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Relative Contribution of Potential Modes of Surface Dust Lead Contamination in the Homes of Boatyard Caulkers

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Abstract: Relative Contribution of Potential Modes of Surface Dust Lead Contamination in the Homes of Boatyard Caulkers: Orrapan UNTIMANON, *et al*. Bureau of Occupational and Environmental Diseases, Ministry of Public Health, Thailand—Objectives: The aim of this study was to quantify the relative contributions to surface lead contamination of boat-caulkers' houses of three contamination modes, namely "take-home" lead from the caulker, "natural" spatial dispersal from boatyard to household and "redistribution" of accumulated lead-laden dust within the house. **Methods:** Boat-caulkers' houses situated in areas surrounding boat repair yards were recruited. Caulkers' houses that were located close together were divided into location-matched pairs, within which one was randomly assigned to be given a cleaning and designated a CL house, and the other was to be left uncleaned and designated a NCL house. Geographically isolated caulker's houses were randomly assigned to one of the two categories. The nearest non-boatyard worker's house (NB) was additionally recruited for each set. The surface lead loading rate (SLLR), defined as the mass of lead deposited in dust per unit area of surface per unit time, was measured over a period of 3 mo in all houses, and the data were modeled using linear mixed effects regression. **Results:** Adjusted values of SLLR differed only slightly between CL and NCL houses (0.96 to 1.02 times) but were between 1.65 and 2.03 times higher in CL and NCL houses than in NB houses depending on proximity to the boatyard and between 2.12 and 2.61 times higher in houses within one km of a boatyard than in more distant houses depending on category of house. **Conclusions:** Newly deposited dust lead likely resulted from the take-home and spatial dispersion modes. The contribution of redistribution is very small.
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Key words: Boatyard, Caulker, Household dust, Lead loading rate, Take-home lead

Lead contamination in the shipbuilding and ship repair industries has resulted from the use of lead-based paint and from welding processes. Previous studies have shown that workers involved in these tasks are especially prone to increased blood lead concentrations[1–3]. The repair of wooden boats in Thailand also involves the use of lead but in the form of powdered lead oxide (Pb_3O_4, plumboplumbic oxide, or red lead) as a component in the caulking material. Workers are directly exposed to lead when mixing caulking materials and when sealing boat hulls. A previous study has reported that 67% of boat caulkers had high blood lead levels (>40 μg/d*l*)[4]. Furthermore, households in communities adjacent to boatyards have been shown to have elevated dust lead concentrations, and children's blood lead concentrations in these communities were high and correlated closely with static measures of household surface dust lead concentration[5].

Remedial measures aimed at reducing the burden of childhood lead contamination in these communities could be directed at reducing the levels of lead contaminating household surfaces, reducing the magnitude of child-lead contact or both. An effective strategy for reducing lead contamination of household surfaces requires an understanding of the dynamics of dust lead deposition in the household. Such understanding is only poorly provided by static measures of lead loading alone, such as the mass of lead wiped from a given area at any one time. Better understanding could be acquired by measurements of the rate at which lead is deposited on household surfaces, espe-

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cially if this deposition could be decomposed into the various modes of contamination.

A method for determining time-averaged surface lead loading rate (SLLR) in terms of mass of lead deposited as dust per unit area and unit time has recently been described[6]. The method involves the placement of clean lead-free artificial surfaces of known area within the home and the measurement of total lead in the dust deposited over a known time interval. This measure reflects the dynamic process of contamination, unlike a static measure such as lead loading in terms of mass of lead per unit area, which is simply a snapshot of conditions at a single time point.

In the setting of boatyard communities in southern Thailand, the principal modes of potential transfer of lead-bearing dust to household surfaces are considered to be 1) the direct deposition of lead dust taken home by the boat caulkers on their bodies, clothes, vehicles or equipment, 2) "natural" transfer from the boatyards to houses such as via a windblown route and its subsequent deposition on household surfaces and 3) the redistribution and re-deposition of accumulated lead-laden dust already existing within houses. This third mode of surface contamination was postulated because the accumulated dust in caulkers' houses had been found in previous studies to have a high lead content[5, 7]. If such dust is disturbed, it could be redistributed to other surfaces in the home, thereby acting as a local source of contamination.

No reliable method for directly measuring the rates of transfer by each of these modes without interfering with the actual transfer rates could be devised. Therefore, a study design was planned whereby the contribution to surface contamination via each of the three modes could be estimated indirectly. In this design, the differences in SLLR values were determined within pairs of households, in which the pair members were expected to differ with respect to a single mode of lead transfer. The relative magnitude of these differences would therefore reflect the relative contribution to household surface dust lead contamination of each mode of transfer. The information gained from the study could indicate the prime modes of contamination towards which remedial measures should be targeted.

