Lead Exposure Among Workers at a Shipyard—Wisconsin, 2015 to 2016

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Objective: In March 2016, the state health departments of Wisconsin and Minnesota learned of three shipyard workers with blood lead levels (BLLs) more than 40 μg/dL. An investigation was conducted to determine the extent of and risk factors for the exposure. **Methods:** We defined a case as an elevated BLL more than or equal to 5 μg/dL in a shipyard worker. Workers were interviewed regarding their symptoms and personal protective equipment (PPE) use. **Results:** Of 357 workers, 65.0% had received more than or equal to 1 BLL test. Among tested workers, 171 (73.7%) had BLL_{max} more than or equal to 5 μg/dL. Workers who received respirator training or fit testing had a median BLL_{max} of 18.0 μg/dL, similar to the median BLL_{max} of workers who did not receive such training (22.6 μg/dL, $P = 0.20$). **Conclusions:** Our findings emphasize the importance of adequate provision and use of PPE to prevent occupational lead exposure.

Keywords: blood lead level analysis, lead, occupational health, occupational lead exposure, personal protective equipment, shipyard worker

Potential for occupational lead exposure continues to be a major health concern in the United States. Approximately, 1.5 million US workers are at risk for lead exposure annually.[1] Exposure to lead can cause acute and chronic adverse effects among persons of all ages. In adults, studies have reported decreased renal function associated with blood lead levels (BLLs) less than 5 μg/dL and increased risk for hypertension and essential tremor at BLLs less than 10 μg/dL.[2] In 2016, yearly estimated societal costs for adverse health effects associated with occupational lead exposures was approximately $141 million; combined direct and indirect costs were approximately $392 million.[3]

Shipyards are subject to the Occupational Safety and Health Administration (OSHA) lead standards for general industry, which set a permissible exposure limit and action levels for airborne lead exposures. OSHA's permissible exposure limit defines maximum exposure to lead as 50 $\mu g/m^3$ of air calculated as an 8-hour, time-weighted average (TWA). An action level, or level at which an employer must begin specific compliance activities, is outlined in OSHA standards as an airborne concentration of 30 $\mu g/m^3$ in an 8-hour TWA of unprotected exposure, regardless of respirator use.[4] Additionally, where lead hazards are present, workers' BLLs should be monitored periodically and workers in general industry should be removed from duties when BLLs are more than or equal to 60 μg/dL; work can be resumed when BLLs are less than 40 μg/dL.[4,5]

Exposure to lead is a well-known hazard in the shipbuilding and shipbreaking industry, and previously has been reported to result in increased BLLs among shipyard workers.[6–8] Lead is used extensively in marine paints as an anticorrosive.[9] In the United States, marine paints can contain 50% to 90% lead by weight; by comparison, household paints must contain less than or equal to 0.009% lead.[7,10] Inhalation is the predominant route for occupational exposure to lead.[1,11] Ship overhaul and retrofitting operations involve paint removal, welding, fitting, and repainting surfaces, and can result in inhalation of aerosolized lead.[6,8–9,12–17] This report describes lead exposure among workers retrofitting a ship at a shipyard in northern Wisconsin.

BACKGROUND

On March 28, 2016, the Minnesota Poison Control System (MPCS) was consulted by an emergency department provider regarding clinical management of a worker with a BLL more than 60 μg/dL at a shipyard in Superior, Wisconsin. Subsequently, MPCS notified the Minnesota Department of Health (MDH). Concurrently, the Wisconsin Department of Health Services (WDHS) received laboratory reports regarding two workers from the same shipyard with BLLs more than 40 μg/dL. In both states, all blood lead results are reportable.[18,19] The National Institute for Occupational Safety and Health (NIOSH) defines elevated BLLs as more than or equal to 5 μg/dL.[5] These three workers had been retrofitting the engine room of a 690-ft ship in dry-dock since January 4, 2016. Shipyard workers were exposed to lead after December 21, 2015, when renovation and retrofitting work on the ship was started.

WDHS and MDH learned that an OSHA enforcement investigation in the same shipyard began on February 10, 2016, because of reported asbestos hazards. The shipyard voluntarily suspended work during March 29 to April 4 in the ship's engine room, the presumptive primary source of lead exposure. On March 29, the shipyard partnered with a local occupational health clinic to provide BLL testing for all workers and WDHS and MDH encouraged employees and household members to obtain a BLL test. Workers and their household members also sought testing from their own healthcare providers. The shipyard hired sanitation crews for lead clean-up and abatement, and provided additional personal protective equipment (PPE) for its employees. Although blood lead results are reportable in both states, on April 1, WDHS and MDH issued advisories to alert regional health care organizations, local public health agencies (LPHAs), and tribal health departments of the

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problem. On April 4, WDHS and MDH launched a joint investigation to characterize the extent and magnitude of lead exposure among shipyard workers and their household members, and determine risk factors that resulted in elevated BLLs and identify measures to prevent future lead exposures.

