Characterization of Lead in US Workplaces Using Data From OSHA's Integrated Management Information System

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Background *Lead hazards continue to be encountered in the workplace. OSHA's Integrated Management Information System (IMIS) is the largest available database containing sampling results in US workplaces.*
Methods *Personal airborne lead sampling results in IMIS were extracted for years 1979–2008. Descriptive analyses, geographical mapping, and regression modeling of results were performed.*
Results *Seventy-nine percent of lead samples were in the manufacturing sector. Lead sample results were highest in the construction sector (median = 0.03 mg/m^3). NORA sector, year, OSHA region, number of employees at the worksite, federal/state OSHA plan, unionization, advance notification, and presence of an employee representative were statistically associated with having a lead sample result exceed the PEL.*
Conclusions *Lead concentrations within construction have been higher than any other industry. Lead hazards have been most prevalent in the north and northeastern US. IMIS data can be useful as a surveillance tool and for targeting prevention efforts toward hazardous industries.* Am. J. Ind. Med. *© 2011 Wiley-Liss, Inc.*

KEY WORDS: lead; surveillance; OSHA; IMIS; construction

INTRODUCTION

Lead has long been known to cause ill effects in workers. Continued presence in the workplace makes lead an agent that needs to be regularly monitored. Lead is used in many things including: storage batteries, alloys in bearings, brass and bronze, solders, radiation shielding, chemical-resistant linings, ammunition, glass, ceramic glazes, plastic stabilizers, caulk, and industrial paints [ATSDR, 2007].

Lead's adverse health effects occur in multiple organ systems, and range from subclinical changes to life-threatening intoxication. Early symptoms in adults are often subtle and nonspecific, making ascertainment of poisoning cases based on symptoms ineffective for prevention and treatment. Recent studies indicate that adverse health effects occur at exposure levels below current lead standards, and that chronic exposures of elevated lead levels can cause cognitive dysfunction or decline, hypertension and other cardiovascular outcomes, reproductive, and renal disease [Kosnett et al., 2007].

Data from the National Institute for Occupational Safety and Health's (NIOSH) Adult Blood Lead Epidemiology and Surveillance (ABLES) program indicate blood-lead levels exceeding 25 μg/dl, have declined from 14.0 cases per 100,000 employed adults in 1994 to 7.8 in 2007 [CDC, 2009]. However, excessive adult exposure to lead remains primarily an occupational health problem in the United States as 95% percent of adults with an identified exposure source were exposed at work [CDC, 2009]. These exposures occurred mainly in manufacturing batteries, mining lead and zinc ores, and painting and paper hanging industries [CDC, 2009].

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The Occupational Safety and Health Administration (OSHA) collects information during its enforcement and consultation visits of worksites and compiles it into a database named the Integrated Management Information System (IMIS). IMIS contains over 1.6 million sampling measurements for chemical and physical agents collected from 1979 to present and is the largest database of occupational samples available in the US. OSHA's on-going collection and input of data make the database a valuable research tool to track and report the status and trends of particular agents, industries, and states. NIOSH has an inter-agency agreement with OSHA which allows NIOSH to use IMIS for research and surveillance purposes.

OSHA's enforcement efforts are conducted through inspections of workplaces. Consultation visits are conducted at the request of employers seeking assistance on controlling hazards and complying with regulations at their worksite. At present, 27 states and territories[1] have developed and operate their own OSHA state plan, which at a minimum satisfies the mandated activities of the OSH Act [OSHA, 2001a].

Along with the measured values, IMIS contains variables potentially useful for occupational hazard surveillance such as the North American Industry Classification System (NAICS) and Standard Industrial Classification (SIC) codes, job description, location, and total number of workers at the worksite. These variables have been described previously [Froines et al., 1989; Gomez, 1997]. Specific chemical and physical agents have been analyzed previously using IMIS including silica [Froines et al., 1986; Stewart and Rice, 1990; Linch et al., 1998; Yassin et al., 2005], noise [Middendorf, 2004], formaldehyde [Lavoue et al., 2008], beryllium [Henneberger et al., 2004], and wood dusts [Teschke et al., 1999] among others. Airborne lead samples have been analyzed previously for the years 1979–1985 [Froines et al., 1990] and the years 1979–1997 [Okun et al., 2004]. Lead is 1 of 12 agents that constitute half of all samples in IMIS.

Previous studies of IMIS data, with the exception of Middendorf [2004] and Okun et al. [2004], have not included exposure data collected during OSHA's consultation visits, primarily due to limited access to the data. Consultation data do not appear in IMIS until 1984, with the exception of a few visits from 1983. Some data variables for consultation visits, such as company name and street address, do not appear in IMIS to assure confidentiality and to avoid discouraging employers from requesting OSHA's assistance.

