American Industrial Hygiene Association Journal

ISSN: 0002-8894 (Print) (Online) Journal homepage: https://www.tandfonline.com/loi/aiha20

Elevated Lead Contamination in Homes of Construction Workers

Greg M. Piacitelli , Elizabeth A. Whelan , W. Karl Sieber & Barbara Gerwel

To cite this article: Greg M. Piacitelli , Elizabeth A. Whelan , W. Karl Sieber & Barbara Gerwel (1997) Elevated Lead Contamination in Homes of Construction Workers, American Industrial Hygiene Association Journal, 58:6, 447-454, DOI: 10.1080/15428119791012694

To link to this article: https://doi.org/10.1080/15428119791012694

Published online: 04 Jun 2010.

Elevated Lead Contamination in Homes of Construction Workers

AUTHORS
Greg M. Piacitelli[a]
Elizabeth A. Whelan[a]
W. Karl Sieber[a]
Barbara Gerwel[b]

[a]National Institute for Occupational Safety and Health, 4676 Columbia Parkway, Cincinnati, OH 45226;
[b]Occupational Health Service, New Jersey Department of Health, CN 360, Trenton, NJ 08625

National Institute for Occupational Safety and Health investigators studied lead exposures among 37 families of construction workers; 22 neighborhood families with no known lead exposures were included for comparison. Workers were identified as having blood lead levels at or above 25 µg/dL. This article reports the levels of lead contamination on hands and interior surfaces of homes and automobiles of study participants. Results indicate that the hands of lead-exposed workers were seven times more contaminated with lead compared with control workers; no difference was found between exposed and control family members' hands. Surface lead contamination was significantly higher in automobiles driven by the lead-exposed workers; some locations, such as armrests, were 10 times more contaminated for the exposed group. High lead loadings in lead workers' automobiles were found on the driver's floor (geometric mean [GM]=1100 µg/m^2), driver's armrest (2000 µg/m^2), and passenger's armrest (1200 µg/m^2). Surface lead concentrations were significantly higher for exposed homes compared with control homes in rooms where work clothing was changed (GM=370 versus 120 ppm; $p=0.005$). While environmental sources of lead were also evaluated, study results strongly suggest that construction workers' occupational exposures together with poor hygiene practices were the primary causes of lead contamination. Requirements intended to prevent "take-home" lead exposures were reported by workers in this study to be infrequently followed by employers. These findings may be limited in representativeness since only highly exposed workers were selected from a specific geographic area. Regardless, targeted education and enforcement efforts are necessary to help ensure that preventive measures are adequately practiced throughout the construction industry.

Keywords: construction workers, lead exposure, paraoccupational exposure, surface lead contamination

APPLIED STUDIES

While lead exposure in the workplace has been a recognized problem for many years, it is only relatively recently that there have been reports indicating that occupationally associated exposures to lead can also extend beyond the work environment.[1–7] Lead dust has been reported to be inadvertently taken from the workplace on workers' skin and clothing, resulting in "take-home" or paraoccupational exposure to nonworkers, particularly workers' families. Practices such as changing from contaminated work clothes and showering at the work site are intended to minimize the potential for take-home exposures. However, because construction work is short-term and transient and typically conducted in isolated locations, proper hygiene facilities may not always be available or utilized to prevent contaminants such as lead from being carried away from work sites. High levels of lead contamination in cars of lead-exposed construction workers have previously been reported.[8] These findings indicated that adequate hygiene practices were not always followed and that the potential exists for lead to be similarly carried into workers' homes.

Investigators from the National Institute for Occupational Safety and Health (NIOSH) have recently completed a study to evaluate the extent of take-home lead exposures among New Jersey construction workers and their families. The results of biological sampling from exposed and control children less than age six are reported elsewhere.[9] In general, it was found that 26% of workers' children had blood lead levels (BLLs) at or above the Centers for Disease Control and Prevention (CDC) action level of 10 µg/dL, compared with 5% of control children (odds ratio = 6.1; 95% confidence interval 0.9–147.2). This article describes the results of environmental sampling for lead contamination on study participants' hands and inside their cars and homes.

MATERIALS AND METHODS

Study Population

Lead-exposed workers in construction-related Standard Industrial Classification codes (15, 16, 17) were selected in 1994 from the New Jersey Adult Blood Lead Epidemiology and Surveillance (ABLES) registry, which requires reporting of adult BLLs at or above 25 µg/dL. To account for nonoccupational lead sources including paint and industrial and past vehicular emissions, a neighborhood control group was enrolled through referrals from lead-exposed participants. Telephone screening interviews were conducted to select lead-exposed workers who (1) had at least one child between 9 months and 8 years of age living in the worker's residence; (2) had been employed in a lead-exposed construction job for at least 1 month during the preceding year; and (3) had lived in his or her current residence while working in a lead-exposed construction job(s). Control households were selected if (1) at least one child between the ages of 9 months and 8 years lived in the home, and (2) no persons living in the home worked in a job with known lead exposures. Note that while the original recruitment included children through age 8, analysis of BLLs included only those children under age 6, who were at highest risk for lead poisoning by ingestion of lead dust.[9,10] This article reports environmental results for all homes visited, regardless of the age of the child(ren) in the home.