METHODS

Target Population and Case Definition

The shipyard in this investigation operates multiple worksites, including sites in both Duluth, Minnesota, and Superior, Wisconsin, neighboring towns located at the southern tip of Lake Superior. Events and exposures addressed in this investigation occurred at the Superior location, hereafter referred to as the Superior worksite. A shipyard worker was defined as any worker regularly present at the Superior worksite, during December 21, 2015 to March 25, 2016. Shipyard workers include persons directly employed by the shipyard and persons contracted by the shipyard. Household member was defined as any person who resided with or spent substantial time in the residence of a shipyard worker during December 21, 2015 to March 25, 2016. Elevated BLL was defined as more than or equal to 5 μg/dL of whole blood in a venous blood sample, consistent with the NIOSH reference level for adults.[5] Elevated BLL case was defined as any shipyard worker with a BLL more than or equal to 5 μg/dL from a sample drawn on or after December 21, 2015, or a household member of a shipyard worker with a venous BLL more than or equal to 5 μg/dL drawn on or after December 21, 2015. Shipyard workers were excluded from analysis if they did not work during December 21, 2015 to March 25, 2016 or did not work at the shipyard's Superior worksite.

Blood Lead Sampling

BLLs from residents of Wisconsin and Minnesota and their household members were reported to WDHS and MDH, respectively. Test results from workers who were residents of other states were requested from those state health departments. Blood samples for BLL tests were obtained during January 16 to August 26, 2016 at multiple locations, including clinics throughout the region and at testing events at the shipyard. WDHS and MDH encouraged BLL testing for all worker household members, especially those at greatest risk, including children aged less than 6 years (who are included in childhood BLL surveillance) and women who were pregnant, planning to become pregnant, or breastfeeding. Childhood BLL surveillance and adult laboratory reports were cross-checked in Minnesota and Wisconsin to verify BLLs and residence. WDHS and MDH collaboratively developed a written protocol to obtain environmental lead samples if a case (ie, BLL is more than or equal to 5 μg/dL) was identified among household members; environmental samples would be obtained by a certified lead testing professional from any vehicles that workers operated for personal use and from worker households.

Worker Surveys

In March 2016, WDHS and MDH designed a survey to identify both Superior worksite and household risks for lead exposure. Survey data were collected and managed using the Research Electronic Data Capture (REDCap) tool hosted at MDH. REDCap is a secure, web-based application designed to support data capture for research studies.[20] The survey collected information, including environmental work conditions at shipyard worksites, worker PPE use, lead-exposure-related job tasks, household members, symptoms commonly associated with lead exposures, and nonshipyard lead exposures (eg, lead paint in the home). A list of Superior worksite employees was compiled from employer records and included contractors and direct employees. Whether all the affected workers were included on the list is unknown. Twenty-one Wisconsin LPHAs worked with WDHS to contact workers residing in their jurisdictions; MDH contacted workers who were residents of Minnesota or other states.

During April 13, 2016 to August 1, 2016, telephone surveys were administered by WDHS and MDH. Survey interviews were conducted in English or Spanish by using interpreter services, according to worker preference. Additionally, an abbreviated version of the telephone survey was developed in English and Spanish for distribution through postal mail to nonrespondents or partial respondents to the telephone survey. The abbreviated survey requested information regarding basic worker and employment demographics, symptoms, PPE use, and information on who resided within their households.

Statistical Analysis

Characteristics of shipyard workers, job tasks, and work environments were first analyzed by using descriptive statistics. Associations between these characteristics and the median of a person's maximum BLL test (BLL_{max}) were further analyzed by using nonparametric (Spearman) correlations for continuous-continuous comparisons and Kruskal–Wallis tests for categorical-continuous comparisons. Similarly, the association between medical symptoms and BLL_{max} were evaluated. In examining associations with BLL, only workers who were both interviewed and BLL tested were considered; consequently, denominators are less than the count of all workers interviewed and sometimes are lower because of nonresponse to certain survey questions.

Multiple characteristics evaluated through the worker survey were found to be highly correlated. To evaluate differences in BLL, we stratified data by exposure or nonexposure to the predominant job task associated with BLLs, which is performing daily or weekly metalwork, such as welding, cutting, grinding, or machining. Within strata, we focused on worker and workplace factors that might confer additional risk for exposure to lead and factors that represent actionable opportunities for education and prevention. The Centers for Disease Control and Prevention (CDC) reviewed this investigation for human subjects protection and determined it to not be research. Therefore, this investigation was exempt from Institutional Review Board (IRB) review.