OSHA's enforcement inspections are not a random or necessarily representative sample of all workplaces. OSHA has had national emphasis programs aimed at reducing lead exposures in general industry since 2001 [OSHA, 2008, 2001b] and since 1996 for construction [OSHA, 1996]. The state plans are encouraged, but not required to have similar emphasis programs. Under the emphasis programs, OSHA targets inspections at worksites within industries where there is potential for exposure to lead hazards. Industries targeted are identified using exposure data from previous inspections, states' surveillance programs of adult blood-lead levels, and historical knowledge of known industries with high employee exposure to lead [OSHA, 2008]. There are no published studies of the effectiveness of OSHA's targeting efforts in finding and inspecting the workplaces at high risk for lead exposures.

IMIS is an on-line data entry and information retrieval system designed to collect, process, retrieve, and communicate penalty assessment, arbitration and monetary collection information regarding OSHA's inspections [OSHA, 2009]. Information is not collected for the purposes of occupational health or hazard surveillance. The extent to which the exposure data in IMIS is representative of exposures found in all US workplaces is unknown. The process by which OSHA selects workplaces for its enforcement and consultation visits is non-random and may over represent workplaces and workers with potentially higher exposures. This bias may be greater for substances for which there is an emphasis program or strategic plan, like lead.

This study provides an update of lead hazards within US workplaces by using airborne sampling results from IMIS to identify industries and states with the highest levels and to determine if select data variables and/or workplace characteristics are associated with sample results exceeding the current 0.05 mg/m^3 permissible exposure limit (PEL) for lead.

METHODS

IMIS airborne lead samples, coded as ''inorganic lead fumes and dusts,'' ''lead arsenate,'' or ''lead chromate,'' from 1979 to 2008 in IMIS were analyzed. 71,620 samples from 21,081 enforcement visits and 29,035 samples from 10,956 consultation visits were extracted from the database and totaled 100,655 samples. Records were excluded if they were exact duplicates (n = 2368), not personal 8-hr time-weighted average samples (n = 10,318), did not have measurement units recorded as mg/m^3 (n = 770), had an exposure level greater than NIOSH's Immediately Dangerous to Life and Health value of 100 mg/m^3 (n = 164), or the sampling date was illogical (n = 38). We considered these to be indicative of data entry error with the exception of records that were not 8-hr time weighted averages. After exclusions, 86,997 records (86%) remained for analysis. Sample results recorded as non-detectable or ''zero'' were included and recorded as an actual zero. Attempts to estimate and impute a value for the sample results marked as non-detectable or zero, were unsuccessful

[1] State and territory OSHA plans include: AK, AZ, CA, CT, HI, IL, IN, IA, KY, MD, MI, MN, NV, NJ, NM, NY, NC, OR, PR, SC, TN, UT, VT, VI, VA, WA, WY. The state plans of CT, IL, NJ, NY, and VI cover public sector employees only.

TABLE I. Two-Digit SIC and NAICS Codes Corresponding to NIOSH NORA Sectors

NORA sector	1987 SIC major group	2002 NAICS sectors
Agriculture, forestry, and fishing	01–09	11
Construction	15–17	23
Health care and social assistance	80	62
Manufacturing	20–39	31–33
Mining	10–14	21
Services	60–79, 81–99	51–56, 61, 71–72, 81, 92
Transportation, warehousing, and utilities	40–49	22, 48–49
Wholesale and retail trade	50–59	42, 44–45

because information needed, such as sampling method, sampling volume, or sampling time, is not recorded in IMIS. The data were analyzed descriptively by the NIOSH National Occupational Research Agenda (NORA) sector and zip code; and analytically by IMIS variables. The SIC and NAICS codes in IMIS were used to assign records to each NORA sector and are shown in Table I. NORA is a NIOSH program that establishes occupational research priorities in the US and collapses the 20 NAICS industrial sectors into eight NIOSH NORA sectors (www.cdc.gov/niosh/nora/).

The primary outcome of interest was the percent of samples that exceeded the PEL (by definition an overexposure), a metric used previously when analyzing IMIS data [Froines et al., 1990; Linch et al., 1998; Middendorf, 2004]. The PEL for lead was lowered from 0.2 to 0.05 mg/m^3 in 1978. An exception was made for the construction industry which was exempt from the 1978 standard. A separate construction industry standard lowered the PEL to 0.05 mg/m^3 in 1993. We applied the current PEL of 0.05 mg/m^3 to all years, so that direct comparisons could be made across all years and sectors using the same metric.

Geographic information system (GIS) mapping by zip code of measurements greater than the PEL (0.05 mg/m^3) was conducted with proportional symbols using ArcGIS™ version 9.2. Because samples from consultation visits did not contain zip codes, they were excluded from GIS mapping.

Data from IMIS were analyzed using logistic regression to evaluate associations between a lead sample exceeding the PEL (0.05 mg/m^3) and 11 variables (NORA sector, Year, OSHA region, number of employees, federal/state OSHA plan, union present, inspection type, advance notice given, inspection scope, presence of employee representative, and interviews of employees) selected by the authors for potentially influencing the outcome of interest. For the variable federal/state OSHA plan, sampling results were categorized as Federal or State according to the states' status at the time of sampling. States with a public-sector only plan were analyzed as federal OSHA plans. Simple regression and multiple regression analyses were performed to determine the contributions of each variable separately and in combination. The reference group for each variable was chosen a priori as the most likely group with the least odds of a sample result exceeding the PEL (0.05 mg/m^3) or as "no" for yes/no variables. Backward elimination of statistically non-significant variables was conducted in the multiple regression analyses. Odds ratios and confidence limits were generated for each. Regression analyses were performed using PROC GENMOD in SAS™ version 9.2 [SAS, Inc., 2008]. Generalized estimating equations method was used to estimate the model parameters with a quasi-likelihood approach. Multiple samples during a single OSHA visit were treated as repeated measures and assumed a compound symmetry variance-covariance structure among the repeated measures.