Materials and Methods

Ethical approval

The study was approved by the Ethics Review Committee of the Faculty of Medicine, Prince of Songkla University, Thailand. A careful explanation of the study was given to all participants, and formal signed consent obtained before any interview, intervention or measurement took place.

Setting

The study was conducted among communities comprising both caulkers' and neighboring non-boatyard workers' households adjacent to boat repair yards in three districts in Songkhla Province and Nakhon Sri Thammarat Province, which are located on the eastern coast of southern Thailand.

The head of each community was provided with an explanation of the project, and permission to perform the study in his locality was requested. After obtaining permission, a map of the households with corresponding name list of residents and whether or not they worked in a boatyard was obtained.

Study design

This was an experimental study comparing household surface lead loading rates (SLLR) within matched sets of three categories of house: 1) caulkers' houses after extensive cleaning to remove lead was conducted (CL), 2) caulkers' houses that were not cleaned (NCL) and 3) non-boatyard workers' houses (NB). The matched sets were stratified by distance from the nearest boatyard.

Logic of comparison

The effect of take-home lead was expressed as the difference in SLLR between CL houses and NB houses, since the cleaning process was implemented to eliminate the redistribution effect. A proxy measure of the contribution of natural dispersal, such as by the wind, was made by examining the effect of distance from the local boatyard on SLLR with adjustment for category of house. Redistribution of household lead dust was expressed as the difference in SLLR between CL houses and NCL houses.

Sample size calculation

Sample size calculation was intended to detect differences between means of the logarithm of SLLR between categories of households. Based on a significance level of 0.05 and a power of 80% to detect differences in the means of two populations when the effect size is at least 0.675 of a standard deviation, assuming equal standard deviations, the sample size required for each of the two categories of house is 35 households. This number was then inflated to compensate for three groups comparison, and the study finally enrolled 42 CL houses, 43 NCL houses and 51 NB houses.

Sampling technique and category allocation

The numbers of households enrolled in this study were 50, 66 and 20 households in the three communities of Singha-nakhon, Pak-panang and Thasala, respectively. Out of these, 32, 40 and 13, respectively, belonged to caulkers. The eligibility criteria for the selected caulkers included 1) having worked as a caulker for an average of at least 10 days/mo in the previous year and 2) having lived in the current house during that period. Caulkers' houses located within 200 m of each other were paired. Within each pair, one house was randomly assigned to the CL category, and the other was assigned to the NCL category. Where pairing was not possible, the isolated caulker's house was randomly assigned into either category. Within 200 m of a paired set or an unpaired caulker's house, the nearest house in which no resident worked in the boatyard or was exposed occupationally, recreationally or domestically to lead was selected and placed into the NB category.

Figure 1 summarizes the actual achievement of data collection. The study enrolled 136 households. All were located within 11 km of a boatyard, of which there were a total of 12 boatyards in the study areas. Geographical grouping resulted in 34 paired sets and 17 unpaired caulkers' houses; 8 of the unpaired caulkers' houses were allocated to the CL category, and 9 were allocated to the NCL category. A NB house was successfully added to each of these. However, during the 3-month deposition period, among the sets of 3 houses, one caulker in a CL house died, and the sampling device of one NCL house broke. In the final analysis, therefore, there were 32 complete sets of CL, NCL and NB houses, 9 sets of CL and NB houses and 10 sets of NCL and NB houses.