Sampling Strategy

A quantitative assessment of lead contamination inside the home and automobile of each family in the study was made by a team of industrial hygienists. All home surveys were conducted during July 1994. In general, homes were visited only when the children and heads of household were both present, typically during weekday evenings or weekends. Samples were collected from similar locations in both exposed and control households. Locations were selected that were most likely to be contaminated from lead on the worker's skin and clothing. In automobiles, these locations included the driver-side and passenger-side front seat, floor, and armrest, and the steering wheel. In residences, sampled locations included both the interior and exterior floors adjacent to the entry door normally used when returning from work; the floor area where work clothes were changed; the laundry room floor and washing machine; the family room floor and sofa; and the children's bedroom floor. Additionally, window sills in the family room and children's bedroom were sampled specifically to evaluate lead from environmental sources such as lead-based paint and industrial emissions. If some locations were not available (for example, if no work automobile or no washing machine were available during our visit), then no sample was collected from these respective locations. Sample areas for each location were marked off using precut disposable plastic templates or were measured on site.

Lead Sampling and Analysis

Surface lead levels were measured using wipe and vacuum sampling methods, depending on the location. On bare and smooth, irregular-shaped surfaces such as window sills and washing machines in homes and the armrests and steering wheels in automobiles, the NIOSH wipe sampling method was used.[11] This method uses premoistened towelettes (Wash 'n Dri®) to wipe sample surfaces in a standardized pattern. The towelettes are then analyzed for the lead content of the collected dust so that the lead loadings (i.e., mass of lead per unit surface area, in µg/m^2) can be determined. This wipe method is similar to that used by the U.S. Department of Housing and Urban Development (HUD) for measuring lead loading levels after lead hazard reduction in public housing.[12] Also, lead loadings measured by this wipe method in households have been shown to be predictive of children's BLLs.[13,14]

The floors in homes and automobiles, sofas, and automobile seats were sampled using a microvacuum method. This method, which uses a personal sampling pump to collect dust from a measured surface onto a preweighed 37-mm filter, has been previously described in detail.[15,16] The microvacuum method has been used in several other human exposure studies, largely because it tends to remove only the surface dust most readily available to humans and not deeply embedded dust that is less likely to be removed by ordinary contact. It has been found to provide results that are well correlated with pediatric blood lead.[17,18] In addition, this method uses equipment that is readily available, highly portable, and easy to use in the field. An advantage of this method compared with the wipe method is that the collection filters can be analyzed for both the lead content and the total mass of collected dust. This method therefore permits both lead loading and lead concentration (i.e., mass of lead per mass of total dust, in micrograms per gram) to be determined. Following conventional practice, micrograms per gram is reported as parts per million in this article.

The ability to measure both lead concentration and lead loading of surface dust is important. The lead concentration is the relative amount of lead present in the ambient dust (e.g., µg/g or ppm). A high lead concentration indicates that a localized lead source, such as contaminated work clothes or leaded paint, is likely contaminating the ambient dust. The lead loading is the amount of lead in a given area (e.g., µg/m^2) and represents the absolute amount available for human exposure. Lead loading equals the lead concentration times the amount of total dust in a given area (µg/g$\times$g/m^2). A high lead concentration is generally an exposure hazard only if a high amount of lead is actually present (i.e., the lead loading is also high). Lead concentration is therefore considered a measure of the potential lead hazard whereas lead loading represents the immediate lead hazard.

Handwipe samples were taken from study participants to assess lead contamination on skin. Participants older than age 5 were instructed to simultaneously wipe both hands for 30 seconds using a premoistened towelette. Hand tracings were made and the surface area of both hands measured for determining the hand lead loadings (in µg/ft^2). Hands of younger participants were wiped by an industrial hygienist using the same method. Workers' hands were frequently sampled in the evening soon after arrival at home but, in some cases, sampling occurred on weekends or on days in which the worker had not been to work.

In addition to collecting wipe samples from sills to assess possible environmental sources of lead contamination in households, paint chip samples were collected to determine the lead content of interior paint. Loose paint chips were collected if a painted surface was found to be in poor, deteriorated condition in a predefined sampling area (i.e., entry, change area, laundry, family room, or bedroom). Therefore, the paint was not sampled for lead

APPLIED STUDIES

content in all study homes or for all painted areas.

All field samples were analyzed by a laboratory that was accredited under the American Industrial Hygiene Association laboratory accreditation program and that participated in the Proficiency Analytical Testing (PAT) Program. Prior to laboratory analysis for lead, microvacuum samples were analyzed gravimetrically to determine the total dust mass.[19] All dust and paint samples were analyzed for lead by flame atomic absorption spectroscopy (AAS) using NIOSH Method 7082.[20] If a sample result was below the analytical limit of detection (LOD) for Method 7082, then the sample was reanalyzed by graphite furnace AAS using NIOSH Method 7105, which has a lower LOD.[21] The LOD was calculated individually for each batch of samples and therefore varied over time and by the type of sample. In general, the LODs were about 0.04 µg/filter and 0.30 µg/wipe.