RESULTS

Descriptive Statistics

After exclusions, OSHA conducted 28,588 visits with 86,997 lead samples collected and recorded in IMIS from 1979 to 2008. We found 43% of all lead samples in IMIS are non-detectable or zero. The number of OSHA visits where lead was sampled and the number of airborne lead samples by year are shown in Figure 1. The number of both visits and airborne lead samples appear to increase from 1979 to 1989, then decrease from 1990 to 2008.

The distribution of airborne lead samples by NORA sector is shown for all years (1979–2008) and the last 6 years (2003–2008) in Figure 2. The last 6 years were chosen because these were years where NAICS codes were recorded in IMIS. The distribution within the last 6 years indicates that manufacturing accounted for fewer lead samples, compared to the whole period, while services and construction accounted for more. Few samples existed in the mining sector because the Mine Safety and Health Administration (MSHA), rather than OSHA, has jurisdiction over occupational safety and health for most mining activities. There were also few samples in the agriculture, forestry and fishing sector because agricultural operations are excluded from the OSHA lead standard [OSHA, 1978] and OSHA authority over fishing is limited to within three nautical miles from the coast.

Airborne lead samples by NORA sector are shown in Table II. The distribution within the last 6 years of data within specific industries (subsectors identified using the six-digit NAICS code, which was complete only for the last 6 years of data) is shown for industries that had at least 20% of sample results greater than the PEL (0.05 mg/m^3) and at least 20 samples.

The construction sector had the highest percentage of samples exceeding the PEL for all years (43%) and for the period 2003–2008 (35%). The median sample result in

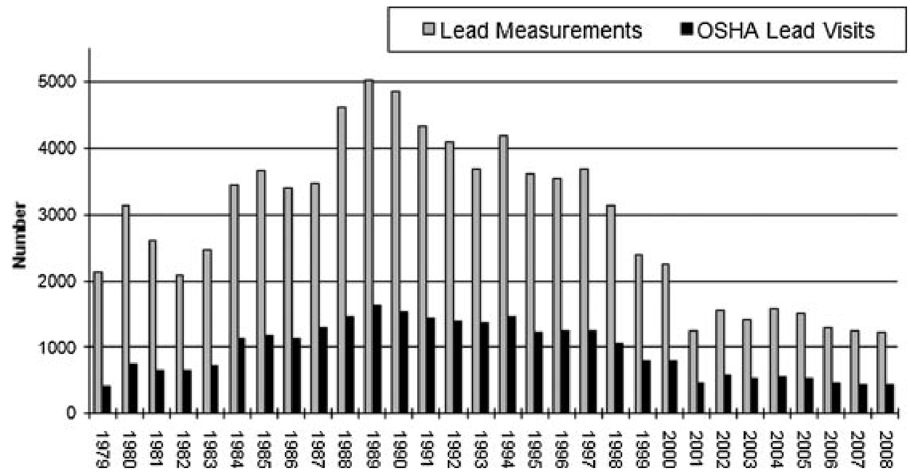

FIGURE 1. Number of airborne lead samples and OSHA visits where airborne lead was measured, 1979–2008.

construction was the highest among all sectors for all years (0.03 mg/m^3) and the period 2003–2008 (0.014 mg/m^3), with the exception of the agriculture, forestry, and fishing sector which only had a single sample result in 2003–2008.