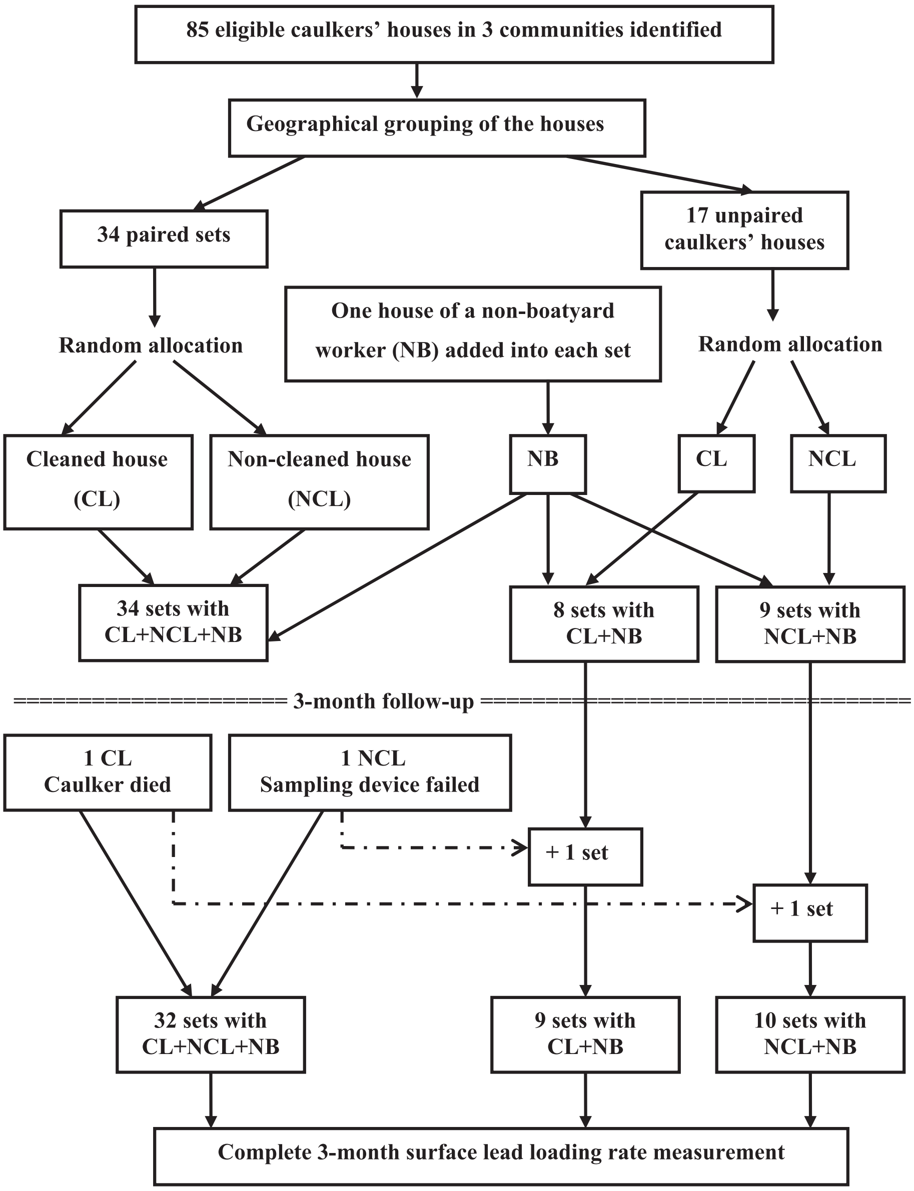

Fig. 1. Flow of participating households through the study.

Baseline data collection

Baseline measurements were made and data were collected during the period of February-March, 2007. The details are described below.

A questionnaire-based face-to-face interview of all consenting participants was conducted to obtain information on boat caulkers' behaviors and on the number, ages and occupations of all other household members. Household characteristics, such as location in relation to road level, proximity to the road, surrounding substrate type, house construction materials, whether painted or not and the presence of carpets or rugs on the floor, were inspected carefully at all study households and recorded on an observation checklist. In addition, the areas within 10 m of the boundary of each household were searched for the presence of other potential sources of lead contamination.

Wipe specimens were collected from 2 areas of 20 × 30 cm, each defined by a masking tape template, on the living room floor of each household for determination of floor lead loading (FLL), that is, the mass of lead per unit area of floor. The templates were placed in a position that was not regularly disturbed but was nevertheless readily accessible to household members. Specimen collection and lead determination followed the protocol specified in the NIOSH Manual of Analytical Methods[8].

Specimens of accumulated household dust were collected in each household for determination of lead content (mass of lead per mass of dust) following the method described by Maharachpong[7]. Specimens of accumulated dust were collected from various little-disturbed places such as the tops of doors, ventilation holes or the tops of wardrobes by brushing lightly with a new toothbrush onto a clean paper sheet and then transferring the dust to a new clean lead-free polyethylene bag, which was then sealed. Dust specimens were collected from at least two places within each household and combined into a single composite specimen in order to provide a better representation of lead content in the house and to reduce problems that might occur due to spatial variation in the distribution of dust and its lead content.

The location of each house and of the local boatyards was recorded with a handheld Global Positioning System (GPS) set to display in the Universal Transverse Mercator (UTM) coordinate system. All coordinate locations were plotted, and the distances house-to-house and boatyard-to-house were determined using ArcView GIS 3.2 (ESRI Thailand Co., Ltd.).

House cleaning procedure

For the CL houses, cleaning was performed on one occasion immediately prior to the beginning of the three-month follow-up period using a fixed protocol. The protocol was adapted from a previous study[9] to suit the particular setting of caulkers' houses in this tropical environment. Before cleaning, all dirty work clothes were laundered to prevent contamination with lead-containing dust. New cleaning materials (e.g., bucket, sponge) were used at each home. All horizontal surfaces (e.g., floors, windowsills, furniture, especially the tops of cupboards and wardrobes, and ceilings) were vacuumed. Having no carpet, all the floors and horizontal surfaces were damp-mopped using water and detergent once and rinsed using a mop with water two times.

