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Skin Lead Contamination of Family Members of Boat-caulkers in Southern Thailand

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Abstract: Powdered lead oxide (Pb_3O_4) is used in the wooden-boat repair industry as a constituent of the caulking material. This study compared skin lead of household members of caulkers' and control homes, and examined the relationship of household member's skin lead with household floor lead loading (FLL) and dust lead content (DLC). FLL and DLC were measured in 67 caulkers' houses and 46 nearby houses with no known lead exposure. In each household, wipe specimens of skin lead were obtained from one selected family member. Hand lead loading (HdLL) and foot lead loading (FtLL) were significantly higher in family members of caulkers than controls (geometric mean 64.4 vs. 36.2 μg m^{-2}; p=0.002 and 77.8 vs 43.8 μg m^{-2}; p=0.002, respectively). This pattern mirrored FLL and DLC, which were also higher in caulkers' than in control houses (geometric mean 109.9 vs. 40.1 μg m^{-2}; p<0.001 and 434.8 vs 80.8 μg g^{-1}; p<0.001, respectively). Multiple linear regression modelling revealed FLL to be a better predictor than DLC for HdLL in all age groups and for FtLL in adult family members. In conclusion, skin lead levels are elevated in family members living in a lead-exposed worker's house and are related to the levels of household lead contamination.

Key words: Boatyard, Caulker, Family member, Skin lead loading, Dust lead content, Floor lead loading

Introduction

An earlier study of children living in communities adjacent to boat-repair yards in southern Thailand revealed considerably elevated blood lead levels especially in those children living closer to a boatyard. In these communities 82% of children had blood lead level of 10 μg/dl or more and 5% of 20 μg/dl or more[1]. Since that time, the wooden-boat repair industry has come to be recognized as a major source of lead contamination in areas surrounding boat-repair yards in several coastal regions of the country[2, 3]. Red lead or plumboplumbic oxide (Pb_3O_4) is used as a component of the mixture used for caulking wooden boat hulls. Caulking is done manually and caulkers use their bare hands in the process of mixing and inserting the caulking and thus have direct skin exposure to lead during their work. A previous study has reported that 67% of caulkers had a blood lead level exceeding 40 μg/dl[4]. Lead used in the boatyard is responsible for the release of lead dust into the environment; therefore, it can pose a health hazard to people living nearby[2]. Hygiene facilities in the boatyard are poor and measures to prevent caulker contamination are lacking with consequent potential for caulkers to inadvertently take home lead on their skin, clothing and vehicles. Lack of personal hygiene practices may be an important pitfall since almost 100% of caulkers reported never taking a shower or changing work-clothes before leaving work[4].

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Lead content in accumulated dust as well as floor lead loadings (mass of lead in dust per unit surface area) has been reported to be higher in the homes of caulkers than in households where no members worked in a boatyard, after controlling for distance from a boatyard[2, 3].

However, whether or not these elevated levels of household dust lead are accompanied by increased lead contamination of family members living in the same households has not been conclusively shown. The aim of this study, therefore, was to compare the skin lead loadings of family members in caulker and control households and to identify the relationship between skin lead contamination of family members and household surface lead contamination. In addition, whether floor lead loadings or accumulated dust lead content could better predict skin surface lead contamination among family members was explored.

Subjects and Methods

Ethical approval

This study was approved by the Ethics Review Committee of the Faculty of Medicine, Prince of Songkla University, Hatyai, Thailand. Before conducting the study, the head of each potential study village was approached with an explanation of the project and asked for permission to conduct the study in their locality. After identification of potential households, a careful description of the study was given to participants, who were then asked to give formal signed consent to participation before any interviews or specimen collections took place. All families received a written report with analysis results. When the levels of household lead were higher than acceptable levels according to the US Environmental Protection Agency and Department of Housing and Urban Development standards[5, 6], members of caulkers' households were advised to take measures to reduce ingress of lead-laden dust on caulkers' clothes and equipment. In addition, those of households situated close to a boatyard recommended closing windows facing the direction of the boatyard whenever possible, and those of all households were advised to wash hands and feet and wet-mop the floor regularly.