Statistical Analysis

Sample data were analyzed using the Statistical Analysis System (SAS; SAS Institute, Cary, N.C.).[22] For surface wipe, vacuum filter, and handwipe samples with lead measurements below the LOD (n=20, 44, and 71, respectively), a lead mass of $LOD/\sqrt{2}$ was used for data analyses.[23] A logarithmic transformation was used to correct skewness in the distribution, as indicated by the Shapiro-Wilk statistic test. Geometric means (GM) and geometric standard deviations (GSD) were calculated, and t-tests were used to test for differences in surface lead contaminations among households of lead workers and neighborhood controls. Correlations between measures of lead in dust were estimated using Pearson correlation coefficients.

Results

Of 306 workers initially contacted from the ABLES registry, 103 (34%) were excluded because they no longer lived in the geographic area of interest (including New Jersey, the Philadelphia metropolitan area, and southeastern New York), and 122 (40%) were ineligible (primarily because a child under age 8 was not living in the home). Forty-seven workers (15%) refused to participate. An additional three workers were referred from a local union. Therefore, a total of 37 homes of lead-exposed construction workers were included in this study. Twenty-two neighbor families nominated by the study workers agreed to participate as neighborhood controls.

Selected demographic and job characteristics of the 37 lead-exposed workers are presented in Table I. Information was reported by 36 study participants during questionnaire interviews; only the construction workers were interviewed about lead-associated work practices. The average time spent in construction work was 11.5 years. Half of the workers had received training about the hazards of lead prior to starting their most recent construction job. About a third of the workers (27.8%) reported that they always wore company-supplied work clothes; three of the workers (18.8%) who wore company clothes reported laundering these clothes at home. Most workers (80.6%) reported wearing some street clothes while at work and most (86.2%) laundered these clothes at home. Half of the workers reported always changing out of work clothes before going home; only 16.7% reported always showering prior to leaving work.

Characteristics associated with potential lead contamination in homes are presented in Table II for both lead-exposed and control households. No factors that may be associated with sources of lead contamination, including age of the home, recent remodeling, and the presence of pets that spend time both indoors and outdoors, were different between the exposed and control groups. Although there was a twofold difference in the percentage of homes in which lead-related hobbies were practiced, this difference was not statistically significant (p=0.46); restricting the analysis to only those homes without lead-related hobbies did not appreciably change study results. Analysis of paint in those exposed and control homes where loose paint chips were evident (34 samples and 27 samples, respectively) indicated no significant difference in the percent of homes with lead-based paint (defined as containing ≥0.5 % lead by weight); 56.3% of the samples from control homes contained lead-based paint compared with 28.6% of exposed homes (p=0.11). The average lead content in paint samples from exposed homes was twice that found in control homes

TABLE I. Characteristics of Lead-Exposed Workers

Employment Characteristics	
Total years worked in construction (mean ± SD)	11.5 (6.0)
Trained about lead hazards at work (%)	50.0
Company-laundered work clothes provided daily (%)	27.8
Shower facilities provided by employer (%)	27.8
Personal Protection and Hygiene Practices	
Wears gloves during job (%)	58.3
Always changes out of work clothes before going home (%)	50.0
Always wears company-supplied work clothes (%)	27.8
Launders company-supplied clothes at home (%)	18.8
Wears street clothes at work (%)	80.6
Launders street clothes worn for work at home (%)	86.2
Always takes or wears work shoes home (%)	47.2
Always showers before leaving work (%)	16.7
Drives personal vehicle to and from work site (%)	75.0

Note: n=36 questionnaire respondents

TABLE II. Characteristics of Study Homes

	Lead-Exposed (n=37)	Control (n=22)	p[A]
Primary child care provider			
age (years; mean, std. dev.)	35.2 (4.2)	35.6 (3.7)	0.79
nonwhite (%)	18.9	14.3	0.73
education (years; mean, std. dev.)	13.0 (3.1)	12.6 (2.2)	0.58
Home built before 1978 (%)	78.6	73.7	0.74
Lead in paint			
lead content in paint (%; mean, std. dev.)	3.7 (9.7)	1.8 (2.7)	0.40
homes with ≥0.5% lead in paint (%)	28.6	56.3	0.11
Lead-related hobbies practiced in home (%)	18.9	9.1	0.46
Remodeled residence during past year (%)	42.9	36.4	0.78
Have indoor/outdoor pet (%)	32.4	33.3	1.0

[A]p-values for categorical variables are from Fisher's exact test (two-sided)

(3.7 versus 1.8 % lead by weight) but this difference was also not statistically significant (p=0.40).

The results of sampling for lead inside automobiles of both lead-exposed and control families are reported in Table III. The car normally driven by the construction worker (or the primary worker in control households) was sampled while parked at the participant's residence. For the seat and floor areas, where vacuum samples were collected, both the lead loading and the lead concentration (ppm) are reported. For other areas, where the wipe method was used, only the lead loading (μg/m²) is reported.