After cleaning, all cleaned houses were checked for surface lead level using a lead swab test kit (Lead Inspector™, Abotex Enterprises Limited, Grand Bend, ON, Canada) to ensure the lead content was below 10 ppm.

Specimen collection for determination of surface lead loading rates

The method for collecting specimens for determination of SLLR was modified from a study conducted in an urban setting in the United States[10] and previously tested in a boatyard community setting[6]. Two glass plates with a deleaded surface for lead deposition, each 20 × 30 cm, were suspended at a position approximately 50 cm from the ceiling in each house. For houses in the CL category, the plates were placed immediately after the cleaning and checking for surface lead level. At the end of the third month, dust deposited on each glass plate was collected following the NIOSH Manual of Analytical Method[8]. Briefly, a technician wore a new pair of powder-free disposable gloves before each wiping to avoid cross contamination of lead dust. While sampling, a technician pressed a clean towelette (Ghost Wipe, Environmental Express, Mt. Pleasant, SC, USA) onto the glass sheet and wiped the entire upper surface of 600 cm^2 in a left-to-right direction; then the towelette was folded with the collected dust inside, and the surface was wiped again with single strokes in a direction perpendicular to the first wiping until all visible material was removed. Another clean towelette was used to wipe the second glass sheet in the same manner. For each pair of sampling plates, two wipes were used and treated as one composite specimen representing a total area of 1,200 cm^2. One field blank was taken per house before dust collection by using a clean towelette (Ghost Wipe, Environmental Express, Mt. Pleasant, SC, USA) immediately unfolded and refolded within the house. All field blanks were subsequently found to have a lead content below the quantification limit. After collection, all wipes were immediately placed in a lead-free screw-capped container, capped tightly and sent for analysis by flame atomic absorption spectrophotometer (Varian Spectra 640) in accordance with NIOSH method 7082/1994[11] at the Reference Laboratory and Toxicology Center, Bureau of Occupational and Environmental Disease, Department of Disease Control, Ministry of Public Health, Thailand. This laboratory unit has participated in the proficiency testing schemes implemented three times each year under the Workplace Analysis Scheme for Proficiency (WASP) of the Health and Safety Laboratory, UK. Blanks were used for quality control of specimen digestion and underwent the same procedure as the specimens. Repeat lead determinations were done in the same laboratory on a random 10 percent subset of specimens within each batch. The quantification limit for the lead concentration in the final solution on which lead determinations were made was 0.01 μg/m*l*, corresponding to 0.1 μg/sample. Results were reported as micrograms of lead per wipe and were then converted to $\mu g/m^2$/day.

Variables related to the three-month period

Information regarding the number of caulking days, whether or not caulking tools were taken home, occurrence of house repairing and frequency of sweeping the floor, mopping the floor or dusting during the 3-month dust deposition period were collected using a structured questionnaire administered at the end of the 3 mo.

Statistical analysis

Descriptive statistics were used to display the characteristics of the houses, the hygiene behaviors of the caulkers before leaving work and after arriving home from work and their work durations, and comparisons were evaluated using the Chi-squared test, *t*-test or Wilcoxon rank-sum test, as appropriate. Baseline values of FLL ($\mu g/m^2$) and of dust lead content (μg/g) were compared among CL, NCL and NB houses using the Kruskal-Wallis test followed by Dunn's multiple comparison test. The median and interquartile range (IQR) of SLLR values were stratified by category of house and distance from the local boatyard. Tests for significant differences within matched sets were performed using the Wilcoxon signed- rank test and those for significant differences between houses located at short (<1 km) and long distances from the nearest boatyard were performed using the Wilcoxon rank-sum test.

To estimate the independent effect of the cross-classification of house category and distance from boatyard on SLLR after controlling for other factors that might confound the crude values, a linear mixed-effects model with a random intercept[12] was constructed. This form of model was employed because the households were arranged in 51 location-matched sets and the households within each set were in the same the physical environments. The sets comprised the random component of the model, whereas a variable representing the cross-classification of category of house and distance from boatyard as well as other independent variables were considered to have fixed effects. The model allows the baseline value of the dependent variable to vary from one set to another, while the effect of each covariate in the model is considered to be fixed for all sets. Because SLLR was right-skewed, it was transformed using the natural logarithm to achieve approximate normality for use as the dependent variable. Each exposure variable was first fitted into separate models already containing the variable for the cross-classification of category of house and distance from boatyard, and those having a likelihood ratio *p*-value of <0.2 were selected for fitting together in the initial multivariate model. This initial model was then refined by backward elimination of variables, other than house category and distance from boatyard, that did not contribute significantly to the fit of the model. Coefficients of the model were subsequently exponentiated to yield multiplication factors indicating the ratio of the adjusted geometric mean SLLR between the subgroup of interest and the reference. Significance was set at 5%. Data were analyzed using the R-2.5.1 software[13].