Study sites

The data collection took place during February–April 2007 in Songkhla province and Nakhon Sri Thammarat province, on the east coast of peninsular Thailand. Two and 10 boatyards respectively were situated in the study areas of these two provinces. Each boat-repair yard was located adjacent to a residential community.

Study design

Cross-sectional baseline data from a larger follow up study was used in this analysis. This larger study matched households by the distance from the nearest boatyard into sets of caulker and non-boatyard worker homes in the ratio of 2:1 wherever possible and 1:1 otherwise.

Study population

Identification of caulkers and their households

Eligibility criteria for caulkers were: 1) having worked as a caulker for an average of at least 10 d/month in the previous year, and 2) having lived in the current house during that period, and 3) having at least one family member resident in the same house, and 4) having no other household member working in a boatyard or having any occupational or recreational exposure to lead. Where possible, caulkers' households were pair-matched on location by selecting pairs of homes that were separated by a distance of not more than 200 m.

Identification of control households

The nearest household to each caulker household set in which no resident worked in a boatyard or had any occupational or recreational exposure to lead and was located within 200 m of the set of caulker households was asked to participate in the study and, if agreeable, was selected into the control non-boatyard worker (NB) group.

Using this selection strategy, 67 caulker homes were recruited among which 21 pairs were identified, whereas the remaining 25 could not be matched into pairs. For each of these pairs or individual caulker households a non-boatyard worker home could be identified, resulting finally in 46 sets, 21 having the ratio of 2:1 and 25 having a ratio of 1:1.

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

In each selected household of both groups the housewife was selected, whenever possible, for collection of skin lead specimens. Where the housewife was not available, another adult or the oldest child was chosen.

Sample size

The size of this sample was estimated to be sufficient to identify a difference in hand or foot lead loading among two groups with an effect size of at least 0.5 of a standard deviation of the lead contamination parameter, with a power of 80%.

Data and specimen collection

During a home visit for specimen collection, a questionnaire-based interview was conducted with the caulker and selected family member in the caulker households, or with the selected household member in the non-boatyard worker households. The questionnaire covered age, sex occupation, smoking behaviour, and time that the family member last showered. The condition of each home was then surveyed and details recorded on an observation checklist. All specimens were collected and observations made in the afternoon or evening during the households' regular activities. No instructions were given to the household members prior to the home visit to reduce the probability of prevent any change in their regular activities before specimen collection.

Household floor lead loading (FLL) specimen collection

Interior floor surface dust was collected for determination of floor lead loading (FLL, the mass of lead per unit surface area), from two locations in each household – one close to the main entrance to the house and the second from the area where household members undertook their main activities. A standard wipe sampling method was used[7]. At each location, a rectangular template measuring 20×30 cm (600 cm^2) was marked out using masking tape. Wearing a new pair of powder-free disposable gloves to avoid cross contamination of lead dust from other areas, a 15×15 cm clean towelette (Ghost Wipe: Environmental Express, South Carolina, US.) was removed from its packing, immediately unfolded, and pressed onto the sampling area. The entire surface was wiped with single strokes in a left-to-right direction, and the towelette then folded with the collected dust inside. The surface was then wiped again with single strokes in a direction perpendicular to the first wiping until all visible mass was removed. After further folding to retain the additional dust collected in the second wiping, the towelette was transferred to a lead-free plastic container. Another clean towelette was used to wipe the second area in the same manner. Two wipes were placed in the same plastic container and treated as one composite specimen representing a total area of 1,200 cm^2. In each house one field blank was taken before wiping by removing a towelette from its packaging, unfolding, refolding and transferring to a lead-free plastic container.

Dust lead content (DLC) specimen collection

Dust specimens from each household were obtained for dust lead content (DLC, the mass of lead per mass of dust). The method followed that described by Maharachpong[2]. Specimens of accumulated dust were collected from little-disturbed places, such as the tops of doors/window sills, 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 the problems which might occur due to spatial variation in the distribution of dust and its lead content.