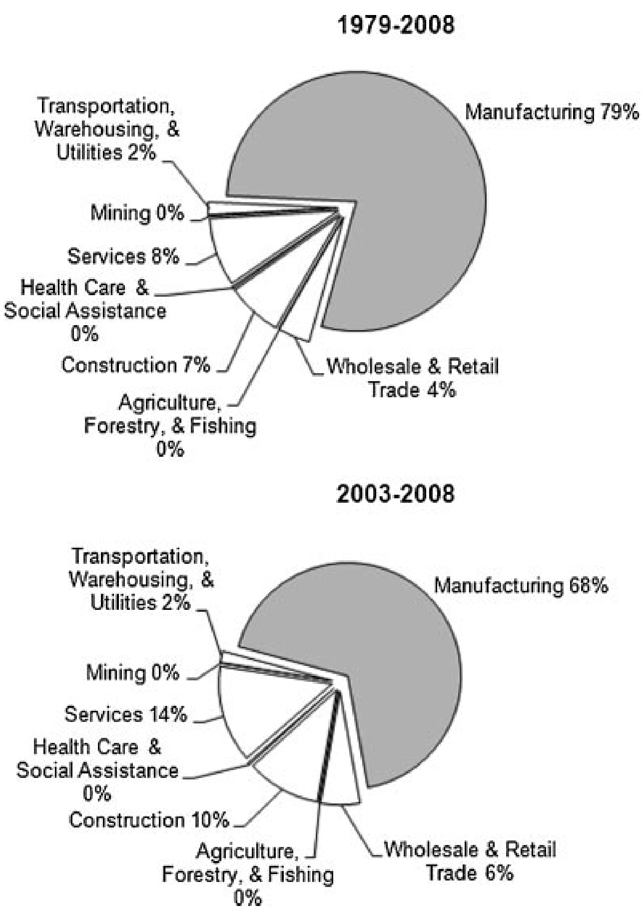

FIGURE 2. Distribution of airborne lead samples by NORA sector for years 1979–2008 and 2003–2008.

Specific NAICS industries within construction with a median sample result exceeding the PEL (0.05 mg/m^3) for years 2003–2008 were all other specialty trade contractors (which may include possible lead exposures during sandblasting of building exteriors) and highway, street and bridge construction (which may include possible lead exposures during reconstruction, rehabilitation, and repair of bridges). In the manufacturing sector there were two industries with a median sample result exceeding the PEL (0.05 mg/m^3) for years 2003–2008: secondary processing of copper (which may include possible lead exposures from formation of copper alloys) and all other basic inorganic chemical manufacturing (which may include possible lead exposures during lead oxide and lead silicate manufacturing).

Figure 3 shows the annual percent of OSHA lead samples greater than the PEL (0.05 mg/m^3) for the construction and manufacturing sectors for years 1979–2008 (data for other NORA sectors not shown for purposes of readability). A significant decreasing trend was found in the manufacturing sector, while no trend was found for the construction sector. The construction sector is the only sector that did not show a decrease in the percent of samples greater than the PEL (0.05 mg/m^3) over the years (slope [95%CI] = 0.0694 [−0.231, 0.369]) while the manufacturing sector, services sector, transportation, warehousing, and utilities sector, and wholesale and retail trade sector decreased throughout the period (slope = −0.953, −0.454, −0.166, and −1.22, respectively). Insufficient data were available for agriculture, forestry, and fishing, health care and mining to test for a linear trend.

GIS mapping was conducted for 15,257 samples from enforcement visits that exceeded the PEL (0.05 mg/m^3) for years 1979–2008 (Fig. 4). The range for the count of samples exceeding the PEL (0.05 mg/m^3) per zip code was 1–173. The zip code with the most instances of a sample result exceeding the PEL (0.05 mg/m^3) was located in East

TABLE II. Airborne Lead Concentrations by NORA Sector for All Years (1979–2008), (2003–2008), and High Hazard* NAICS Subsectors (2003–2008)

Industry (years) [NAICS]	Number of measurements	Median (mg/m^3)	Mean (mg/m^3)	SD	#>PEL	%>PEL
All industry sectors (1979–2008)	86,997	0.003	0.355	3.4	17,897	21%
Last 6 years (2003–2008)	8,278	0.0003	0.43	3.82	1,161	14%
Agriculture, forestry, and fishing (1979–2008)	16	0.00	0.116	0.385	3	19%
Last 6 years (2003–2008)	1	0.045	0.045		0	0%
Construction (1979–2008)	6,006	0.03	1.63	6.8	2,600	43%
Last 6 years (2003–2008)	872	0.014	1.53	6.46	306	35%
All other specialty trade contractors [238990]	48	0.11	3.23	9.82	29	60%
Highway, street, and bridge construction [237310]	232	0.07	2.21	6.74	130	56%
Painting and wall covering contractors [238320]	241	0.02	2.28	7.9	100	42%
Steel and precast concrete contractors [238120]	45	0.00	0.108	0.285	10	22%
Health care and social assistance (1979–2008)	229	0.00	0.004	0.017	4	2%
Last 6 years (2003–2008)	24	0.00	0.008	0.031	1	3%
Mining (1979–2008)	72	0.003	0.18	0.649	14	19%
Last 6 years (2003–2008)	8	0.00	0.065	0.137	0	0%
Manufacturing (1979–2008)	68,329	0.002	0.228	2.71	12,739	19%
Last 6 years (2003–2008)	5,625	0.00	0.217	2.81	556	10%
Secondary processing of copper [331423]	39	0.092	0.257	0.415	26	67%
All other basic inorganic chemical mfg. [325188]	23	0.052	0.141	0.302	12	52%
Primary battery manufacturing [335912]	47	0.041	0.069	0.073	23	49%
Other miscellaneous chemical product mfg. [325998]	325	0.006	0.122	0.192	15	43%
Secondary processing of other nonferrous [331492]	124	0.022	1.24	4.67	43	35%
All other miscellaneous manufacturing [339999]	55	0.006	0.418	2.21	17	31%
Storage battery manufacturing [335911]	250	0.028	0.057	0.086	75	30%
Primary nonferrous metal, except Cu and Al [331419]	52	0.015	0.301	1.6	13	25%
Small arms manufacturing [332994]	38	0.001	1.46	8.43	9	24%
Spring, light guage, manufacturing [332612]	43	0.014	0.026	0.029	10	23%
Household cooking appliance manufacturing [335221]	24	0.006	0.556	1.75	5	21%
Copper foundries, except die-casting [331525]	129	0.02	2.26	11.3	26	20%
Services (1979–2008)	7,413	0.004	0.492	4.2	1,453	20%
Last 6 years (2003–2008)	1,149	0.004	0.631	0.137	198	17%
Hazardous waste treatment and disposal [562211]	30	0.088	0.542	2.17	18	60%
Sports and recreation instruction [611620]	24	0.026	0.356	1.28	9	38%
All other amusement and recreation industries [713990]	64	0.018	0.298	0.95	23	36%
Remediation services [562910]	66	0.009	1	2.95	23	35%
Other general government support [921190]	40	0.006	5.9	12.9	13	33%
Other automotive mechanical and elec. repair [811118]	54	0.006	1.6	7.71	14	26%
Automotive body and interior repair [811121]	31	0.002	0.135	0.281	7	23%
Transportation, warehousing, and utilities (1979–2008)	1,382	0.0006	0.307	3.97	238	17%
Last 6 years (2003–2008)	134	0.0002	0.047	0.196	28	21%
Other support activities for water transport [488390]	37	0.027	0.04	0.047	12	32%
Wholesale and retail trade (1979–2008)	3,470	0.008	0.399	4.28	846	24%
Last 6 years (2003–2008)	465	0.004	0.584	4.83	70	15%
Metal merchant wholesalers [423510]	26	0.001	0.052	0.121	6	23%