Results

Baseline household characteristics of the three categories are displayed in Table 1. The other nearby sources of lead were a metal soldering shop, an old boatyard (shut down three years prior to the study) and lead sinkers for fishing nets at a nearby house. There were no significant differences in characteristics among the 3 house categories apart from the levels of floor lead loading and dust lead content at baseline, which were significantly higher in CL and in NCL houses ($p<0.001$) than in NB houses but not significantly different between CL and NCL houses. None of the houses had carpeted floors, and most of the residents kept their windows either always or sometimes open. Large accumulations of dust were observed on tops of cupboards and wardrobes.

Baseline characteristics and behaviors of caulkers are demonstrated in Table 2. Neither working history nor hygiene practices of caulkers differed significantly between CL and NCL houses.

All but 6 of the houses in the CL category achieved a target surface lead load of less than 10 ppm as indicated by the swab test kit after a single cleaning. A repeat cleaning was undertaken in the remaining 6 houses.

Variables related to the 3-month dust deposition

Table 1. Baseline household characteristics classified by category assignment (N=134)

Characteristic	Caulkers' houses		NB houses (n=51)
	CL (n=41)	NCL (n=42)	
Distance of the house to the nearest boatyard [no. (%)]			
<1 km	21 (51.2)	24 (57.1)	29 (56.9)
≥1 km	20 (48.8)	18 (42.9)	22 (43.1)
Proximity to road [no. (%)]			
Adjacent to road	13 (31.7)	13 (31.0)	18 (35.3)
More than 10 m from road	28 (68.3)	29 (69.0)	33 (64.7)
Age of houses (yr) [no. (%)]			
1–19	24 (58.5)	23 (54.8)	22 (43.1)
≥20	17 (41.5)	19 (45.2)	29 (56.9)
Location in relation to road level [no. (%)]			
Lower than road	3 (7.3)	6 (14.3)	7 (13.7)
Same level as road	22 (53.7)	17 (40.5)	29 (56.9)
Higher than road	16 (39.0)	19 (45.2)	15 (29.4)
Window opened [no. (%)]			
Always open	27 (65.9)	25 (59.5)	43 (84.3)
Sometimes open	10 (24.4)	10 (23.8)	4 (7.8)
Never open	4 (9.8)	7 (16.7)	4 (7.8)
Painted house [no. (%)]			
Yes	5 (12.2)	10 (23.8)	10 (19.6)
No	36 (87.8)	32 (76.3)	41 (80.4)
Type of ventilation use [no. (%)]			
Natural wind	7 (17.1)	5 (11.9)	6 (11.8)
Fan	34 (82.9)	37 (88.1)	45 (88.2)
Presence of other lead sources within 10 m [no. (%)]			
Yes	1 (2.4)	1 (2.4)	4 (7.8)
No	40 (97.6)	41 (97.6)	47 (92.2)
Floor lead loading (μg/m^2) [no. (%)][a, b]			
<431	36 (87.8)	37 (88.1)	51 (100.0)
≥431	5 (12.2)	5 (11.9)	0 (0.0)
Median (IQR)[c]	118.2 (53.4–224.7)	140.3 (52.6–278.9)	37.2 (19.7–73.2)
Dust lead content (μg/g)[b]			
Median (IQR)[c]	463.0 (220.0–799.0)	409.5 (249.0–940.0)	67.0 (27.0–243.0)

CL=cleaned. NCL=non-cleaned. NB=non-boatyard. IQR=Interquartile range. [a]USEPA levels of concern for lead loading on floor surface, 40 μg ft^{-2} (≈ 431 μg m^{-2})[42]. [b]Values for houses in the CL category refer to measurements prior to cleaning. [c]CL vs. NB and NCL vs. NB: $p<0.001$ for both floor surface lead loading and dust lead content (Kruskal-Wallis test followed by Dunn's multiple comparison test).

period are shown in Table 3. There was no significant difference in cleaning frequency among all three categories of house. Few houses underwent structural repair during the period, and the repairs were only on a small scale. The proportions of caulkers taking tools home did not differ significantly between CL and NCL houses. The number of caulking days was significantly higher in CL houses than in NCL houses (p=0.021).