Table III. Surface Lead Levels in Automobiles

Location	Method	Exposed			Control			
		n[A]	GM[B]	GSD[C]	n	GM	GSD	p[D]
Driver's floor	vacuum	32	1100 μg/m²	7.9	21	250 μg/m²	7.3	0.01
			990 ppm	2.6		250 ppm	2.5	0.0001
Driver's seat	vacuum	32	160 μg/m²	18.8	21	41 μg/m²	10.3	0.08
			2000 ppm	3.8		450 ppm	3.5	0.0002
Driver's armrest	wipe	32	2000 μg/m²	4.0	21	190 μg/m²	2.5	0.0001
Passenger's floor	vacuum	31	460 μg/m²	8.7	19	57 μg/m²	6.0	0.0009
			900 ppm	3.0		260 ppm	2.3	0.0001
Passenger's seat	vacuum	30	130 μg/m	11.3	23	38 μg/m²	14.4	0.09
			1700 ppm	4.6		220 ppm	2.9	0.0001
Passenger's armrest	wipe	30	1200 μg/m²	4.3	20	120 μg/m²	2.2	0.0001
Steering wheel	wipe	32	240 μg/m²	3.9	21	41 μg/m²	3.9	0.0001

[A]n=number of samples
[B]GM=geometric mean
[C]GSD=geometric standard deviation
[D]p=p-value of t-test comparing logarithmic values

The means for both lead loading and concentration were significantly higher in the exposed group than in controls for most sample locations inside automobiles. High lead loadings in lead workers' automobiles were found on the driver's floor (GM=1100 μg/m²), driver's armrest (2000 μg/m²), and passenger's armrest (1200 μg/m²). The highest loading measured in the control group was 250 μg/m² on the driver's floor.

Sampling results from inside homes are shown in Table IV. Highly significant differences in lead concentrations were observed for areas where work clothing was changed and for the children's bedroom floor. For example, the lead concentration on the carpet where workers normally change their clothes was three times greater in lead-exposed homes than in control homes (GM=370 versus 120 ppm; p=0.005). Other differences in the lead concentration between exposed and control homes were found for the family room sofa (p=0.06), exterior entry floor (p=0.10), family room floor (p=0.12), and laundry floor (p=0.15). The mean concentration on the interior entry floor was higher in control homes than in exposed homes (470 versus 350 ppm), although this difference was not statistically significant (p=0.40).

There were no statistically significant differences between exposed and control homes in the lead loadings on sampled surfaces. Mean lead loadings were generally higher in exposed homes. The greatest difference was found for the interior entry floor, where the GM was 23 μg/m² in exposed homes compared with 9 μg/m² in control homes (p=0.08). The lead loadings measured on window sills, which are often coated with lead-based paint, were not different in exposed and control homes.

The lead contamination levels on the laundry room floor and washing machine were not significantly different between exposed and control households. However, within the group of exposed homes, significant differences in lead levels were found on these surfaces depending on whether or not work clothes were laundered at home. In homes where work clothes were laundered (n=24), the mean lead loadings on the washing machine and the laundry floor were 87 and 55 μg/m², respectively (not shown). The mean loadings at these same locations in workers' homes where work clothes were not laundered (n=4) were 23 and 8 μg/m² (p=0.04 and 0.09, respectively). The mean lead concentration on the laundry floor was 680 ppm in homes where work clothes were laundered, compared with 340 ppm in the other exposed homes (p=0.18) and 290 ppm in control homes (p=0.05).

Correlations of lead levels on the front floor and seat of automobiles with similar measures of lead contamination (i.e., μg/m² or ppm) on the floor of the change area and laundry area in homes are presented in Table V. The highest correlation was for the lead concentration between the driver's floor and the laundry floor (r=0.53; p=0.0001). Correlations between locations were higher for lead concentration than for lead loadings.

Lead levels were significantly higher on lead-exposed workers' hands than on control workers' hands (GM=150 versus 22 μg/m²; p=0.0005); there was no difference between other family members, including young children (Table VI). Further analysis based on questionnaire responses indicated that this significant difference between controls and lead workers was restricted to workers who reported not showering before leaving work (p=0.0003). There was no difference in hand contamination between the workers who showered and the control group (p=0.31). A statistically significant correlation was also found between the lead loading on the steering wheel and the lead loading on the worker's hand (r=0.53; p=0.0002).

Discussion

These results indicate elevated levels of lead contamination in automobiles and homes of lead-exposed construction workers compared with controls. There is substantial evidence that the construction workers' occupational exposure to lead is the primary source of the surface lead contamination found inside their homes (except window sills) and automobiles. The high levels of lead measured on workers' hands clearly indicate that lead contamination is being carried from construction sites on their skin. Additionally, most workers in this study reported that work clothes are regularly taken home. While contaminated hands and clothing directly increase the risk of lead ingestion by the worker, another consequence is the secondary contamination of surfaces in their automobiles and homes. The significant correlations for lead levels between workers' hands and cars and between cars and homes help to elucidate the pathway for lead contamination between the workplace, worker, car, and home.