*20% prevalence of measurements exceeding the PEL with a minimum of 20 measurements.

Helena, Montana with 173 instances, where a lead smelter operated until it closed in 2001. Ohio was the state that had the most instances of samples exceeding the PEL (n = 1,647) and the most lead samples collected (n = 7,000).

Analytical Statistics

One-way logistic regression analyses examined the unadjusted association between sample results exceeding the PEL (0.05 mg/m^3) and each of the 11-predictor variables

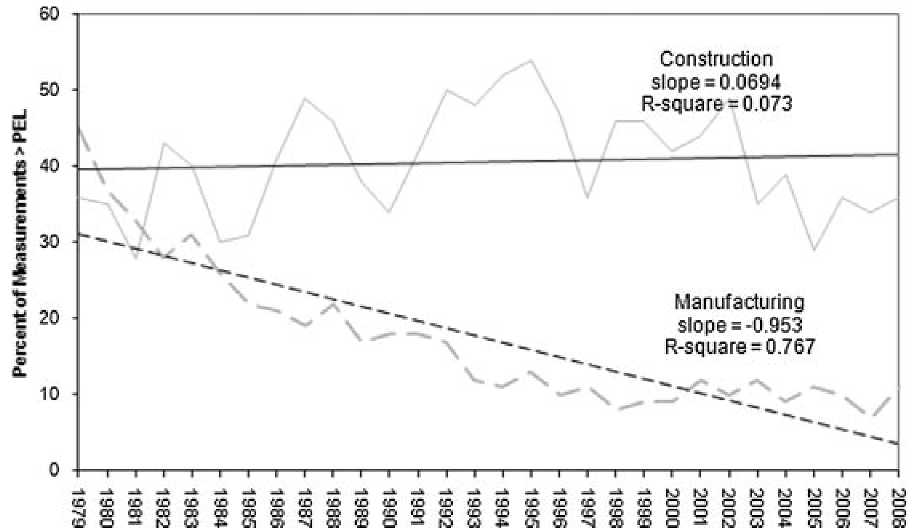

FIGURE 3. Trends of percent of airborne lead samples greater than the PEL (0.05 mg/m^3) in NORA construction and manufacturing sectors from 1979 to 2008.

(Table III). Since 6 of the 11 variables were not recorded in the database for consultation visits, data from these visits were excluded. The effect of the data when including results from the consultation visits did not show a difference for the five variables it included (data not shown). The variables showing no effect of a sample result exceeding the PEL (0.05 mg/m^3) were OSHA inspection type and OSHA inspection scope. Eight variables were significantly

