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Occupational Lead Exposure Aboard a Tall Ship

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To evaluate occupational exposures to lead in shipfitters cutting and riveting lead-painted iron plates aboard an iron-hulled sailing vessel, we conducted an environmental and medical survey. Lead exposures in seven personal (breathing zone) air samples ranged from 108 to 500 $\mu g/m^3$ (mean 257 $\mu g/m^3$); all were above the Occupational Safety and Health Administration (OSHA) standard of 50 $\mu g/m^3$. In two short-term air samples obtained while exhaust ventilation was temporarily disconnected, mean lead exposure rose to 547 $\mu g/m^3$. Blood lead levels in ten shipfitters ranged from 25 to 53 $\mu g/dl$ (mean, 37.8 $\mu g/dl$); levels in three of these workers exceeded the upper normal limit of 40 $\mu g/dl$. Blood lead levels in shipfitters were significantly higher than in other shipyard workers (mean 10.0 $\mu g/dl$; $p < 0.001$). Smoking shipfitters (mean, 47 $\mu g/dl$) had significantly higher lead levels than nonsmokers (mean, 32 $\mu g/dl$; $p = 0.03$). Lead levels in shipfitters who wore respirators were not lower than in those who wore no protective gear ($p = 0.68$). Four shipfitters had erythrocyte protoporphyrin (EP) concentrations above the adult upper normal limit of 50 $\mu g/dl$. A close correlation was found between blood lead and EP levels ($r = 0.70$). Prevalence of lead-related symptoms was no higher in shipfitters than in other workers. No cases of symptomatic lead poisoning were noted. These data indicate that serious occupational exposure to lead can occur in a relatively small boatyard.

Key words: lead, boat building, occupational lead exposure

INTRODUCTION

Lead is a classic hazard in boat building. Because it resists salt corrosion, neutralizes acid, and bonds to thermally elastic surfaces, lead is used extensively in the manufacture of marine paints [Hunter, 1978]. Lead-based marine paints consist of a suspension of lead oxide in oil, and they contain 50–90% lead by weight [Landrigan et al, 1982]; by contrast, interior house paints in the United States are permitted to contain no more than 0.06% lead [Needleman and Landrigan, 1981]. Boat builders can be exposed occupationally to lead during the application or removal of lead-based paint [Rieke, 1969]. Particularly hazardous exposures result from high-temperature operations such as welding, riveting, or flame-cutting, in which a fume may be evolved from lead-painted surfaces [Fischbein et al, 1981; Hamilton and Hardy, 1974].

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In January 1985, we were asked to evaluate occupational exposures to lead in shipfitters cutting and riveting lead-painted iron plates belowdecks on the *Joseph Conrad*, a 103-year-old iron-hulled sailing vessel berthed at the Mystic Seaport, Mystic, Connecticut. We report here on the results of that evaluation. The episode illustrates the hazards of high-temperature work with lead-based paint [Fischbein et al, 1981]. It demonstrates that serious occupational exposure to lead can occur in even a relatively small boatyard.

BACKGROUND

The *Joseph Conrad*, originally named the *Georg Stage*, was launched at Copenhagen, Denmark, on March 11, 1882. From 1882 to 1934, she saw service as a training vessel for Danish naval cadets. In 1934, she was converted to a private yacht, and over the next two years with Alan Viliers as Captain she circumnavigated the globe by way of Cape Horn and the Cape of Good Hope. In 1939, the *Conrad* was turned over to the U.S. Maritime Commission. Berthed at St. Petersburg, Florida, she served throughout the war years as a merchant marine training ship. In 1947, ownership of the *Conrad* was transferred by Act of Congress to the Mystic Seaport. Since that time she has been permanently berthed at Mystic, where she serves in the sail training program.

The refitting of the *Conrad* began in September 1984. She was down rigged. Work was then undertaken to replace the decking, the electrical wiring, and the sprinkler system. The structure was altered so as to conform more closely to the vessel's original design. To enable this work to continue through the winter, the undecked hull was covered with protective plastic sheeting.