RESULTS

Characteristics of the Total Worker Population

By August 31, 2016, a total of 357 workers were identified. Of these, 185 (51.8%) completed telephone or mail surveys, 148 (41.5%) were unable to be contacted, 10 (2.8%) refused participation, and 14 (3.9%) were excluded because they did not meet inclusion criteria (ie, they did not work at the Superior worksite or did not work during the period in question). From the 357 shipyard workers, 649 BLL test results were received from 130 Wisconsin resident workers, 93 Minnesota resident workers, and nine workers who were residents of seven other states. In total, 232 (65.0%) of 357 workers received more than or equal to 1 BLL test; the median BLL_{max} was 16.0 μg/dL (interquartile range: 4.6 to 30.7 μg/dL). Among interviewed and nonexcluded workers with BLL test results ($n = 130$), median BLL_{max} was 18.4 μg/dL (Table 1). Among all 232 tested workers (regardless of interview status), 171 (73.7%) had BLL_{max} more than or equal to 5 μg/dL, 151 (65.1%) had BLL_{max} more than or equal to 10 μg/dL, 33 (14.2%) had BLL_{max} more than or equal to 40 μg/dL, and 2 (0.9%) had BLL_{max} more than or equal to 60 μg/dL. Samples for BLL tests were primarily obtained by venipuncture (94%). However, five samples were reported as capillary blood draws and 37 samples were unspecified. The proportion of workers receiving more than or equal to 1 BLL tests among those interviewed was not statistically

TABLE 1. Characteristics of Workers at the Superior Shipyard—Wisconsin, 2016

Characteristic	All $N = 357$	Interviewed $N = 185$	Not Interviewed $N = 172$
Median (25th, 75th percentiles)			
Age in years (range)	40 (29, 51) ($n = 331$)	40 (29, 52) ($n = 180$)	40 (30, 49) ($n = 151$)
Number with blood lead tested	232	130	102
Maximum blood lead level (μg/dL) (range)	16.0 (4.6, 30.7)	18.4 (8.1, 30.4)	12.4 (2.3, 31.0)
Percent (No.)			
State of residence			
Wisconsin	55.2 (197)	51.9 (96)	58.7 (101)
Minnesota	35.9 (128)	38.4 (71)	33.1 (57)
Other	8.4 (30)	9.7 (18)	7.0 (12)
Unknown	0.6 (2)	0.0 (0)	1.2 (2)

different than among noninterviewed workers (chi-square, $P = 0.14$). Among workers who had multiple tests more than or equal to 1 week apart ($n = 126$; 35.3%), BLLs decreased over time, with 88.1% (111/126) reporting a decline in BLL between tests.

Of 185 workers who completed telephone or mail surveys, 176 (95.1%) were men, four (2.2%) were women, and five (2.7%) did not report their sex. In total, 144 (77.8%) respondents were non-Hispanic white, 10 (5.4%) were Hispanic, 10 (5.4%) were non-Hispanic non-white, and 21 (11.4%) did not provide data regarding their race or ethnicity. Median age of respondents was 40 years (interquartile range: 29 to 52 years) (Table 1). The majority (51.9%, 96/185) of respondents had permanent residences in Wisconsin; other workers resided in Minnesota (38.4%, 71/185), or other states (9.7%, 18/185) (Table 1). Age and state of residence were similar between workers who were included (ie, interviewed and worked at the Superior worksite during the time frame) and workers who were not included (age analysis of variance, $P = 0.47$; State chi-square, $P = 0.22$) (Table 1).

Through worker interviews, 135 workers reported having other people living in their house who could potentially have been exposed to take-home lead contamination. In total, these 135 workers reported 322 household members, a median of two each, including 70 children aged less than 6 years. Of those 70 children, 18 (25.7%) received a BLL test, and none had an elevated BLL. Among all 322 household members, 45 received a BLL test (14.0%) and none had an elevated BLL. An additional 29 household members of noninterviewed workers received tests and none had an elevated BLL.

Survey Results

Shipyard Work Areas and Employment Conditions

Our findings from worker surveys ($N = 185$) included information on employment conditions, job tasks, and use of PPE. Where specific questions were unanswered, the denominator is less than the total number of workers surveyed. Workers were primarily seasonal with 67.4% (124/184) of respondent workers reporting the 2015 to 2016 winter ship-repair season as their first time working at the Superior worksite. Of 148 workers who responded, 63 (42.6%) were employed by contractors and 85 (57.4%) directly employed by the shipyard. Workers were predominantly union members (69.6%, 117/168; Table 2), and the majority were associated with two local boilermaker unions. Common job titles included: boilermaker, electrician, laborer, shipfitter, welder, and foreman, accounting for 80.6% (137/170) of survey respondents; 14 (8.2%) described their job titles as other supervisory, other professional, or support roles. Among 184 workers who responded, 151 (82.1%) worked the day shift, 24 (13.0%) the night shift, and nine (4.9%) another shift or combination of shifts. Among 185 respondents, 86 (47%) worked exclusively aboard the ship, 70 (38%) worked on the ship and at other locations, and 29 (16%) did not work on the ship at all. Among 182 respondents, 103 (57%) worked daily or weekly in the engine room of the ship (Table 2).

Job Tasks

Daily metalwork (including cutting, grinding, machining, or welding) was reported by 147 (80.3%) workers; four (2.2%) workers reported weekly metalwork, and 32 (17.5%) workers reported less frequent or no metalwork. The majority of workers reported performing multiple different tasks and similar types of tasks, such as metalwork and working with scrap metal. For example, 86 (48.6%) of 177 workers reported removing paint daily or weekly; of these, 81/86 (94.2%) also performed metalwork daily or weekly, 53/81 (65.4%) also performed cleanup work such as sweeping daily or weekly, 67/82 (81.7%) handled scrap metal daily or weekly, and 71/86 (82.6%) performed demolition-type work daily or weekly.