Comparisons of the median and interquartile range of crude SLLR values between categories of house, between distance-from-boatyard groups and within matched sets of CL and NB houses for each distance-from-boatyard group are shown in Table 4. CL houses had significantly higher SLLRs than NB houses. An effect of distance was demonstrated by the comparison of houses within one kilometer and those at least one kilometer from a local boatyard for each category of house. In each category, houses nearer to a boatyard had higher SLLRs than those further away. However, the difference in SLLRs between CL and

Table 2. Baseline characteristics and behaviors of caulkers

Characteristic	Caulker group	
	CL (n=45)[a]	NCL (n=47)[b]
Working duration (yr) [mean (SD)]	18.6 (9.7)	20.6 (11.5)
Working hours [mean (SD)]	8.6 (0.5)	8.6 (0.5)
Decontamination at boatyard [no. (%)]		
Changes clothes	4 (8.9)	6 (12.8)
Washes hands	25 (55.6)	21 (44.7)
Does nothing	16 (35.6)	20 (42.6)
Launders work clothes [no. (%)]		
At the boatyard	4 (8.9)	6 (12.8)
At home	41 (91.1)	41 (87.2)
Keeps dirty clothes [no. (%)]		
At the boatyard	4 (8.9)	6 (12.8)
Inside the house	18 (40.0)	20 (42.6)
Outside the house	23 (51.1)	21 (44.7)
Cleans shoes before going home [no. (%)]		
Always	13 (28.9)	11 (23.4)
Sometimes	20 (44.4)	16 (34.0)
Never	12 (26.7)	20 (42.6)
Keeps dirty shoes [no. (%)]		
Inside the house	1 (2.2)	1 (2.1)
Outside the house	44 (97.8)	46 (97.9)

CL=cleaned. NCL=non-cleaned. [a]4 houses had 2 caulkers resident; [b]5 houses had 2 caulkers resident.

Table 3. Variables related to the 3-month dust-deposition period by category assignment

Variable	Caulkers' houses		NB houses (n=51)
	CL (n=41)	NCL (n=42)	
Frequency of sweeping the floor [no. (%)]			
< Daily	7 (17.1)	8 (19.0)	6 (11.8)
Daily	34 (82.9)	34 (81.0)	45 (88.2)
Frequency of mopping the floor [no. (%)]			
< Once per week	13 (31.7)	18 (42.9)	21 (41.2)
≥ Once per week	28 (68.3)	24 (57.1)	30 (58.8)
Frequency of dusting [no. (%)]			
< Once per week	26 (63.4)	32 (76.2)	42 (82.4)
≥ Once per week	15 (36.6)	10 (23.8)	9 (17.6)
House repair [no. (%)]			
Yes	4 (9.8)	4 (9.5)	0 (0)
No	37 (90.2)	38 (90.5)	51 (100)
Caulking tools taken home [no. (%)]			
Yes	27 (65.9)	24 (57.1)	-
No	14 (34.1)	18 (42.9)	
Number of caulking days [no. (%)]			
≤25	8 (19.5)	20 (47.6)	-
>25–49	17 (41.5)	10 (23.8)	
≥50	16 (39.0)	12 (28.6)	
Median (IQR)[a]	42 (32–55)	28 (13–50)	-

CL=cleaned. NCL=non-cleaned. NB=non-boatyard. IQR=Interquartile range. [a]CL vs. NCL: p=0.021 (Wilcoxon rank-sum test).

Table 4. Comparison of surface lead loading rates (μg m^{-2} day^{-1}) to test hypotheses of the three components of household surface lead contamination

Component I: Possible take-home effect			
	CL houses Median (IQR)	NB houses Median (IQR)	*p*-value[a]
≥1 km from boatyard; n=20 pairs	0.80 (0.50, 1.81)	0.36 (0.31, 0.53)	<0.001
<1 km from boatyard; n=21 pairs	1.69 (0.96, 2.89)	0.74 (0.49, 2.81)	0.023
Component II: Spatial dispersal effect			
	≥1 km from boatyard Median (IQR)	<1 km from boatyard Median (IQR)	*p*-value[b]
CL houses	0.80 (0.50, 1.81)	1.69 (0.96, 2.89)	0.005
NCL houses	0.82 (0.65, 0.94)	1.50 (0.82, 2.80)	0.007
NB houses	0.36 (0.31, 0.53)	0.74 (0.49, 2.18)	<0.001
Component III: Possible redistribution effect			
	CL houses Median (IQR)	NCL houses Median (IQR)	*p*-value[a]
≥1 km from boatyard; n=15 pairs	0.71 (0.49, 1.69)	0.81 (0.65, 0.90)	0.910
<1 km from boatyard; n=17 pairs	1.97 (0.96, 2.89)	1.48 (0.95, 2.97)	0.493

CL=cleaned. NCL=non-cleaned. NB=non-boatyard. IQR=Interquartile range, [a]Matched-paired analyses using Wilcoxon signed-rank test, [b]Unmatched analyses using Wilcoxon rank-sum test.