Hand and foot lead specimen collection

Hand-wipe specimens were obtained from family members to assess lead contamination on the skin as mass per two hands. Adult participants were instructed to remove the wipe from the packet of pre-moistened towelettes and unfold it. The subject then thoroughly wiped both hands for 30 s on the palms, the back of the hands and each finger using normal hand washing pressure[8]. After taking the hand-wipe specimen, subjects were asked to obtain a foot-wipe specimen following a method analogous to hand-wipe specimen collection. The hand-wipe and foot-wipe specimens of children aged less than 7 yr were collected by the sampling technician. The technician wore a new pair of powder-free disposable gloves, wiped children's hands, then changed the gloves before collecting foot-wipe specimens following the same NIOSH method[8]. Hand- and foot-wipe specimens were placed in separate lead-free plastic containers.

Lead Determination

For determination of surface lead loading, wipes were initially digested with concentrated nitric acid and hydrogen peroxide and the digestate further processed according to the NIOSH method 7082/1994[9]. For determination of dust lead content, an amount of dust between 0.5 and 1 g was weighed to the nearest microgram and similarly digested and processed for lead determination according to EPA method 3050 B 1996[10]. Lead determinations were made using flame atomic absorption spectrophotometry (Model: Varian Spectra 640). After construction of a standard curve, the concentration of lead in 4 aliquots of each specimen solution was measured and the relative standard deviation of the 4 determinations calculated. A lead content standard was injected after every 20 specimens in order to detect any deviation in the calibration. Analyses were carried out at the Reference Laboratory and Toxicology Centre, Bureau of Occupational and Environmental Diseases, Ministry of Public Health, Thailand. This laboratory has participated in the proficiency testing schemes three times each year under the Workplace Analysis Scheme for Proficiency (WASP) of Health and Safety Laboratory, UK. The limit of detection of the NIOSH and the EPA methods in this laboratory for the concentration of lead in the specimen solution was 0.015 ppm, which translates to 0.15 μg per wipe specimen used in the analysis and for between 0.15 and 0.30 μg g^{-1} dust lead content depending on the weight of dust used for analysis. Blanks were used for quality control of specimen digestion, undergoing 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.

Expression of Floor and Skin Lead Loading and Dust Lead Content

Using appropriate conversion, household floor dust lead loading was expressed in units of micrograms per square metre, household dust lead content in terms of micrograms per gram, and hand and foot lead in units of micrograms per estimated square metre of skin surface.

To adjust for sex and age differences, hand lead levels (μg/2 hands) and foot lead levels (μg/2 feet) were converted to hand lead loading (HdLL; μg m^{-2}) and foot lead loading (FtLL; μg m^{-2}), respectively. However, as surface area values for hands and feet of Thai or Asian subjects were not available, the surface area used in this study was that based on Caucasian subjects studied in US[11]. While there may be some sytematic discrepancies between the values for Caucasian and Asian subjects, the variation with age and sex are likely to be similar, so that relative levels of contamination are unlikely to have substantial error. Surface areas of hands and feet of in adults (>17 yr) was taken to be 0.099 m^2 and 0.131 m^2 for male and 0.082 m^2 and 0.114 m^2 for female[11]. For family members aged ≤ 17 yr, the surface areas of hands and feet were individually calculated depending on age and sex using mean percentage of the median surface area of the whole body represented by the hands and the feet[11].

For example:

Percentage of hands surface area in children aged 9–10 yr = 5.30

Median of total body surface area of male children aged 9–10 yr = 1.07 m^2

Hands surface area of this subject = $5.30 \times 1.07/100 = 0.0567$ m^2

If hand lead level of this subject = 3.6 μg/2 hands

Hand lead loading = 3.6/0.0567 = 63.49 μg/m^2

Statistical methods

Comparison of family member characteristics between caulker and NB worker groups was done using χ^2 test or Fisher exact test for categorical variables. For analysis of lead contamination parameters, logarithmic transformation was performed in order to render their distributions approximately normal, and summarized using geometric mean and geometric standard deviation. Comparisons of these logarithm-transformed parameters between groups were made using Student *t*-test. Pearson correlation was used to explore the correlations between the logarithm-transformed household dust lead parameters and skin lead loading of family members. Non-overlapping correlations were compared using the method given in Zar[12]. The R package, CompOverlapCorr, was used to compare correlations between overlapping pairs of variables (HdLL vs. FLL and DLC, FtLL vs. DLC and FLL)[13].