Exposure Prevention Measures

Respondents reported using an assortment of PPE, such as respirators, different coveralls, gloves, helmets, steel-toed boots, welding masks, welding jackets, and hearing protection. Several workers reported wearing or being provided coveralls only after OSHA's enforcement investigation began.

Respirator use and training were inconsistent among workers. According to worker interviews and OSHA investigation sampling results, workers primarily used a 3 M half facepiece mask with P-100 filters.[21] Overall, 112 of 174 (64.4%) workers reported ever wearing a respirator at the shipyard (Table 2). Of these, 85/120 (70.8%) reported they received training to use the respirator, and 84/122 (68.9%) had been fit tested; 31/130 (23.8%) received neither fit testing nor training. Among those who wore a respirator, 46/112 (41.1%) reported always wearing a respirator, 42/112 (37.5%) usually wore a respirator, and 24/112 (21.4%) sometimes wore a respirator. Regarding proportions of workers wearing a respirator between job tasks, limited variation was detected, with the exception that respirator use was more common among daily/weekly metalworkers than workers who performed metalwork less frequently or not at all (107/151, 70.9% vs 15/32, 46.9%), (chi-square $P = 0.01$) and among workers who performed demolition work than those who did not perform demolition work (90/123, 73.2% vs 30/56, 53.6%) (chi-square; $P = 0.01$).

Survey respondents were also asked about hand washing practices, eating at work, tobacco use at work, and practices such as showering and changing clothes, associated with possible take-home exposures. A majority of workers (144/168, 85.7%) reported eating lunch in the lunchroom, an area removed from work activity. A majority of respondents (137/167, 82.0%) also reported regularly washing their hands before eating lunch, but only (56/166) 33.7% reported removing the dust from their clothes or removing their outer layer of clothes before eating.

TABLE 2. Characteristics and Median Blood Lead Level (IQR) Among Interviewed Workers Stratified by Frequency of Metalwork (Daily/Weekly vs Monthly/Seldom/Never), Superior Shipyard—Wisconsin, 2016