Table 5. Independent variables predicting ln (surface lead loading rates in μg m^{-2} day^{-1}) from linear mixed effects modeling (51 sets, 134 houses)

Variables	N	Coefficient	MF	95% CI	*p*-value*	Ratio[#] close/far	Ratio[$] CL/NB	Ratio[$] NCL/CL
House category and distance from the nearest boatyard (km)					<0.001			
Far from boatyard (≥1 km)								
NB houses (reference)	22	0[a]	1					
CL houses	20	0.71[b]	2.03	1.22, 3.06			2.03	
NCL houses	18	0.67[b]	1.95	1.22, 3.10				0.96
Close to boatyard (<1 km)								
NB houses	29	0.96[b]	2.61	1.63, 4.06		2.61		
CL houses	21	1.46[c]	4.30	2.56, 7.24		2.12	1.65	
NCL houses	24	1.48[c]	4.39	2.46, 7.39		2.25		1.02
No. of caulking day per 3 mo					0.014			
≤25	79	–0.26[a]	0.77	0.51, 1.17				
>25–49 (reference)	27	0[a, b]	1					
≥50	28	0.37[b]	1.45	0.96, 2.18				
Other lead sources near house					0.005			
No (reference)	128	0	1					
Yes	6	1.04	2.83	1.30, 5.21				

CL=cleaned. NCL=non-cleaned. NB=non-boatyard. 95% CI=95% Confidence interval of the multiplication factor. [a, b, c]Coefficients within each variable not having a superscript in common differ significantly (p<0.05). The coefficients have been transformed (e^{β}) and expressed as multiplication factors (MF). *The *p*-value gives the significance of the contribution of each factor to the fit of the model based on the likelihood ratio test. [#]Ratio of MF within house category; [$]Ratio of MF within distance group.

NCL houses within matched sets was only slight and not statistically significant.

Variables selected for inclusion in the initial multivariate model were age of the house, proximity to a road, vertical location in relation to road level, painted or unpainted house, pattern of window opening, usual type of ventilation employed, number of days the caulker worked in the 3-month deposition period (for non-boatyard workers, this was considered to be zero), number and occupation of other household members and presence of other lead sources within 10 meters of the house. After including these variables together and refining the resulting model, only the cross-classification of house category and distance from boatyard, caulking days and the presence of nearby lead sources remained as significant predictors (Table 5). The SLLR in CL houses exceeded that in NB houses in both distance groups (2.03 times in the distant group, p=0.003, and 1.65 times [=4.30/2.61] in the near group, p=0.017). The SLLR of houses in the near-boatyard group was significantly higher than that of houses more distant in all categories of house, 2.61 times (p<0.001), 2.12 [=4.30/2.03] times (p=0.007) and 2.25 [=4.39/1.95] times (p=0.004), respectively, in the NB, CL and NCL categories. Compared with the SLLR of CL houses, that of NCL houses was not significantly different, 0.96 [=1.95/2.03] times in the distant group and 1.02 [=4.39/4.30] in the near group.

The presence of other lead sources within 10 m of the home was associated with an increased SLLR (MF=2.83, p=0.005). In addition, an increased number of caulking days within the 3-month deposition period was associated with an increased SLLR (p=0.014).

Discussion

Using a matched design and mixed-effects analysis, this study revealed the independent relative contributions of the take-home, natural spatial dispersal and within-home redistribution modes to the overall rate at which dust lead was deposited on household surfaces. Of these three potential modes, only the first two made significant contributions. The rate of deposition was higher in households in closer proximity to a boatyard and also increased in caulkers' houses with increasing number of working days within the 3-month period.

The findings that caulkers' houses, regardless of the cleaning status, had a higher SLLR than their close NB worker neighbors and that the SLLR in caulkers' houses increased with the number of caulking days in a dose-dependent manner reflect the substantial contribution of take-home lead to the deposition of dust lead in caulkers' houses. In a previous study, caulkers were recorded as being exposed to higher levels of airborne lead dust (median=29.5 $\mu g\ m^{-3}$) than carpenters who worked in the same boatyard (median=3.3 $\mu g\ m^{-3}$)[4]. Thus, caulkers might readily carry home lead-laden dust from the boatyard on their bodies, clothes, shoes and vehicles. The poor personal hygiene practices of these workers may add to the magnitude of take-home lead — only about 10% changed their clothes, and none took a shower before leaving the boatyard in the evening. Similar findings were also reported in an earlier study conducted in the same general area as the current study[4]. The take-home lead mechanism has also been given as the explanation for elevated dust lead concentrations in the houses of workers in other lead-related industries, such as electric-cable splicers in the United States[14], construction workers in the United States[15], mining workers in Australia[16, 17] and Germany[18] and battery plant workers in the Czech Republic[19].