Multivariate modeling was also performed on the logarithm-transformed parameters to satisfy the assumption of normality of residuals. Base-2 logarithm was used in the transformation for ease in subsequent interpretation —a unit increase in the transformed value thus represented a doubling of the untransformed value of the lead parameter. Missing values of continuous independent variables included in the models were adjusted for using the mean adjustment method[14].

To take account of the possible correlation among households within the same set, mixed random-intercept models were initially constructed in which the matched set was the random component. However, when the intercept variance did not differ by more than chance levels, the model was simplified by omitting the random component[15] and an ordinary generalized linear model used instead.

Initial multivariate models were constructed to account as fully as possible for variation in HdLL and FtLL on the basis of household floor lead loading, dust lead content, age and sex of family members, group of study (caulker's family or NB workers' family), smoking habit, occupation, and interval between last showering and skin-lead specimen collection of family members. Models were refined by a backward elimination process guided by the change in log likelihood of successive models while age and sex of family member were retained in the model irrespective of their statistical significance. Final significance level was set at 0.05. Individual regressors' contributions to the models were quantified using partial R^2 as implemented in the R package, relaimpo[16]. R software, version 2.6.0, was used for data analysis.

Results

The eligible participants included one family member from each of 67 caulker households and 46 non-boatyard worker homes. Demographic characteristics of these family members are displayed in Table 1. The caulker group included a larger proportion of children and students and the non-boatyard worker group more smokers. Sex and interval between last showering and skin lead specimen collection were resonably well balanced across the groups.

Skin and household lead specimens from one caulker household were damaged, as were the hand lead specimens from another 2 caulker and 2 non-boatyard-worker households. In addition, adequate dust specimens could not be obtained from 6 caulker households. Lead determinations and statistical analysis was finally performed on 60 dust lead, 64 hand lead and 66 each of other specimen types from caulker households and on 44 hand lead and 46 each of other specimen types from non-boatyard worker households.

The correlation coefficient for analytical standard curves exceeded 0.999 in all analytical batches. The within-specimen relative standard deviation of all determinations ranged from 0.3% to 13.5%. All field blanks were found to have lead content below the detection limit. Household floor lead loading, dust lead content, and hand and foot lead loading of family members were all significantly higher among the caulker group than among the NB group (Table 2).

Taking all households together, there was a moderate correlation between logarithm-transformed contamina-

Table 1. Characteristics of enrolled family members

Characteristic	Family members of caulkers (N=67) No (%)	Family members of non-boatyard workers (N=46) No (%)	p-value
Age (yr)			<0.001[a]
< 7	8 (11.9)	1 (2.2)	
7–15	14 (20.9)	1 (2.2)	
16–59	39 (58.2)	28 (60.9)	
≥ 60	6 (9.0)	16 (34.8)	
Median (IQR)	38.0 (13.0, 50.5)	50.5 (41.0, 65.0)	<0.001[b]
Sex			0.216[a]
Female	52 (77.6)	30 (65.2)	
Male	15 (22.4)	16 (34.8)	
Occupation			0.009[a]
Preschool	8 (11.9)	1 (2.2)	
Student	16 (23.9)	3 (6.5)	
Vendor or labourer	16 (23.9)	19 (41.3)	
Housewife	27 (40.3)	23 (50.0)	
Smoking	1 (1.5)	10 (21.7)	<0.001[c]
Interval between showering and skin lead collection (hours)			0.133[a]
< 5	22 (32.8)	12 (26.1)	
5–13	34 (50.8)	19 (41.3)	
14–22	11 (16.4)	15 (32.6)	

IQR – Interquartile range, [a]χ^2 test, [b]Wilcoxon rank sum test, [c]Fisher's exact test.