	All Workers	All Blood Lead Tested Workers			Daily/Weekly Metalworkers, Blood Lead Tested			Infrequent/Never Metalworkers, Blood Lead Tested		
Characteristic	***n**** **(%)**	***n**** **(%)**	**Median (IQR)**	***P**†*	***n**** **(%)**	**Median (IQR)**	***P**†*	***n**** **(%)**	**Median (IQR)**	***P**†*
All workers	185 (100)	130 (100)	18.4 (8.1, 30.4)	–	109 (100)	22.3 (11.9, 34.0)	–	20 (100)	6.3 (2.3, 13.5)	–
Union member										
Yes	117 (70)	89 (75)	21.1 (12.3, 31.3)	0.02	84 (84)	21.9 (12.2, 33.5)	0.95	5 (28)	17.6 (14.7, 20.2)	0.05
No	51 (30)	29 (25)	14.0 (2.3, 22.8)		16 (16)	21.3 (11.2, 36.1)		13 (72)	3.5 (2.3, 12.8)	
Shift										
Day only	151 (82)	105 (81)	16.0 (8.0, 26.4)	<0.01	86 (80)	19.2 (9.4, 30.3)	<0.01	18 (90)	9.6 (2.3, 16.0)	0.47
Other	33 (18)	24 (19)	28.7 (18.3, 43.5)		22 (20)	31.3 (21.4, 44.2)		2 (10)	2.9 (2.3, 3.5)	
Worked aboard ship										
Yes	156 (84)	117 (90)	20.2 (11.0, 31.3)	<0.01	102 (94)	22.7 (12.3, 34.9)	0.04	14 (70)	11.5 (2.3, 16.0)	0.14
No	29 (16)	13 (10)	2.3 (2.3, 17.3)		7 (6)	9.4 (2.3, 18.0)		6 (30)	2.3 (2.3, 3.5)	
Worked in engine room of ship										
Daily/Weekly	103 (57)	85 (66)	22.3 (12.8, 35.1)	<0.01	73 (68)	24.2 (14.4, 35.7)	<0.01	11 (55)	10.2 (2.3, 17.6)	0.48
Monthly/Seldom/Never	79 (43)	44 (34)	12.6 (2.3, 23.3)		35 (32)	13.6 (3.0, 29.7)		9 (45)	2.3 (2.3, 14.0)	
Metalwork										
Daily/Weekly	151 (83)	109 (84)	22.3 (11.9, 34.0)	<0.01			–		–	–
Monthly/Seldom/Never	32 (17)	20 (16)	6.3 (2.3, 15.4)				–			
Metalwork on painted surfaces										
Daily or Weekly	124 (72)	90 (74)	23.5 (13.2, 35.1)	<0.01	90 (88)	23.5 (13.2, 35.1)	<0.01	0 (0)	–	–
Monthly/Seldom/Never	49 (28)	32 (26)	3.5 (2.3, 15.4)		12 (12)	2.9 (2.3, 19.9)		20 (100)	6.3 (2.3, 15.4)	
Paint removal										
Daily/Weekly	86 (49)	60 (48)	18.6 (11.5, 32.3)	0.40	56 (52)	20.9 (11.5, 34.5)	0.87	4 (22)	13.4 (11.5, 15.8)	0.27
Monthly/Seldom/Never	91 (51)	65 (52)	19.7 (4.1, 29.8)		51 (48)	22.6 (12.0, 33.2)		14 (78)	2.9 (2.3, 16.0)	
Cleanup										
Daily/Weekly	87 (51)	64 (52)	21.9 (10.0, 35.0)	0.11	57 (55)	24.0 (11.9, 35.4)	0.36	7 (39)	14.0 (3.5, 20.2)	0.12
Monthly/Seldom/Never	85 (49)	58 (48)	15.5 (5.8, 25.7)		47 (45)	19.7 (10.0, 30.3)		11 (61)	2.3 (2.3, 14.7)	
Demolition and/or scrap metal handling										
Daily/Weekly	140 (77)	101 (79)	23.3 (13.1, 35.1)	<0.01	97 (90)	23.6 (13.1, 35.4)	<0.01	16 (80)	17.8 (9.9, 22.1)	0.17
Monthly/Seldom/Never	41 (23)	27 (21)	3.5 (2.3, 12.8)		11 (10)	3.5 (2.3, 9.4)		4 (20)	2.9 (2.3, 13.4)	
Respirator fit testing and/or training										
Yes	99 (76)	71 (76)	18.0 (8.0, 30.4)	0.20	59 (74)	21.1 (8.8, 33.2)	0.49	11 (85)	12.8 (2.3, 17.6)	0.84
No	31 (24)	23 (24)	22.6 (10.0, 37.8)		21 (26)	25.7 (12.6, 37.8)		2 (15)	11.3 (2.3, 20.2)	
Respirator use										
Always	46 (26)	34 (28)	17.0 (5.8, 23.6)	0.61	29 (28)	19.0 (5.8, 26.9)	0.32	5 (26)	16.0 (14.0, 18.0)	0.10
Usually/Sometimes	66 (38)	48 (39)	20.5 (10.1, 35.0)		43 (42)	21.1 (11.9, 35.7)		5 (26)	10.2 (9.0, 12.8)	
Never	62 (36)	40 (33)	18.4 (5.7, 29.0)		31 (30)	24.2 (14.3, 35.4)		9 (47)	2.3 (2.3, 3.5)	
Lunchroom used										
Always	121 (72)	86 (73)	21.9 (12.0, 34.9)	<0.01	82 (82)	23.0 (12.3, 35.1)	0.27	4 (22)	13.3 (5.7, 18.9)	0.20
Usually/Sometimes	23 (14)	14 (12)	19.2 (8.0, 30.3)		12 (12)	19.2 (6.1, 34.9)		2 (11)	19.5 (12.8, 26.1)	
Never	24 (14)	18 (15)	8.4 (2.3, 14.7)		6 (6)	13.5 (6.5, 20.4)		12 (67)	2.9 (2.3, 14.4)	
Cigarette smoking at work										
Yes	53 (45)	53 (45)	22.6 (10.0, 33.2)	0.37	47 (47)	25.7 (11.0, 35.7)	0.35	6 (35)	6.9 (2.3, 12.8)	0.40
No	64 (55)	64 (55)	17.8 (8.1, 26.5)		53 (53)	19.0 (12.0, 30.3)		11 (65)	14.7 (2.3, 18.0)	

*Some totals do not sum to the column total due to non-response or "don't know" responses to some survey questions.
†Kruskal–Wallis test for difference in distribution of BLL_{max}.

In total, 99 (59.6%) of 166 workers reported tobacco use at work, including chewing tobacco, cigarettes, or e-cigarettes. Among 98 workers who used tobacco, 18 (18.4%) regularly washed their hands before using tobacco and 20 (20.4%) stored their tobacco in an area away from work activity. Showers were not available at the shipyard; 118/167 (70.7%) workers reported showering immediately after returning home from work. Multiple workers lived in temporary residences while working at the shipyard with 54 (29.2%) of 185 reporting to have stayed in area hotels.

Factors Associated With Elevated BLLs

Worker Characteristics and Blood Lead Levels

BLLs of workers were compared with worker characteristics, behaviors, job tasks, and work environments identified in the surveys. Survey findings for workers who completed a survey and had more than or equal to 1 BLL test result ($n = 130$) were analyzed for factors associated with elevated BLLs. For the majority of workers, BLL_{max} was either the first (61.5%) or second (36.2%) lead test. Persons who worked aboard the ship had higher BLL_{max} than those who did not (median 20.2 μg/dL vs median 2.3 μg/dL; $P < 0.01$) (Table 2).