TABLE IV. Surface Lead Levels in Homes

Location	Method	Exposed n^A	Exposed GM^B	Exposed GSD^C	Control n	Control GM	Control GSD	p^D
Main entry exterior floor	vacuum	36	110 μg/m²	15.3	22	73 μg/m²	8.9	0.57
			640 ppm	4.2		330 ppm	4.7	0.10
Main entry interior floor	vacuum	38	23 μg/m²	7.3	22	9 μg/m²	7.5	0.08
			350 ppm	3.8		470 ppm	3.7	0.40
Changing area floor	vacuum	34	16 μg/m²	9.4	18	6 μg/m²	4.7	0.12
			370 ppm	3.9		120 ppm	4.7	0.005
Laundry room floor	vacuum	32	36 μg/m²	13.6	20	39 μg/m²	13.7	0.91
			530 ppm	3.6		290 ppm	4.8	0.15
Laundry washing machine	wipe	28	72 μg/m²	4.1	20	38 μg/m²	5.0	0.16
Family room floor	vacuum	36	6 μg/m	3.7	22	7 μg/m²	4.9	0.70
			250 ppm	2.5		150 ppm	4.3	0.12
Family room window sill	wipe	25	360 μg/m²	4.7	18	460 μg/m²	6.2	0.66
Family room sofa	vacuum	35	10 μg/m²	6.4	20	8 μg/m²	8.7	0.77
			340 ppm	3.4		172 ppm	4.1	0.06
Children's bedroom floor	vacuum	47	6 μg/m²	6.1	31	3 μg/m²	4.0	0.16
			220 ppm	3.1		110 ppm	3.3	0.01
Children's bedroom window sill	wipe	38	450 μg/m²	5.3	23	370 μg/m²	5.7	0.68

[A]n=number of samples
[B]GM=geometric mean
[C]GSD=geometric standard deviation
[D]p=p-value of t-test comparing logarithmic values

The possibility of contributions of lead from sources other than the workplace was considered in this study. These confounding sources include residential lead-based paints, particulate fallout from local sources of industrial air pollution, soil contaminated from past motor vehicle emissions, and disintegration of exterior lead-based paints. The lead content in paint chips and in dusts from window sills and the main entry were collected specifically to help evaluate these other sources of lead. It was felt that any lead found on these particular surfaces was more indicative of ambient sources rather than of contamination on workers or their work clothing. Sample results from these locations were not significantly different between the exposed and control homes. These findings suggest that contamination from possible confounding sources of lead probably does not account for the increased lead levels in the construction workers' homes in this study.

The highest lead concentrations measured on any surface in this study were found in worker's automobiles, generally on the driver-side front seat and floor. These areas are likely to come in contact with the worker's skin, clothing, and shoes immediately after the worker has left the work site. Lead contamination found on the passenger-side may be the result of contaminated items such as clothing, lunch boxes, and tools being placed on the seat or floor. It is also possible that lead-exposed co-workers are sometimes passengers in these cars and therefore contribute to contamination on the passenger-side.

The low levels and uniform distribution of lead loadings and concentrations in control cars (i.e., no significant differences between the driver- and passenger-side) suggest that there was no localized source of lead contamination in these cars. Rather, background levels of lead in the ambient soil were likely the primary source of lead contamination in control cars—and a contributing source of contamination in the exposed cars. As reported in previous studies, low to moderate lead levels can be measured in most cars, indicating that lead-contaminated soil and street dust are ubiquitous and likely sources of lead found in cars, regardless of the owner's occupational exposure.[8]

In homes, the effect of lead-contaminated clothing on residential lead levels was most evident in the area where work clothes were changed. The difference in mean lead concentrations at this location in the homes of construction workers compared with their neighbors was highly significant. The contribution of lead from contaminated clothing is also indicated by the higher lead concentrations on the laundry floor in homes where work clothing was reportedly laundered compared with both exposed and control homes in which no lead-contaminated clothes were laundered.

TABLE V. Correlation Between Lead Contamination in Automobiles and in Homes

Home	Automobile	r^A
Changing area floor (μg/m²)	versus driver's floor (μg/m²)	0.31
Changing area floor (ppm)	versus driver's floor (ppm)	0.46^B
Changing area floor (μg/m²)	versus driver's seat (μg/m²)	0.07
Changing area floor (ppm)	versus driver's seat (ppm)	0.37^B
Laundry room floor (μg/m²)	versus driver's floor (μg/m²)	0.36
Laundry room floor (ppm)	versus driver's floor (ppm)	0.53^B
Laundry room floor (μg/m²)	versus driver's seat (μg/m²)	0.06
Laundry room floor (ppm)	versus driver's seat (ppm)	0.36^B

[A]Pearson correlation coefficient
[B]$p \leq 0.01$

The higher lead concentration on the children's bedroom floor (220 versus 110 ppm; p=0.01) in exposed homes compared with control homes is an interesting finding since the reason for this difference is not as evident as for other locations. There is no obvious presence of lead-contaminated clothing in these rooms, and the similar levels of lead on bedroom window sills in exposed and control homes suggest that lead-based paint does not account for the significant difference in lead concentrations found on floors. Lead tracked into the bedroom on shoes contaminated with paint chips or soil could possibly explain this difference. Also, while the children's bedroom was a separate room in most homes, in five of the exposed homes the children and parents shared the same bedroom. In these five homes, this was also the room

TABLE VI. Lead Loadings (µg/m²) on Hands

	Exposed			Control			
	n[A]	GM[B]	GSD[C]	n	GM	GSD	p[D]
Workers (all)	31	150	6.2	18	22	4.0	0.0005
shower after work	4	60	5.6		NA[E]		0.31[F]
do not shower after work	27	170	6.3		NA		0.0003[F]
Other family members (all)	104	34	3.5	66	32	3.7	0.75
< age 6	36	43	3.4	22	35	3.0	0.52

