiving children (6%). Two percent of the workers had been diagnosed with anemia. In general, laborers and ironworkers reported more symptoms compared to all the other trade groups.

Association between BLL, FEP, and Risk Factors

Table III presents the associations between BLL or FEPs and potential risk factors for exposure to lead by calculating Spearman Correlation coefficients. Risk factors at work that were significantly associated by themselves with an increased BLL included: lead dust/fumes generated on the most recent job (especially for certain trades); current respirator use; highway/bridge repair; commercial/industrial demolition; new construction of highways/streets and bridges; residential remodeling; repair of lead membrane waterproofing; and older residences. Among hobbies performed in the last 3 months, casting/smelting lead was the only one significantly and positively associated with an elevated BLL. Electric cable splicing was associated with significantly lower BLL. None of the correlation coefficients for BLL were strong; the highest correlation were for lead dust/fumes generated ($r = 0.54$ for laborers), casting/smelting lead ($r = 0.338$), and older homes ($r = -0.256$). Significant correlations for FEPs were primarily in the opposite direction of BLL correlations except for residence in an older home. The correlation coefficients for FEPs for hobbies performed in the past 3 months were significantly and negatively correlated for most of the hobbies.

Construction trade was previously found to be a significant predictor of increasing BLLs and FEPs (Table II) compared to the US adult populations (NHANES III). Blood lead levels and FEP were significantly associated with type of construction on most recent job, type of project, and type of residence when analyzed by nonparametric test (Kruskal–Wallis Chi square) as shown in Table IV. Demolition, lead abatement, renovation/remodeling on bridges and highways/streets were associated with higher BLL. We further analyzed a subset of construction workers ($n = 16$) with BLL greater than 20 μg/dL and found that 75% of them were laborers and were involved with specific

TABLE III. Significant Spearman Correlations of BLLs and FEPs with Questionaire Variables in Lead Exposed Construction Workers in Iowa and Illinois, 1994–1996

	BLL		FEP	
Variable	**r**	**p**	**r**	**p**
Jobsite factors				
Lead dust/fumes generated in work area				
(On most recent job)				
Overall	0.27	<0.01		
Laborers	0.54	0.01		
Ironworkers	0.38	0.05		
Electricians	0.30	0.10		
Received written information or training	0.14	0.007	0.09	0.088
Currently has/uses respirator	0.12	0.02		
Symptoms experienced for more than a week during last 3 months				
Headache			0.09	0.078
Dizziness	0.091	0.076		
Vomiting			−0.088	0.084
Shaking hands/feet	0.096	0.062		
Most recent project in last 3 months				
Highway/railroad bridge repair	0.128	0.029		
Commercial/industrial demolition	0.117	0.043	−0.102	0.076
Transmission/communication tower maintenance			0.101	0.089
New construction/commercial			−0.097	0.085
New construction/industrial	−0.098	0.084		
New construction/highways-streets	0.127	0.032		
New construction/bridges-tunnels-elevated highways	0.136	0.023		
Electric cable splicing	−0.133	0.025		
Residential remodeling	0.202	<0.001		
Repair/removal of water lines with lead			−0.111	0.069
Repair of lead membrane waterproofing	0.128	0.039		
Repair/replace/remove water mains or hydrants	0.114	0.068		
Exposures outside the workplace Home				
What year was your home built?	−0.256	0.0001	−0.119	0.025
1 = before 1900				
11 = 1990's				
Is exterior of home painted?			0.087	0.086
Condition of paint (1 = excellent, 3 = poor)			0.108	0.079
Condition of interior paint (1 = excellent, 3 = poor)			0.177	0.0006
Hobbies performed in last 3 months				
Stained glass			−0.321	0.064
Art-paints/pigments			−0.259	0.098
Ceramics			−0.395	0.023
Riflery/shooting			−0.189	0.057
Casting/smelting lead	0.338	0.035		
Lead manufacturing			−0.414	0.021
Battery manufacturing			−0.409	0.025
Radiator repair			−0.474	0.003
Use of leaded gasoline			−0.282	0.005
Auto repair			−0.220	0.060