Spatial dispersal of lead into the area surrounding boat repair yards was indicated by the elevated SLLR in houses closer to a boatyard. A similar pattern was previously reported in a cross-sectional study in which static measurements of dust lead content were made in the homes of randomly selected schoolchildren living in the vicinity of a boat repair yard[7] and a similar falloff in household lead levels with distance has been described in areas surrounding lead smelters[18, 20, 21]. Particularly strong evidence for the effect of spatial dispersal by non-anthropogenic means is provided in the current study by the closely similar effects of distance on time-averaged lead deposition rates in all three categories of household.

The probable explanation for the spatial pattern of household SLLR's is transfer of windblown lead oxide from a local boat repair yard. The majority of houses in the study had their windows either always or sometimes open throughout the year, which would allow entry of windblown dust. Higher surface lead loadings were found on windowsills than on household floors in communities adjacent to boatyards[22] and have been widely reported in smelting communities[23, 24] and in urban communities[25–30]. A previous study from Australia reported that wind direction was the major contributing factor for outdoor surface lead deposition rates[31]. Wind direction was not monitored during the deposition period in our study, which was conducted within the months of February to May. However, most of the households were located to the west of the boatyards, and the prevailing local wind direction was reported to be from the east during the months of February to April, but it changed to the southwest during May to July[32].

The close similarity in values of SLLR in CL and NCL houses within matched sets leads to the conclusion that redistribution of lead-laden dust within the home did not contribute significantly to the new deposition of lead in this study. This finding was somewhat unexpected considering the high dust lead content of caulkers' houses at baseline in this study and reported in previous studies[5, 7], as redistribution could potentially be an important secondary source of dust lead deposition. The most reasonable explanation, then, is that the accumulated dust commonly seen on relatively inaccessible surfaces in the house remains relatively undisturbed by air currents, ventilation or household activities. Carpets have been reported to be an important potential secondary source of lead-laden dust in other settings[25, 33, 34] but were not found in the households in this study.

The elevated rates of dust lead deposition in caulkers' houses and in any houses located close to a boatyard underline the paraoccupational hazard posed to occupants of these households. Children residing in homes in which one or more members worked in a boatyard as well as those whose homes were close to a boatyard have been reported to have higher blood lead levels than those residing in non-boatyard workers' houses further away from a boatyard[5, 6]. Distance was also an important risk factor for elevated blood lead levels of children who lived less than 500 m from a battery recycling plant in Brazil compared with those who lived more than 500 m away (OR=2.54)[35]. Another study from Brazil also reported that a residential area close to a lead refinery (around 2 km) was associated with high childhood blood lead levels (OR=10.38)[36].

Our study did not include measurements of lead content in soil surrounding each house. However, the levels of lead in soil might be expected to be influenced by natural dispersal effects similar to those contributing to household surface lead contamination. Previous studies have shown that soil lead content peaked at the locations of a boat repair yard[7], a former lead smelter[19, 37, 38] and a lead battery manufacturing plant[34], with soil lead content decreasing with increasing distance from the point source. Lead-contaminated exterior soil has been reported to be a contributing source of interior lead dust[39–41]. However, the correlations between soil lead and dust lead concentration of households located in lead-contaminated areas surrounding boat repair yards in the same area as the current study were found to be low and not significant[7]. Similarly, a lack of correlation between the levels of lead in soil and in household dust was reported in the area surrounding a lead smelter[38]. At present it cannot be concluded whether or not soil lead represents an intermediate stage in the mechanism of spatial dispersion of lead from boat repair yards. Nevertheless, other nearby point sources of lead, including a metal soldering shop, a disused boatyard and a site of lead sinker use, were identified as contributing to household lead deposition in the setting of this study.

With the evidence of spread of lead-laden dust from boatyard to household both via the take-home mode and through spatial dispersion and the failure to demonstrate a contribution from redistribution of accumulated lead-laden household dust, future interventions to reduce the magnitude of this paraoccupational risk should be directed towards these modes. Thus, effective and feasible abatement measures might include avoiding the release of airborne lead-laden dust from the boat repair yards, for instance by providing a suitably enclosed filter-ventilated room for mingling lead oxide powder with caulking fibre, and reducing the conveyance to the home of lead-contaminated material on the clothes, bodies and equipment of boat-caulkers, such as by installing facilities for workers to shower and change their clothes before leaving work to go home.

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