Exposure to lead in workers was highest in the engine room of the ship, particularly among those who worked there on a daily basis, such as welders. An investigation carried out by OSHA revealed that workers welding, grinding, and performing demolition work in the engine room and nearby areas were subjected to airborne levels more than 20 times OSHA's permissible exposure limit.[21]

Those who worked daily/weekly in the ship's engine room had significantly higher BLL_{max} (median 22.3 μg/dL) than those

who worked in the engine room less frequently or never (median 12.6 μg/dL; $P < 0.01$). Among daily/weekly metalworkers, the association between work in the engine room and higher BLL_{max} persisted.

Among daily/weekly metalworkers, routine cutting, welding or grinding, or machining on or through painted metal surfaces was associated with higher BLL_{max} (median 23.5 μg/dL vs median 2.9 μg/dL; $P < 0.01$; Table 2). Workers performing metalwork, handling scrap metal, and performing demolition on a regular basis (ie, daily or weekly) had substantially higher BLL_{max} than workers who performed these job tasks less frequently or not at all (Table 2). The correlation of job tasks, or many workers conducting multiple types of high-risk tasks, limits the generalizability of task associations with BLLs reported in Table 2. However, when stratified on daily/weekly metalwork versus infrequent/never metalwork, daily/weekly demolition and/or scrap metal handling tasks were still associated with higher BLL_{max} relative to doing these tasks less frequently or never among daily/weekly metalworkers, but not among infrequent/never metalworkers. Additional job tasks and association with BLL_{max} can be found in the supplemental table, http://links.lww.com/JOM/A455 (Table S1).

When stratified by frequency of metalworking job tasks, union membership was not associated with a difference in BLL_{max} among daily/weekly metalworkers ($P = 0.95$; Table 2); very few union members who reported infrequent/never metalwork. The difference in BLLs among workers of day versus night shifts persisted when restricting to workers who performed metalwork daily or weekly ($P < 0.01$).

No significant differences were detected in BLL_{max} among workers who reported always using respirators and those who reported less frequent use. Despite consistent use, workers who reportedly always used respirators ($n = 34$) had a median BLL_{max} of 16.0 μg/dL (Table 2). Even among the group of daily/weekly metalworkers, no difference was reported in BLL_{max} between those who used and did not use a respirator (Table 2). Furthermore, among workers who used a respirator, workers who received respirator training and/or fit testing had median BLL_{max} of 18.0 μg/dL, which was lower than—but not statistically different from—the median BLL_{max} of workers who did not receive respirator training or fit testing (22.6 μg/dL) ($P = 0.20$).

Always using the lunchroom for eating meals was associated with higher BLL_{max} (median 21.9 μg/dL vs median 8.4 μg/dL; $P < 0.01$), likely because BLL-tested workers who reported always using the lunchroom ($n = 86$) also performed metalwork daily or weekly ($n = 82$, 95.0%; Table 2).

Cigarette use at work was not associated with a difference in BLL_{max}. Among daily/weekly metalworkers, those who used cigarettes at work ($n = 47$) had a median BLL_{max} of 25.7 μg/dL. This value was higher than that found among the daily/weekly metalworkers who did not use cigarettes at work (19.0 μg/dL) ($n = 53$) (Table 2); however, the difference was not statistically different. Additional characteristics were tested and not significantly associated with BLL_{max}, including sex and race.

Worker Reported Symptoms and BLLs

Respondents were asked about medical symptoms experienced during the 3 months before the telephone or mail surveys. The majority of reported symptoms were extreme tiredness (99/126, 78.6%) and muscle or joint pain (95/130, 73.1%) (Fig. 1A). A majority of respondents reported multiple symptoms (Fig. 1B). BLL_{max} was significantly associated with multiple self-reported symptoms and number of total symptoms. Only 17/130 (13%) workers reported no symptoms; median BLL_{max} was 3.5 μg/dL among this group.

Nonshipyard Lead Exposures

Workers reported information regarding potential nonoccupational lead exposures. One (<1%) of 118 workers reported engaging in a hobby that involved melting lead, possibly resulting in elevated BLLs. Furthermore, 48/88 (54.5%) workers reported living in a house built before 1979, where lead-based paint might be present, although the risk for elevated BLLs from paint among adults is minimal without substantial disruption of the paint (eg, renovation activities). Among these 48 workers, 13 (27.1%) reported recent renovation that might have disrupted lead-based paint. However, no significant difference was detected in BLL_{max} for these workers, compared with those who did not report potential nonoccupational lead exposures ($P = 0.51$).

DISCUSSION

Workers retrofitting a 690-ft ship at a shipyard in Superior, Wisconsin, were exposed to lead likely because of insufficient engineering control measures,[21–23] lack of respirator use and inadequate PPE training. Metalwork tasks, such as welding, grinding, and cutting surfaces containing lead paint in the ship's engine room without sufficient ventilation or adequate PPE resulted in substantial exposure of workers to high concentrations of airborne lead.[21] These results were supported by OSHA's investigation which determined that workers were overexposed to airborne lead, particularly in the engine room of the ship.