[A]n=number of samples
[B]GM=geometric mean (in µg/m²)
[C]GSD=geometric standard deviation
[D]p=p-value of t-test comparing logarithmic values
[E]NA=not asked
[F]p-value of t-test for subset of exposed workers versus all control workers

in which the construction worker reported changing his work clothes, therefore accounting for a possible source of lead in the room defined as the children's bedroom. (In these homes different areas of the same room were sampled to provide separate change area and bedroom samples for analysis). Lead concentrations on the children's bedroom floor of these five homes were significantly higher compared with the other 32 exposed homes in which the children's bedroom was separate from the change area (GM of 820 versus 190 ppm; p=0.05). However, the lead concentrations on the children's bedroom floor for both groups of exposed homes (i.e., shared or separate bedroom and change area) were significantly higher in exposed than in the control homes (p=0.05 and 0.04, respectively). No definitive reason is available for the higher lead concentrations found on the bedroom floors of exposed homes in which no work clothes were reportedly present.

Higher correlations between the surface lead in automobiles and homes were found for lead concentrations than for lead loadings. Differences in cleanliness between homes and automobiles may help to explain this finding. Cleaning a contaminated surface generally reduces the lead loading without changing the lead concentration, since most cleaning methods do not preferentially remove lead from the dust.[24] In other words, cleaning a surface will typically reduce the total amount of dust, thereby resulting in a low lead loading, but any remaining dust may still have a high lead concentration. Surfaces cleaned by different methods or with different frequency would therefore have different lead loadings. For example, lead loadings from an infrequently cleaned automobile would not likely correlate with lead loadings in a well-kept home. On the other hand, the lead concentration is independent of cleaning but instead related to the source of the lead contamination. If the source of lead is common to both the automobile and the home (such as lead-contaminated clothing), a high correlation would be expected—regardless of the cleanliness of surfaces.

The types of surface from which samples were collected in this study varied, and the greatest variation was found among vacuum sample locations. Residential floors, for instance, were generally carpeted although some were linoleum, wood, or concrete (particularly in the laundry room and exterior entry). Vinyl mats were as common as carpeting on floors in automobiles. Sofas and car seats were usually made of fabric, although a few were made of vinyl. While the surface materials were sometimes different (either metal, plastic, or wood) for locations where wipe samples were collected, the surface textures were essentially the same—smooth and hard. In general, the differences in surface types for similar locations were not disproportionate between exposed and control households. For example, the percentage of family rooms with carpeted floors was 83% in exposed homes and 82% in control homes; the percentage of laundry room floors with carpet was the same in exposed and control homes (25%). The largest percent difference in surface types between exposed and control groups was only 2% (60% of exposed cars had carpeted floors compared with 62% of control cars). There was no apparent effect of surface type on measured lead levels between exposed and control homes. Since the surface types for similar locations were proportionately the same between exposed and control homes, any effects of surface type should not significantly affect the observed differences in mean lead levels between exposed and control homes. Therefore, the impact of surface type on the overall findings in this study is thought to be negligible.

Currently there are no health-based federal regulations for lead dust in homes or automobiles. HUD and the Environmental Protection Agency have recommended "clearance levels" for surface lead levels in public housing following lead hazard control work.[25,26] The following lead loading levels are based on wipe sampling: 100 µg/ft² on bare and carpeted floors; 500 µg/ft² on interior window sills; and 800 µg/ft² on window wells or troughs (equivalent to 1080, 5380, and 8610 µg/m², respectively). No standards are currently available for vacuum sampling. Direct comparison of these criteria with results in this study is difficult since wipe sampling was not always used to measure lead loadings. A previous study reported that results from the wipe method and the microvacuum method were well correlated (r=0.70, p=0.0001) on uncarpeted floors but that wipe samples collected about twice as much lead dust as vacuum samples.[16]

Also, the HUD clearance levels are intended to "indicate whether a lead hazard exists for young children following hazard control efforts."[25] However, the basis for these levels is not entirely health-related but based on empirical evidence that the levels were achievable by prudent cleanup procedures. Regardless, the presence of any lead on a household surface represents a potential exposure for ingestion, especially by young children. The consequences of lead contamination found in construction workers' homes and resultant exposures among their families can be significant. As previously reported, the children of lead-exposed workers were six times more likely to have a BLL of 10 µg/dL or greater than were children of neighbors who were not occupationally exposed to lead.[9] Among exposed children, BLLs were correlated with environmental dust levels. Similar correlations between residential dust lead levels and pediatric BLLs have been reported.[13,14,16,27]

The Occupational Safety and Health Administration's (OSHA'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.[28] These provisions include requirements for employer-laundered work clothing, shower and change facilities, and employee training on the hazards of lead. However, these hygiene provisions are only required for workers with airborne lead exposures exceeding the permissible exposure limit of 50 µg/m³, which may not be a reliable measure of their potential for lead-contaminated skin and clothing. In a previous study conducted by the authors at a construction site where the hygiene provisions were strictly followed only by workers with high exposures to airborne lead, workers with low air exposures were found to have the highest levels of lead contamination in their cars.[8] Survey observations indicated that the proximity and time spent by some workers near lead sources did not result in high air exposures. However, their work activities still involved lead deposition onto clothes and skin from contact with contaminated surfaces and/or dust settling. Therefore, considering exposures to airborne lead alone is not necessarily sufficient for determining the potential for lead-contaminated clothing and skin and the need for protective clothing and hygiene facilities at construction sites.