Extensive iron work was undertaken belowdecks. In keeping with the shipyard's use of traditional techniques, iron plates were joined with rivets, rather than by welds. In this technique, old rivets are removed with a pneumatic rivet-buster, and old lead-painted plates are cut with oxyacetylene torches. New plates are then secured with rivets, which are heated in a forge, placed with tongs, and fastened with pneumatic rivet guns. In the early stages of this work, a putty, which consisted of 15% lead tetraoxide, was applied at the point of insertion of each rivet. That practice was, however, discontinued, because the heated putty emitted a dense and acrid smoke.

Ventilation consisted initially of only a fan situated at the top of the covered hull. Later, as concern arose about lead, a local exhaust ventilation system employing a flexible duct was installed; this system allowed an exhaust duct to be placed adjacent to the riveter.

Carbon cartridge respirators with prefilters, approved for protection against dust and organic vapors, were available to workers for use during riveting. A comprehensive program for respirator maintenance had, however, not been established, and workers were permitted to wear respirators over beards.

EVALUATION DESIGN AND METHODS

Industrial Hygiene

To evaluate workers' exposures to airborne lead, personal (breathing zone) and area air sampling was undertaken. Breathing zone air samples were collected on seven shipfitters, all of whom were working on the *Conrad*. Area air samples were collected at two stationary locations belowdecks while riveting was underway.

To recreate the more adverse exposure conditions that were reported to have existed during the initial phases of the refitting, we collected two short-term air samples with the local exhaust ventilation temporarily disconnected and with temporary reintroduction of the lead-based putty.

Air samples were collected on cellulose ester filters with a pore size of 0.8 μm. Samples were weighed, ashed with nitric and perchloric acids, and then diluted at a volume of 25 ml, in accord with NIOSH method 7300 [NIOSH, 1979b]. Analyses were undertaken by atomic absorption spectroscopy, in accord with NIOSH method 7082 [NIOSH, 1979c].

Medical

All 15 workers involved in refurbishing the *Conrad* were invited to participate in the medical evaluation. Also, for purposes of comparison, workers from other areas of the shipyard were invited to participate. Signed, informed consent was obtained from all survey participants. Evaluation consisted of a brief medical and occupational history. Information was sought on the occurrence in the preceding month of the following possibly lead-related symptoms: headache, appetite loss, abdominal pain, muscle weakness, insomnia, joint pains, and irritability [Baker et al, 1979].

To evaluate lead absorption, a venous blood sample was obtained from each worker. These samples were analyzed for blood lead concentration, erythrocyte protoporphyrin (EP) level, and hemoglobin content. Analyses were performed by Environmental Sciences Associates (ESA) Inc, Bedford, Massachusetts. Blood lead analyses were performed by anodic stripping voltammetry [Searle et al, 1979], and the EP determinations by an acid extraction technique [Chisolm and Brown, 1975].

RESULTS

Industrial Hygiene

Lead concentrations in seven personal air samples on shipfitters ranged from 108 to 500 $\mu g/m^3$ (mean, 257 $\mu g/m^3$). All were above the Occupational Safety and Health Administration (OSHA) standard for occupational lead exposure of 50 $\mu g/m^3$ [OSHA, 1978].

Airborne lead concentrations in two general area samples obtained with local exhaust ventilation in operation were 73 and 108 $\mu g/m^3$ (mean, 90.5 $\mu g/m^3$). However, when the ventilation was temporarily disconnected and lead-based putty put back into use, air lead concentrations in two short-term samples rose to 375 and 718 $\mu g/m^3$ (mean, 547 $\mu g/m^3$) (Fig. 1).

Medical

Occupational and medical histories were obtained on 14 workers. A venous blood sample was obtained on 13 of these workers; for the 14th, results were available of recent blood lead and EP determinations performed at the laboratory of the Connecticut Department of Health Services.