In workplaces where safety programs and engineering controls are deficient, workers believed to be at low risk for exposure to lead can have elevated BLLs.[24,25] Workers in all areas of the Superior worksite, including those workers who were not in traditionally high-risk occupations, had elevated BLLs. The spread of lead from the ship across the Superior worksite premises is supported by OSHA's findings, which demonstrate that lead was dispersed beyond the work areas, including the lunchroom; lead was found on wipe samples collected from lunch boxes, buttons of the lunchroom microwaves, lunchroom tables, and vending machine buttons.[21]

Studies have reported that night-shift workers are at higher risk for injury than daytime shift workers. One investigation reported that persons working night shifts have approximately twice the risk for injury than their daytime counterparts.[26] Another investigation reported that the relative risk for accidents is highest on the night shift, compared with morning and afternoon shifts.[27] Our investigation indicates failures in engineering and administrative control measures during non-dayshift work might have been present. Non-dayshift workers who frequently engaged in metalwork had higher BLL_{max} than day-shift workers who frequently engaged in metalwork (Table 2). Although we are unsure about why this occurred, the possibility exists of decreased or absent safety oversight presence during non-dayshifts. Oversight of non-dayshift workers also provides a possible point of intervention for shipyards to reduce exposure among workers; with proper engineering controls in place, including adequate ventilation systems and implementation of training and proper use of respirators according to OSHA standards, lead exposures can be reduced.[28,29]

Personal protective equipment including respirators, are key to protection in environments where hazards are not well controlled. Previous studies regarding respirator use and practices in the private sector revealed that employers often had unsatisfactory respiratory protection programs, indicating that a substantial number of employers do not follow NIOSH and OSHA requirements for selection and use of respirators.[30,31] Our investigation provides evidence that respirators were often not worn or not worn effectively. Although the nonsignificant trend of increasing BLLs with decreasing frequency of respirator use among frequent metalworkers indicates that use of respirators might have had some role

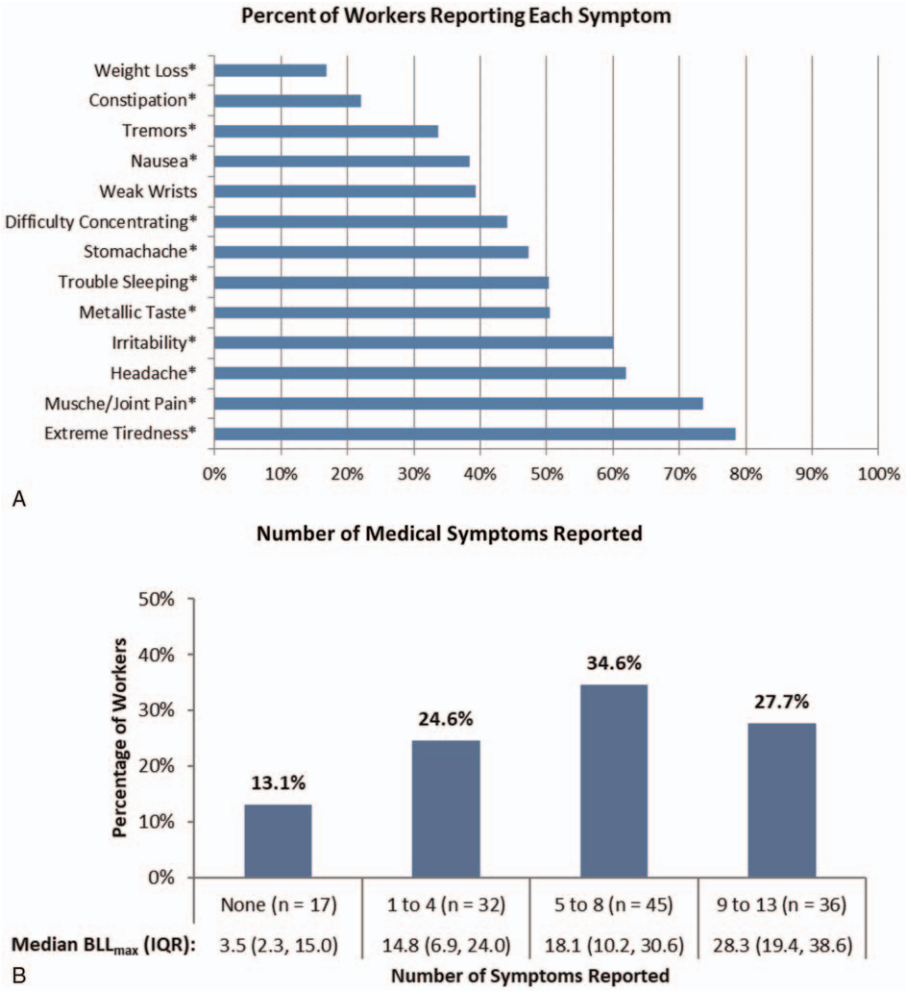

FIGURE 1. A. Symptoms reported among interviewed workers with blood lead test results, Superior Shipyard—Wisconsin, 2016 ($N = 130$). *BLL_{max} is significantly higher among workers who reported this symptom, compared with those workers who did not report the symptom. B. Median of BLL_{max} (IQR) by number of medical symptoms reported among interviewed workers with blood lead test results, Superior Shipyard—Wisconsin, 2016 ($N = 130$).