Many workers in the current study reported that their current employers did not provide work clothing and facilities for changing and showering. This may be because construction sites are frequently not well-suited for providing convenient and acceptable hygiene facilities due to isolated locations, transient conditions, and limited space. Also, some workers do not always use protective clothing and shower/change facilities, even if provided by their employer. This is shown by the fact in this study that fewer workers reported that they shower before leaving work (16.7%) compared with workers who reported that shower facilities were provided by their employer (27.8%). These findings suggest that educational and enforcement efforts may be needed to motivate both employers and workers to follow the necessary steps for preventing lead from leaving work sites.

This study is limited in representativeness. Because the workers were identified through a lead registry on the basis of elevated BLLs (i.e., at or above 25 μg/dL) and only from a limited geographic area, workplace conditions may not be representative of the construction industry as a whole. Assuming that BLLs are reflective of workplace conditions, the employers of workers in this study may have been less compliant, in general, with the OSHA regulations for lead. Since the OSHA lead standard for construction had only been in effect for 1 year prior to this study, it is possible that any lead dust that was measured was a result of earlier conditions, including previous employers. Although it is not possible to definitively determine when the lead was deposited inside the cars and homes, there are reasons to believe this contamination had occurred rather recently relative to sampling. First, high lead loadings would not be expected to persist on smooth surfaces that are frequently touched, such as car seats, armrests, and steering wheels and the uncarpeted laundry room floors. On these surfaces, in particular, lead dust is most likely being constantly removed and deposited through regular contact with clothing and skin. Second, lead dust deposited onto rough porous surfaces, such as carpets and upholstery, likely gets ground in and bound within the substrate over time. The vacuum method used in this study tends to collect only loosely bound particles from the topmost surface. Therefore, only dust that had been recently deposited or left undisturbed over time would primarily be collected from carpet and fabric surfaces. Third, the significant lead levels found on workers' hands provide clear evidence that lead contamination was occurring at the time of this study. The authors therefore believe that the lead levels measured in cars and homes during this study were mainly a result of recent contamination. These findings reflect conditions soon after the 1993 OSHA lead regulations were implemented. Additional information is needed to better assess whether these regulations have indeed been effective in preventing take home lead exposures throughout the construction industry.

CONCLUSION

This study has shown that a group of lead-exposed construction workers with elevated BLLs were contaminating their automobiles and homes with lead from their workplace. Lead contamination could be measured along the workers' occupational pathway from their hands, clothing, and shoes, into their cars, and then into their homes. The presence of lead on workers' hands clearly indicates that personal hygiene practices at the work site were inadequate. Rigorous efforts are needed to ensure compliance by employers and workers with measures intended to prevent lead contamination beyond the workplace.

ACKNOWLEDGMENTS

The authors wish to thank Don Booher, Mark Boeniger, Marion Coleman, Lynda Ewers, Susan Fossett, Linda Goldenhar, Deborah Guary, Barbara Jenkins, Dino Mattorano, Marion Pearson, Wayne Sanderson, Paula Skelton, Frank Stern, and Ken Wallingford for their assistance in collecting field data. They also appreciate the help of Janie Gittleman, Thomas Matte, and Martha Stanbury in arranging this study. They thank R. Leroy Mickelsen, Aaron Sussell, David Valiante, Judith Klotz, Bruce Lanphear, and Elizabeth Ward for their critical review of earlier drafts of this article.

REFERENCES

1. **Baker, E.L., D.S. Folland, T.A. Taylor, M. Frank, et al.:** Lead poisoning in children of lead workers: home contamination with industrial dust. *N. Engl. J. Med. 296:*260–261 (1977).

2. **Rice, C., A. Fischbein, R. Lilis, L. Sarkozi, et al.:** Lead contamination in the homes of employees of secondary lead smelters. *Environ. Res. 15:*375–380 (1978).

3. **Dolcourt, J.L., H.J. Hamrick, L.A. O'Tuama, J. Wooten, et al.:** Increased lead burden in children of battery workers: asymptomatic exposure resulting from contaminated work clothing. *Pediatrics 62(4):*563–566 (1978).

4. **Morton, D.E., A.J. Saah, S.L. Silberg, W.L. Owens, et al.:** Lead absorption in children of employees in a lead related industry. *Am. J. Epidemiol. 115(4):*549–555 (1982).

5. **Matte, T.D., J.P. Figueroa, S. Ostrowski, G. Burr, et al.:** Lead poisoning among household members exposed to lead-acid battery repair shops in Kingston, Jamaica. *Int. J. Epidemiol. 18(4):*874–881 (1989).

6. **Watson, W.N., L.E. Witherell, and G.C. Giguere:** Increased lead absorption in children of workers in a lead storage battery plant. *J. Occup. Med. 20:* 759–761 (1978).

7. **Garrettson, L.K.:** Childhood lead poisoning in radiator mechanics' children. *Vet. Hum. Toxicol. 30:*112 (1988).