Ten of these workers were actively engaged in refitting the *Conrad*; the participation rate in this group was 67% (10 of 15). The remaining four workers were

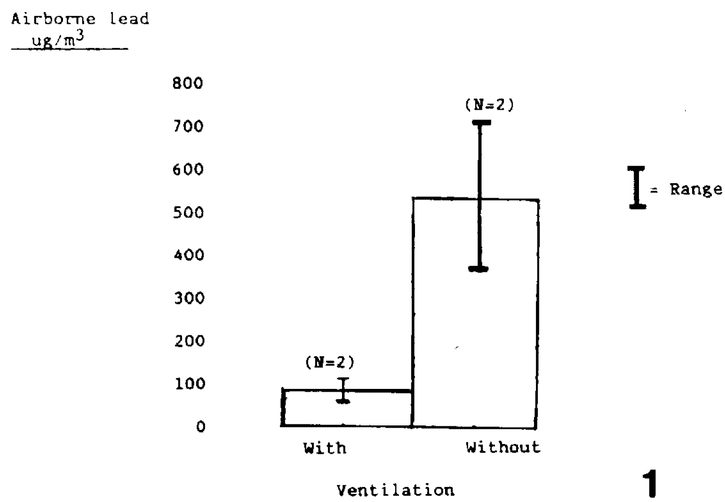

Fig. 1. Belowdecks air lead concentrations with and without local exhaust ventilation: Mystic Seaport, 1985.

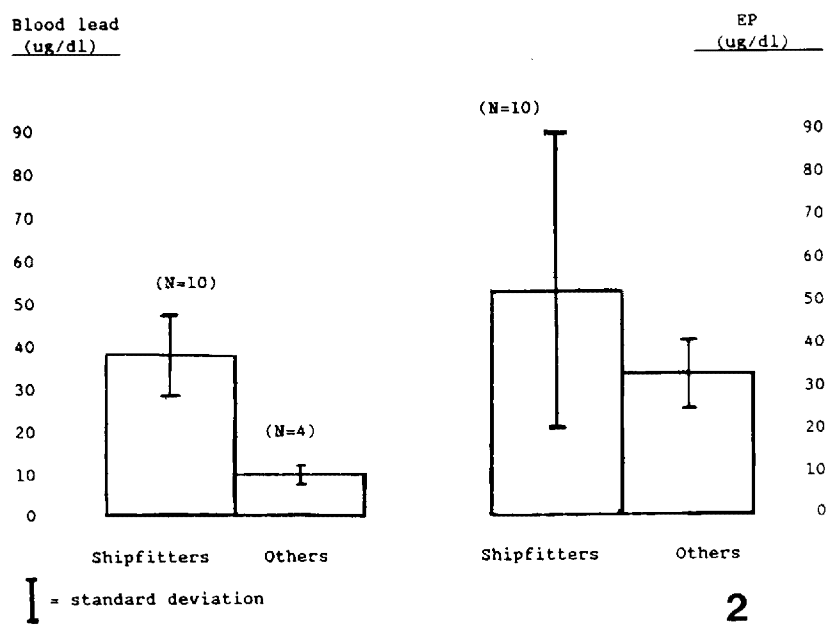

Fig. 2. Blood lead and erythrocyte protoporphyrin (EP) levels in shipfitters and other workers: Mystic Seaport, 1985.

employed in other areas of the shipyard, where they had occasional contact with lead, but no exposure to heated lead or lead fume.

Blood lead levels in the ten shipfitters ranged from 25 to 53 μg/dl whole blood (mean, 37.8 μg/dl; SD 9.3 μg/dl). (Fig. 2). Levels in three of these workers (45, 52, and 53 μg/dl) exceeded 40 μg/dl, the upper limit of normal for blood lead concentration in adults [OSHA, 1978].

Blood lead levels in the four members of the comparison group ranged from 7 to 12 μg/dl (mean, 10.0 μg/dl; SD, 2.1 μg/dl). This mean level was significantly lower than that in the shipfitters ($p < 0.001$).

Blood lead levels were found to be significantly higher in smoking shipfitters than in nonsmokers (46.8 vs 31.8 μg/dl; $p = 0.03$). Neither respirator use ($p = 0.68$) nor frequent hand-washing ($p = 0.36$) produced any significant reduction in blood lead levels. No association was found between blood lead level and either the number of hours worked with lead each week ($p = 0.54$) or total duration of exposure to lead at the shipyard ($p = 0.44$).