Table 2. Household and skin lead contamination among family members of caulker and non-boatyard workers

Lead contamination parameter	Family members of caulkers		Family members of non-boatyard workers		p-value[a]
	GM	GSD	GM	GSD	
Household floor lead loading (μg m^{-2})	109.9	3.21	40.1	2.73	<0.001
Household dust lead content (μg g^{-1})	434.8	3.20	80.8	4.67	<0.001
Hand lead loading (μg m^{-2})	64.4	2.58	36.2	2.43	0.002
Foot lead loading (μg m^{-2})	77.8	2.61	43.8	2.48	0.002

GM Geometric mean; GSD Geometric standard deviation.
[a]p-value from t-test.

Table 3. Correlation matrix of household and family-member skin-lead contamination parameters (after logarithmic transformation) with comparisons of the correlation coefficients

Contamination parameter	Pearson correlation coefficient					
	Log_2 (Hand lead loading)			Log_2 (Foot lead loading)		
	Family members of caulkers	Family members of non-boatyard workers	p-value[a]	Family members of caulkers	Family members of non-boatyard workers	p-value[a]
Log_2 (Floor lead loading)	0.149	0.372*	0.274	0.215	0.499**	<0.001
Log_2 (Dust lead content)	0.023	0.076	0.797	0.292*	0.355*	0.750
p-value[b]	0.398	0.110	–	0.592	0.386	–

**p-value < 0.001, *0.01 ≤ p-value < 0.05.
[a] = p-value of comparing independent correlation coefficients.
[b] = p-value of comparing overlapping correlation coefficients between household lead parameters using Z-test.

Table 4. Independent risk factors for hand lead loadings of family members identified by multiple linear regression modeling. The dependent variable of the model is $\log_2$ (hand lead loading in units of $\mu g\ m^{-2}$)

Factor	Coefficient	MF	(95%CI)	p-value	R^2 contribution (total R^2=0.265)
$\log_2$ (floor lead loading)	0.24	1.18	(1.06–1.32)	0.004	0.088
$\log_2$ (lead content)	0.10	1.07	(0.98–1.18)	0.146	0.040
Sex of family members				0.024	0.051
Female (reference)	0	1			
Male	0.72	1.65	(1.08–2.53)		
Age of family members (yr)				0.023	0.086
< 7	0.99[ab]	1.99	(0.95–4.14)		
7–15	1.09[b]	2.13	(1.22–3.71)		
16–59 (reference)	0[a]	1			
≥ 60	0.09[ab]	1.06	(0.65–1.73)		

95%CI=95% Confidence Interval.
The coefficients (β) have been transformed (2^{β}) and expressed as multiplication factors (MF) for the untransformed hand lead loading.
[a, b]Coefficients within each variable not having a superscript in common differ significantly (p<0.05).

tion parameters of FLL and DLC (Pearson correlation, r=0.42, p<0.001). Overall, foot lead loading was rather more strongly correlated with floor lead loading and dust lead content (r=0.40, p<0.001 and r=0.43, p<0.001 respectively) than was hand lead loading (r=0.32, p<0.001 and r=0.22, p=0.03, respectively (data not shown). However, within each group of subjects the correlations were mostly rather weaker. Foot lead loading was moderately correlated with both household lead parameters in the NB group (r=0.355 to 0.499) and but less strongly in the caulker group (r=0.215 to 0.292). Hand lead loading was moderately correlated only with FLL in the NB group (r=0.372). The correlation of foot lead loading with FLL was significantly stronger among the non-boatyard workers than among the caulkers (p<0.001).

Multivariate models including all family members having outcome data and adjusting for other variables confirmed the association of hand lead with FLL, increasing some 18 percent for a doubling of FLL, with no evidence of difference in this relationship among the age groups. However, hand lead loading was also 65 percent higher in males than in females and about 2 times higher in children aged less than 16 than in older family members (Table 4).