TABLE IV. Associations of BLL and FEPs with Exposures (Wilcoxon Rank sum - Kruskal-Wallis Test) in Lead Exposed Construction Workers in Iowa and Illinois, 1994–1996

Parameter	Rank order of categories	Mean score	Probability	Biomarker
Type of construction	Bridges/tunnels	280	0.0001	BLL
Most recent job	Highways/streets	229		
	Residential	203		
	Commercial	184		
	Industrial	168		
Type of construction	Bridges/tunnels	207	0.049	FEP
Most recent job	Residential	205		
	Commercial	201		
	Highways/streets	183		
	Industrial	139		
Type of project	Demolition	268	0.017	BLL
	Lead Abatement	259		
	Other	209		
	Renovation/remodeling	189		
	New Construction	170		
	Asbestos Abatement	141		
Type of residence	Other	286	0.057	BLL
	Duplex/zero lot	210		
	Single family	196		
	Mobile home	194		
	Condominium	176		
	Apartment	160		
	Quadruplex/multifam	107		

TABLE V. Stepwise Multiple Linear Regression Model for BLL in Lead Exposed Construction Workers in Iowa and Illinois, 1994–1996

Dependent variable	Independent variables in final model	Coefficient	p-value	Model R^2	Model P
Blood Lead Level	Intercept	7.420	< 0.001		
	Bridge work	2.677	0.014		
	New construction	−0.928	0.032		
	Lead dust present	2.486	< 0.001		
	Plumber (trade)	−1.322	0.022		
	Laborer (trade)	1.545	0.028		
	Electrician (trade)	−2.246	< 0.001		
	New construction				
	bridges/highways	6.010	< 0.001		
	Residential remodeling	3.067	< 0.001		
	Year home built	−0.209	0.004	0.33	0.055

Models for FEPs were not significant.

tasks of bridge renovation, welding, cutting, sweeping, and rivet busting on their most recent job. None of these laborers used respirator protection or engineering controls during the bridge renovation work.

Risk factors, which were significantly correlated with BLL or FEPs that represented more than 10 participant responses, were tested using stepwise multiple linear regression models to evaluate their relationships taking into consideration the other risk factors. None of the independent variables or models was significant for FEP. The model calculated for BLL is shown in Table V. Risk factors that remained in the final model included bridge work (high), new construction (low); lead dust present (high), plumber (low); laborer (high), electrician (low); new construction on bridges/highways (high), residential remodeling (high); and older homes (high). This model explains 33% of the variability in BLLs ($p = 0.055$), and reinforces the importance of risk factors identified through Spearman Correlations and other previous approaches.

Characteristics of the 16 individuals with BLLs exceeding 20 µg/dL (3 painters, 1 plumber, 1 ironworker, and 12 laborers), reinforces the association between elevated BLL and bridge renovation, specific tasks of welding, cutting, and rivet busting along with failure to use engineering or personal protective equipment controls.

DISCUSSION

Overall, the geometric mean BLL of 4.7 µg/dL found for the Iowa-Illinois construction workers in this study, is only slightly higher than the U.S. national average of 3 µg/dL reported in NHANES III [National Center for Health Statistics, 1984]. Differences in blood lead concentrations were found by trade, with laborers who perform activities such as median cutting, blow-off of lead-containing dust from exposed beams, and cleanup during renovation of bridges having the highest levels. The geometric mean BLLs for painters, ironworkers (cutting and structural steel work) and plumbers were next highest, while the BLLs for electricians were significantly lower.

The workers in this study had BLLs within the lower range of results from prior studies of other construction populations. A mean BLL of 8.0 µg/dL, and a range of 2–30 µg/dL was seen in a group of ironworkers and laborers in a cross-sectional study of unionized Maryland construction workers [Sokas et al., 1997]. Participants who had 'ever' worked in demolition, burning paint and metal and who had welded outdoors had higher levels than those who had done none of these activities. Similar results were seen in another study where ironworkers currently working on leaded structures and who were engaged in "rivet busting" as their predominant job task showed statistically significant blood lead elevations [Forst et al., 1997].