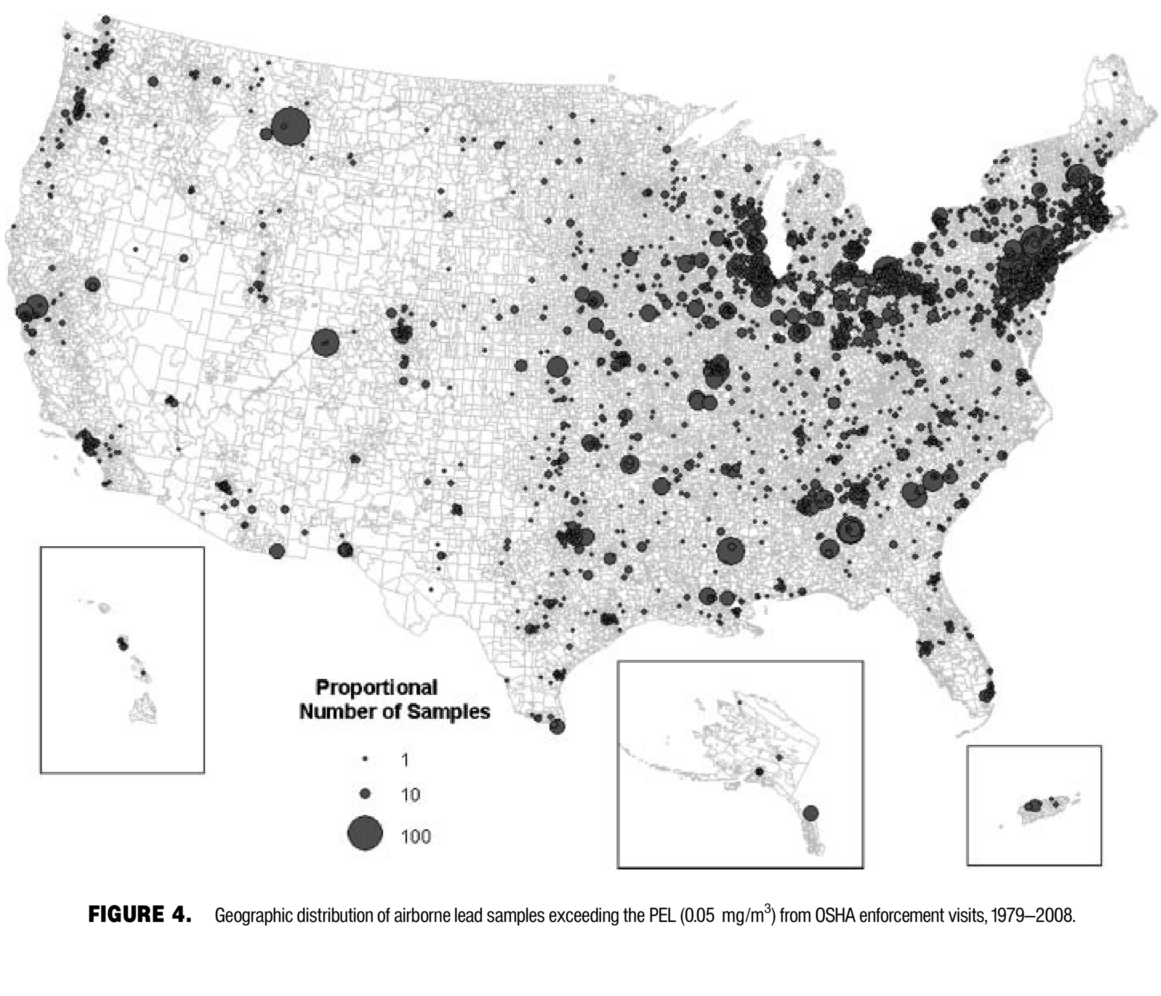

FIGURE 4. Geographic distribution of airborne lead samples exceeding the PEL (0.05 mg/m^3) from OSHA enforcement visits, 1979–2008.

TABLE III. Unadjusted Odds Ratios for Airborne Lead Sample Results Greater Than the PEL (0.05 mg/m^3) During an OSHA Enforcement Visit for Selected Variables

Variable	**Number of OSHA visits**	**Odds ratio**	**95% confidence interval**
NORA sector			
Agriculture, forestry, and fishing/mining	29	1.44	0.62–3.33
Construction	1,796	3.58**	2.82–455
Health care and social assistance	56	0.16**	0.05–0.56
Manufacturing	13,612	1.04	0.83–1.31
Services	1,980	1.29*	1.01–1.65
Transportation, warehousing, and utilities	393	1.00	
Wholesale and retail trade	935	1.71**	1.32–2.22
Year			
1979–1988	6,871	1.87**	1.70–2.05
1989–1998	8,473	1.19**	1.09–1.31
1999–2008	3,457	1.00	
OSHA region			
01	1,379	1.59**	1.32–1.91
02	2,039	1.52**	1.27–1.82
03	1,772	2.23**	1.87–2.66
04	3,078	1.25**	1.05–1.49
05	5,384	1.23**	1.04–1.45
06	2,130	1.32**	1.10–1.58
07	938	1.55**	1.26–1.90
08	890	1.00	
09	564	2.20**	1.76–2.74
10	627	1.80**	1.44–2.25
Employees at worksite[a]			
01–99	12,513	2.00**	1.76–2.26
100–499	4,709	1.53**	1.34–1.75
>500	1,566	1.00	
Federal/state OSHA plan			
Federal	13,882	1.09*	1.02–1.18
State	4,919	1.00	
Unionized worksite			
Yes	6,353	1.23**	1.16–1.32
No	12,425	1.00	
Inspection type			
Programmed	6,194	1.03	0.96–1.10
Unprogrammed	12,606	1.00	
Advance notifice of inspection			
Yes	383	1.36**	1.12–1.68
No	18,418	1.00	
Inspection scope			
Comprehensive	7,840	0.97	0.91–1.03
Non-comprehensive	10,961	1.00	
Employee representative present			
Yes	5,265	0.84**	0.79–0.91
No	13,536	1.00	
Employees interviewed			
Yes	6,311	0.75**	0.70–0.81
No	12,490	1.00	