in protecting against elevated BLLs, respirator use was not fully protective. OSHA's investigation indicated that many workers were not fit-tested for respirators and that some wipe samples from the interior of respirators contained lead.[21] In addition, air lead levels exceeded the rating of the respirators being used, providing evidence that even with adequate fit and consistent use the respirators would not be fully protective. This is consistent with our data that show frequent metalworkers who reported always wearing a respirator had a median BLL_{max} of 17.0 μg/dL, not significantly different than the BLL_{max} of frequent metalworkers who never wore a respirator, 24.2 μg/dL ($P = 0.32$).

Symptoms from lead exposure are highly variable and often nonspecific. Health effects can occur at BLLs as low as 5 μg/dL and lower for certain workers, but only at higher levels of exposure for others.[32] Symptoms can occur at BLLs below OSHA's general industry threshold for medical removal from work tasks, set at more than or equal to 60 μg/dL.[4,33] In this investigation, BLL was significantly associated with multiple self-reported symptoms and total number of symptoms. Symptoms included extreme tiredness, muscle and joint pain, headache, irritability, trouble sleeping, metallic taste, stomachache, difficulty concentrating, nausea, weak wrists, constipation, and weight loss (Fig. 1A). These symptoms are commonly reported among persons who have been exposed to lead. Additionally, symptoms observed might not be solely attributable to the elevated BLLs in workers. Baseline symptoms and BLL data were unavailable; other contaminants reported by OSHA's investigation, including asbestos, arsenic, cadmium, and hexavalent chromium might have contributed to certain observed symptoms.[21]

Previous studies have documented elevated BLLs among families and children of workers who themselves had elevated BLLs from workplace exposures.[34,35] Work practices such as not changing clothes before returning home or not having access to areas such as locker rooms to store clean clothes can increase the potential for take-home lead contamination.[34,35] However, the substantial proportion of workers (29.2%) who lived in nearby hotels while working at the shipyard might have limited the potential for exposure of household members. In this investigation, take-home lead contamination remains unknown because of low participation rates.

POTENTIAL LIMITATIONS

Respondents to our survey might not represent all exposed workers and it is possible that worker lists were incomplete, due to changes in shifts worked, use of multiple contractors, and a largely temporary workforce. Among those tested, no significant difference in BLL_{max} was detected between workers who were interviewed and those who were not interviewed. Another limitation related to available BLL data is that certain workers were tested or tested multiple times, whereas others were not. There was no significant difference in the probability of a worker receiving at least one BLL test between interviewed and non-interviewed workers (Table 1). Furthermore, it is possible that venous BLL tested with a Magellan

Diagnostics' LeadCare® (Magellan Diagnostics, Billerica, MA) analyzer might be higher than reported. This investigation was conducted prior to the US Food and Drug Administration's safety communication warning stating that LeadCare® analyzers might provide falsely low results.

Workers living in states other than Minnesota or Wisconsin ($n = 30$) were less likely to have a BLL test result on file (33% for residents of other states, compared with 69% for Minnesota and Wisconsin). This might be attributable to challenges for MDH and WDHS to locate BLL test results from out-of-state residents or to actual decreased likelihood of out-of-state residents to receive BLL tests.

Many workers might have been exposed to lead before the ship retrofitting project, which might have contributed to elevated BLLs observed among workers. A review of the Wisconsin and Minnesota adult lead surveillance databases during 5 years before this investigation (December 21, 2010 to December 21, 2015) revealed that 9% of workers at this shipyard residing in Minnesota or Wisconsin had a prior history of elevated BLLs. These data indicate that a minimum of 9% of workers likely worked in industries at high risk for lead exposure because adult blood lead screening is only routinely conducted for workers in high-risk industries.

Substantial overlap was reported among workers in job tasks and work locations, with the majority of workers reporting multiple types of job tasks and multiple work locations, although we did not collect specific information concerning timing and locations of job tasks. Because of resulting multicollinearity and the dataset's limited size, we were unable to generate a valid multivariate generalized linear regression model.

CONCLUSION

Occupational exposure to lead remains a major public health concern to workers and their families. The WDHS-MDH joint investigation resulted in rapid identification of widespread exposure to a lead hazard and increased awareness of the potential for take-home lead exposure among workers and their families. OSHA's enforcement investigation played an integral role in describing the failures by the shipyard to protect workers from lead and other hazardous exposures and to enforce the industry standards. The investigation findings emphasize the need to identify measures to prevent future events of lead exposure. Periodic BLL monitoring and BLL surveillance, adequate engineering controls, proper provision and use of PPE, and training on how to appropriately use PPE are crucial to reducing exposures to lead and other hazards and providing a safe workplace for workers in shipyards.

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