The BLL is a good index of current or recent lead absorption. This study focused on relationships between elevated BLLs and work activities occurring within the past 3 months. It is worth noting the possibility that a very high exposure to lead several months earlier could contribute to a chronically elevated BLL, as chronically blood lead is in equilibrium with lead in bone. It is therefore possible, that we may have missed a few extremely high exposures from previous jobs.

Lead-containing materials continue to be commonly found throughout the construction industry. The results of this study reinforce the need to focus efforts on controlling and preventing exposure to lead during high-risk activities. Welding, sand blasting, rivet busting, burning lead-painted structures, and demolition work have all been reported to cause elevation in blood-lead levels in laborers and ironworkers [Forst et al., 1997; Rae et al., 1991; Sokas et al., 1997]. This study, by looking at the characteristics of individuals with BLLs exceeding 20 µg/dL, reinforces the association between elevated BLL and bridge renovation, specific tasks of welding, cutting, and rivet busting along with lack of use of engineering or personal protective equipment controls. Unlike a previous study, living in an older home was also an important risk factor for elevated BLLs in this study population. [Piacitelli et al. 1997].

The Occupational Safety and Health Administration's Lead in Construction Standard, which became effective in August 1993, includes provisions specifically intended to prevent lead from leaving the workplace on employees and their clothing. These provisions include requirements for employer-laundered work clothing, shower and change facilities, and employee training on the hazards of lead [Occupational Safety and Health Administration, 1993]. These hygiene provisions are only required for workers with airborne lead exposures exceeding the permissible exposure limit of 50 $\mu g/m^3$, which may not be a reliable measure of their potential for lead-contaminated skin and clothing [Piacitelli et al., 1997].

In the current study, 81% of workers with potential for lead exposure reported that their current employers did not provide work clothing, clothes changing facilities, or washing facilities; some workers did not always use these facilities even if provided by their employer. This is shown by the fact that fewer workers reported taking a shower before going home (3%) compared with workers who reported that shower facilities were provided (15%). Further, 61% reportedly were provided water for washing hands/face, but only 31% washed hands at work each time before eating and only 10% before drinking.

Healthy work-practices, like washing face/hands before eating and drinking, and changing from contaminated work clothes and showering at the work site are important for minimizing take-home exposures. However, these hygiene facilities may not be adequate due to the isolated location, and the short-term nature of construction work, or may be ignored by the workers who are ignorant of their use/consequences. Rigorous efforts are needed to ensure compliance by employers and workers with educational and enforcement measures intended to prevent lead exposure and contamination beyond the workplace.

A recent study found that baseline and maximum blood levels among ironworkers employed in structural steel rehabilitation, as well as maximum increments in blood lead concentrations, fell significantly after implementation of the provisions of the OSHA Lead in Construction Standard [Levin et al., 1997]. Although the number of workers performing lead abatement projects in the present study is small ($n = 10$), the trend for lower BLL in this group suggested that training, implementation of engineering controls, and proper use of personal protective equipment such as respirators are effective in controlling lead exposure.

While this study focused on union members working on small to midsize projects in the midwestern U.S., the study population was randomly selected from trade unions whose members work in a wide variety of conditions, and therefore may be representative of the overall worker population in the construction industry. Similarly, the following recommendations may be generalized to both union and non-union construction workers throughout the U.S. Targeted implementation and enforcement of current regulatory requirements at job sites likely to involve exposure to lead would significantly reduce the prevalence of lead exposure in construction industry. Specifications for evaluation and control of lead exposures, such as that recommended by the Center to Protect Worker Rights, should be required in bid specifications. A more concerted effort to provide information to union and non-union workers, to contractors and to architects, engineers, and other professionals responsible for planning and conducting construction activities could be most effective.

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