*$P < 0.05$.
**$P < 0.01$.
[a]Maximum number of employees during the previous 12 months.

associated with sample results exceeding the PEL (0.05 mg/m^3) when adjusted for contributions from the other variables: NORA sector, year of inspection, OSHA region, number of employees at the worksite, federal/state OSHA plan, union status, advance notification of inspection given, and employee representative present during inspection (Table IV). Two NORA sectors, construction and wholesale and retail trade were significantly elevated for risk of a sample result exceeding the PEL (0.05 mg/m^3) (odds ratios = 3.69 and 1.66, respectively), while health care sector was less likely to have a sample result exceed the PEL (0.05 mg/m^3) (odds ratio = 0.18).

The adjusted odds ratios for NORA sectors (Table IV) were highest among the construction sector and the wholesale and retail trade sector. A decreasing quadratic trend for odds ratios was seen over the years starting with 1979. The OSHA region with the highest odds was region 09 (Arizona, California, Guam, Hawaii, and Nevada). A decreasing quadratic trend was found with each increasing size category of employees at the worksite. The size categories of 01–99 and 100–499 employees had odds ratios of 1.90 and 1.64, respectively compared to $\geq$500 employees. The odds ratio for measurements collected in a state with a federal OSHA plan was significant in both the unadjusted and adjusted models (1.09 and 1.22, respectively). The odds ratio with a presence of a union on site was 1.23. When advance notice of an OSHA inspection was given to the employer there was an increased chance that a sample exceeding the PEL (0.05 mg/m^3) was observed (odds ratio = 1.33). Having an employee representative present during the inspection decreased the odds of having a sample result greater than the PEL (0.05 mg/m^3). Employees interviewed during the inspection was no longer a significant variable when adjusted for all other variables in the multiple regression model.

TABLE IV. Adjusted Odds Ratios for Lead Sample Results Greater Than the PEL (0.05 mg/m^3) During an OSHA Enforcement Visit for Selected Variables

Variable	Odds ratio	95% confidence interval
NORA sector		
Agriculture, forestry, and fishing/mining	1.64	0.67–3.98
Construction	3.69**	2.89–4.70
Health care and social assistance	0.18*	0.04–0.80
Manufacturing	0.95	0.76–1.20
Services	1.29*	1.01–1.65
Transportation, warehousing, and utilities	1.00	
Wholesale and retail trade	1.66**	1.28–2.17
Year		
1979–1988	2.20**	1.98–2.45
1989–1998	1.19**	1.08–1.31
1999–2008	1.00	
OSHA region		
01	1.40**	1.15–1.70
02	1.40**	1.16–1.70
03	2.07**	1.72–2.50
04	1.56**	1.30–1.88
05	1.43**	1.20–1.70
06	1.38**	1.14–1.67
07	1.69**	1.37–2.09
08	1.00	
09	2.45**	1.93–3.12
10	2.30**	1.80–2.95
Employees at worksite[a]		
01–99	1.90**	1.66–2.17
100–499	1.64**	1.43–1.88
>500	1.00	
Federal/state OSHA plan		
Federal	1.22**	1.12–1.34
State	1.00	
Unionized worksite		
Yes	1.23**	1.14–1.34
No	1.00	
Advance notifice of inspection		
Yes	1.33**	1.08–1.65
No	1.00	
Employee representative present		
Yes	0.89**	0.81–0.97
No	1.00	

*$P < 0.05$.
**$P < 0.01$.
[a]Maximum number of employees during the previous 12 months.

DISCUSSION

The results, both descriptively and analytically, suggest that overall lead hazards within US workplaces have been decreasing with time; a trend also observed and reported by the NIOSH ABLES program [CDC, 2009]. However, it is important to note that the results suggest that the percentage of lead samples exceeding the PEL (0.05 mg/m^3) per year did not systematically decrease over time in the construction sector. Okun et al. [2004] found a similar pattern for lead within the construction industry using IMIS data and the ABLES program has also reported higher blood lead levels in this industry sector [CDC, 2009]. This is in contrast to the manufacturing; services; transportation, warehousing, and utilities; and wholesale and retail trade sectors where the percentage exceeding the PEL per year declined in our study.

Arithmetic mean and median sample results for lead in construction were much higher than those found in the other industry sectors. Multiple regression analyses showed that samples collected by OSHA in the construction sector are at much higher odds of exceeding the PEL (0.05 mg/m^3) than any other sector. Exposures in the construction industry are difficult to control. The process, location, and environment are typically in a state of constant change as opposed to other sectors such as manufacturing where these factors are more static, and more easily controlled through design and engineering. Nonetheless, successful intervention strategies to lower lead exposures among construction have been performed previously [Vork et al., 2001; Materna et al., 2002].