8. **Piacitelli, G.M., E.A. Whelan, L. E. Ewers, and W.K. Sieber:** Lead contamination in automobiles of lead-exposed bridgeworkers. *Appl. Occup. Environ. Hyg. 10(10):*849–855 (1995).

9. **Whelan, E.A., G.M. Piacitelli, B. Gerwel, T.M. Schnorr, et al.:** Elevated blood lead levels in children of construction workers. *Am. J. Pub. Health* (in press).

10. **Centers for Disease Control and Prevention:** *Preventing Lead Poisoning in Young Children.* Atlanta, GA: National Center for Environmental Health and Injury Control, 1991.

11. **National Institute for Occupational Safety and Health (NIOSH):** Lead in surface wipes. Method 9100. In *NIOSH Manual of Analytical Methods,* 4th edition, P.M. Eller, ed. (DHHS/NIOSH pub. no. 94-113). Cincinnati, OH: NIOSH, 1994.

12. **U.S. Department of Housing and Urban Development (HUD):** *Lead-Based Paint: Interim Guidelines for Hazard Identification and Abatement in Public and Urban Housing.* Washington, DC: HUD, 1990.

13. **Lanphear, B.P., M. Emond, D.E. Jacobs, M. Weitzman, et al.:** A side-by-side comparison of dust collection methods for sampling lead-contaminated house dust. *Environ. Res. 68:*114–123 (1995).

14. **Rabinowitz, M., A. Leviton, H. Needleman, D. Bellinger, et al.:** Environmental correlates of infant blood lead levels in Boston. *Environ. Res. 38:*96–107 (1985).

15. **Que Hee, S.S., B. Peace, C.S. Clark, J.R. Boyle, et al.:** Evolution of efficient methods to sample lead sources, such as house dust and hand dust, in the homes of children. *Environ. Res. 38:*77–95 (1985).

16. **Clark, C.S., R.L. Bornschein, W. Pan, W. Menrath, et al.:** An examination of the relationships between the U.S. Department of Housing and Urban Development floor lead loading clearance level for lead-based paint abatement, surface dust lead by a vacuum collection method, and pediatric blood lead. *Appl. Occup. Environ. Hyg. 10(2):*107–110 (1995).

17. **Bornschein, R.L., P.A. Succop, K.N. Dietrich, C.S. Clark, et al.:** The influence of social and environmental factors of dust lead, hand lead, and blood lead levels in young children. *Environ. Res. 38:*108-118 (1985).

18. **Bornschein, R.L., P.A. Succop, K.M. Krafft, C.S. Clark, et al.:** Exterior surface dust lead, interior house dust lead, and childhood lead exposure in an urban environment. *Trace Substances in Environ. Health 11:*322-332 (1986).

19. **National Institute for Occupational Safety and Health (NIOSH):** Particulates, total—Method 0600. In *NIOSH Manual of Analytical Methods,* 4th ed., P.M. Eller, ed. (DHHS/NIOSH pub. 94-113) Cincinnati, OH: NIOSH, 1994.

20. **National Institute for Occupational Safety and Health (NIOSH):** Lead by flame AAS—Method 7082. In *NIOSH Manual of Analytical Methods,* 4th ed., P.M. Eller, ed. (DHHS/NIOSH pub. 94-113) Cincinnati, OH: NIOSH, 1994.

21. **National Institute for Occupational Safety and Health (NIOSH):** Lead by HGAAS—Method 7105. In *NIOSH Manual of Analytical Methods,* 4th ed., P.M. Eller, ed. (DHHS/NIOSH pub. 94-113) Cincinnati, OH: NIOSH, 1994.

22. **SAS Institute, Inc.:** *SAS Companion for the Microsoft Windows Environment: Version 6.10.* Cary, NC: SAS Institute, 1993.

23. **Hornung, R.W. and L.D. Reed:** Estimation of Average concentration in the presence of nondetectable values. *Appl. Occup. Environ. Hyg. 5:* 46–51 (1990).

24. **Milar, C.R. and P. Mushak:** Lead contaminated housedust: hazard, measurement and decontamination. In *Lead Absorption in Children.* J. Chisholm and D. O'Hara, eds. Baltimore, MD: Urban & Schwarzenberg, 1992.

25. **U.S. Department of Housing and Urban Development:** *Guidelines for the Evaluation and Control of Lead-Based Paint Hazards in Housing.* Washington, DC: Office of Lead-Based Paint Abatement and Poisoning Prevention, 1995.

26. **L.R. Goldman:** "Guidance on Residential Lead-Based Paint, Lead-Contaminated Dust, and Lead-Contaminated Soil." U.S. Environmental Protection Agency Office of Prevention, Pesticides, and Toxic Substances, Washington, DC. [Memorandum]

27. **Bornschein, R.L., P. Succop, K.N. Dietrich, C.S. Clark, et al.:** The influence of social and environmental factors on dust, lead, hand lead, and blood lead levels in young children. *Environ. Res. 38:*108–118 (1985).

28. "Lead Exposure in Construction: Interim Final Rule. Occupational Safety and Health Administration." *Code of Federal Regulations,* Title 29, Part 1926. 1993. pp. 26590–26649.