EP levels in shipfitters ranged from 27 to 132 μg/dl (mean, 53.9 μg/dl; SD, 33.1 μg/dl) (Fig. 2). EP levels in four shipfitters exceeded the adult upper normal limit of 50 μg/dl [Roels et al, 1979]. EP levels in the comparison group ranged from 25 to 40 μg/dl (mean, 33.5 μg/dl; SD, 6.9 μg/dl). The difference in EP levels between the two groups was of marginal significance ($p = 0.09$). A close correlation was found between blood lead and EP levels (correlation coefficient, $r = 0.70$).

No cases of anemia were observed; all hemoglobin values were above 13.0 g/dl.

Symptoms of headache, decreased appetite, abdominal pain, muscle weakness, insomnia, joint pain, and irritability were all equally common in *Conrad* workers and the comparison group. (Table I). No cases of clinical lead poisoning were observed.

DISCUSSION

The environmental and medical data from this evaluation indicate that a serious hazard of occupational exposure to lead existed for workers refitting lead-painted wrought iron on the iron-hulled sailing vessel *Joseph Conrad*.

Two factors appear to have augmented the severity of these exposures. First and most important was that the critical operations—riveting and plate cutting—are high-temperature procedures. Such operations have the capacity to generate a lead fume from lead-painted surface [Fischbein et al, 1981]. Lead fumes, because of their small particle size, are inherently more dangerous than the coarser lead dusts produced by low-temperature operations such as sanding, grinding, or drilling [Hamilton and Hardy, 1974]. The second aggravating factor was that much of the cutting and riveting had to be undertaken in confined spaces. Ventilation in such areas is inherently difficult [NIOSH, 1979a].

TABLE I. Prevalence of Reported Symptoms in Shipfitters and Other Workers: Mystic Seaport, 1985

	Symptoms prevalence (%)		Significance of
Symptom	Shipfitters (N = 10)	Other workers (N = 4)	difference (p-value)
Headache	40	25	0.58
Abdominal pain	20	25	1.00
Decreased appetite	0	25	0.29
Muscle weakness	10	25	0.51
Insomnia	40	25	1.00
Joint pain	10	25	0.29
Irritability	30	50	0.58

Our finding that smoking shipfitters had significantly higher blood lead levels than nonsmokers parallels the results of previous studies. In the first National Occupational Hazard Survey, conducted by NIOSH from 1972 to 1974, blood lead levels among smokers in the lead trades were found to be consistently higher than those among nonsmokers in the same industries [CDC, 1983]. Likewise, in an international comparative study of lead absorption among adult schoolteachers conducted by the World Health Organization, blood lead levels in smoking teachers were higher in each of ten countries evaluated than those in nonsmokers [Vahter, 1982]. Apparently the opportunity that cigarette smoking affords for the transfer of lead dust from the fingers to the mouth accounts for this increased absorption.

Respirators were found to provide little protection against increased lead absorption. This finding reflects the inherent inefficiency of respirators as a form of protective equipment; it underscores the need for efficient extraction ventilation as a first line of defense against airborne toxins [U.S. Congress, OTA, 1985]. Also, however, the observed inefficiency of the respirators reflects the fact that no systematic program for respirator use had been established at the shipyard; thus, no fit testing or respirator maintenance programs had been developed, and workers were allowed to wear respirators over beards [NIOSH, 1976].

Fortunately, no cases of clinically evident lead poisoning occurred among workers on the *Conrad*, and there was no anemia. The two factors that appear to have prevented development of more severe toxicity were the use of the local exhaust ventilation system and the relatively brief duration of the belowdecks refitting. The demonstration of a sixfold increase in mean air lead concentration (from 90 to 547 $\mu g/m^3$) during temporary disconnection of the local exhaust ventilation attests to the value of that system.

The hazards observed in this investigation are now abated, since the belowdecks refitting of the *Conrad* has largely been completed. The problems observed in this evaluation will, however, recur if additional refitting is done in the future. The best long-term solution to the problem of occupational lead exposure will be, whenever possible, to replace lead-based materials with materials that are formulated of less toxic substances. Zinc-based paints have, for example, been substituted for lead-based coatings in many situations. Such substitution must, however, be approached cautiously. It is important to ascertain in advance that a substitute material is indeed less hazardous than the substance that it is intended to replace.

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