The number of samples for lead and the number of OSHA visits where lead was sampled decreased throughout the 1990s and leveled off in the 2000s to the lowest levels since quantitative sampling results were entered in IMIS. A similar pattern was seen for other agents. The reason for the decrease in samples for lead and other agents is unknown, but could reflect declining trends in manufacturing employment [Berman, 2005] where most exposure sampling by OSHA has occurred. Potential causes that might explain the decreasing trend, such as, OSHA fiscal year budget, number of full-time employees, and total hours logged during each inspection, were evaluated but did not show substantial changes that would have negatively impacted the number of samples collected and OSHA visits performed.

The majority of OSHA lead samples were collected from the manufacturing sector. However, the percent of total lead samples collected by OSHA within the construction and services sectors has increased in recent years. This follows the pattern of increasing employment growth overall in these sectors [Berman, 2005].

The two most western regions (Regions 9 and 10) had the highest odds of having a sample result exceed the PEL (0.05 mg/m^3). However, these regions had the lowest number of inspections with lead sampling. It is possible that these inspections were primarily in high risk industries, resulting in the higher odds ratios.

Our findings show that smaller sized businesses had increased odds of having sample results exceed the PEL (0.05 mg/m^3) (Table IV). Similar findings have been reported for the lead battery industry, where higher mean concentrations were found in smaller sized establishments [Gomez, 1997]. This is not surprising as smaller companies tend to have fewer resources, both financial and personnel, to dedicate to occupational safety and health.

Although there was an association between a sample result exceeding the PEL (0.05 mg/m^3) and union presence at a facility, the presence of unions should not necessarily be interpreted to mean that union presence causes a greater potential for exposure to lead, but could instead indicate that hazardous work places are more likely to be unionized than low-hazard workplaces. This has been documented with higher injury rates associated with union workforces [Litwin, 2000; Neff, 2006]. It is also possible that unions are effective in identifying and informing OSHA of hazards in the workplace. Advance notice of an inspection was also associated with a higher likelihood of a sample result exceeding the PEL (0.05 mg/m^3); advance-notice inspections constituted 2% of inspections with lead samples. Advance notice may be provided in cases of apparent imminent danger; where an inspection can be most effective after business hours or where special preparations are needed; where it is necessary to assure the presence of representatives of the employer and employees or personnel needed to aid the inspection; or where the Area Director determines it will enhance the effectiveness of the inspection [Code of Federal Regulations, 1996].

The GIS map shows that the majority of sample results exceeding the PEL (0.05 mg/m^3) are in metropolitan areas near large bodies of water in the north and north east. This area has a higher percentage of housing units with lead based paints [Jacobs et al., 2002] and, presumably, a high number of bridges that were painted with lead-containing paint. This may also explain why the two industries with the most sample results exceeding the PEL, as shown in Table II, are Highway, Street, and Bridge Construction and Painting and Wall Covering Contractors. The ability of ArcGIS to identify geographic locations where lead hazards exist can be useful in conducting exposure surveillance and can be used to target interventions, such as educational materials, engineering controls, and field assistance, where lead exposure is most likely to occur that will have the greatest impact for reducing exposures.

It is important to note that this study included sample results recorded as non-detectable. Previous studies of IMIS data have excluded results that were non-detectable or zero, resulting in exclusion of 25–35% of samples [Froines et al., 1990; Linch et al., 1998; Melville and Lippmann, 2001; Lavoue et al., 2008]. Previous researchers excluded these values out of convenience or due to concerns of data quality. However, we saw no evidence to support the idea that data quality is worse for samples with results that were non-detectable or zero than for other samples, and was not possible to determine whether a non-detectable or zero result reflected a sample that failed to detect the presence of lead or a sample where lead was not present in measurable amounts. Samples where lead was not present and not the intended analyte being investigated could have occurred in instances where a laboratory reports the results of several metals, including lead, from a single sample.

Okun et al. [2004] found lead samples in IMIS still showed significant declining trends when analyses were restricted to detectable values and inspections where lead was the only analyte investigated. The main outcome measure used in our study focused on the sample results that exceeded the PEL (0.05 mg/m^3), allowing the use of all data. The median and mean results reported in our study are intended to be used for comparisons between industry sectors.

Interpretation and application of IMIS data must be done cautiously due to potential sampling bias. For consultation visits, employers who request assistance from OSHA may lack industrial hygiene resources or have difficulty controlling exposures. Workers that are selected for exposure monitoring, during both enforcement and consultation visits, theoretically are chosen by the OSHA officer because they are likely to have the highest exposures. This sampling strategy makes attempts to describe the true distribution of exposures among the entire US workforce challenging. A survey with a representative statistical sample of all workplaces, and exposed workers within those workplaces, would be much more useful for these purposes.

Despite the limitations that exist in using IMIS data, the large amount of data, the ongoing collection of data, the ability to track trends over time, the ability to identify specific industries as hazardous, and the ability to geographically plot hazards are useful for surveillance purposes. The data should be further utilized for surveillance of other hazards. Using this data, specific industries and locations may be targeted for future research and preventative interventions.

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