The relationships of foot lead loading with household lead levels, however, were more complex, as the relationship with FLL differed across the age groups. In the model shown in Table 5, the values for log2 of floor lead loading have been centred on the gemometric mean of FLL. Only among adults, and especially among the elderly, was the foot lead loading clearly associated with floor lead loading, with a doubling of FLL being accompanied by a 71 percent increase in foot lead loading in subjects aged 60 and above. There was no evidence of any sex difference in foot lead loading.

Discussion

Crude analysis of the data in the study has shown that family members in boat-caulker households have higher hand and foot lead levels than family members

Table 5. Independent risk factors for foot lead loadings of family members identified by multiple linear regression modeling (significant interaction term between floor lead loading and age). The dependent variable of the model is $\log_2$ (foot lead loading in units of μg m^{-2})

Factor	Coefficient	MF	(95%CI)	p-value	R^2 contribution (total R^2=0.330)
Log_2 (floor lead loading) in family members of age (yr)				<0.001	0.196
< 7	–0.15^a	0.90	(0.65–1.25)		
7–15	0.07^a	1.05	(0.80–1.38)		
16–59	0.17^a	1.13	(1.00–1.28)		
≥ 60	0.77^b	1.71	(1.35–2.17)		
Log_2 (lead content)	0.19	1.14	(1.05–1.24)	0.002	0.107
Sex of family members				0.527	0.002
Female (reference)	0	1			
Male	–0.17	0.89	(0.60–1.31)		
Age of family members (yr) at GM of FLL				0.356	0.025
< 7	0.74	1.66	(0.85–3.27)		
7–15	0.36	1.29	(0.77–2.16)		
16–59 (reference)	0	1			
≥ 60	0.33	1.26	(0.78–2.01)		

95% CI=95% confidence interval.
The coefficients (β) have been transformed (2^β) and expressed as multiplication factors (MF) for the untransformed foot lead loading.
a, bCoefficient within each variable not having a superscript in common differ significantly (p<0.05).
The values for $\log_2$ of floor lead loading have been centred on the mean of $\log_2$ (FLL).

in other households. This situation differs from that reported in construction workers in the US, among whom workers' hand lead loadings were higher than those of control workers (GM=150 μg/m^2 compared with 22 μg/m^2), but whose family members' hand lead loadings did not differ, despite household surface lead concentrations in the rooms where work clothes were changed being significantly higher in the construction workers' homes than in control homes[17]. In the current study of boat-caulkers, household floor lead loadings and dust lead content also differed markedly between caulker and control households. The elevated levels of household lead contamination of caulkers' homes may be a result of take home lead on the caulkers' bodies and clothes. It had been reported that almost none of the caulkers changed their clothes before going home, 60 percent did not shower until at least half an hour after returning home and about 70 percent took their hand tools back home after work[4].

Somewhat surprisingly, foot lead loading and, to a lesser extent, hand lead loading of family members was more strongly correlated with floor lead loading in homes of non-boatyard workers than in those of caulkers. However, the levels of skin lead loading in family members in caulkers' homes were also considerably higher than those in non-boatyard workers' homes. A possible explanation for this counter-intuitive pattern of correlation is that skin lead loading in members of non-boatyard workers' homes was limited principally by the magnitude of household surface lead contamination, whereas that in members of caulkers' homes was limited rather by the maximum amount of lead or lead-laden dust that could be retained on the skin surface, given that excess dust lead (not intimately adhering to the skin or retained within furrows of the skin) is likely to be rubbed off during normal household activities.

That hand and foot lead loadings were related to floor lead loading in this setting after adjustment for confounding variables is possibly related to the high degree of contact between family members and the floor. Although it is the Thai custom to remove shoes before entering the home, and thereby avoid lead-containing dirt on the shoes being transferred from the workplace to the home floor, nevertheless much of the home activity is conducted on the floor – whether it be eating, relaxing or watching television. In many households, family members also sleep close to the floor, on a mat or thin mattress placed on the floor. Floor dust is, therefore, readily picked up on the hand and feet, especially the latter as shoes are not worn in the home. The physical nature of the lead oxide used by boat-caulkers also facilitates its ready adherence to the skin surface. Approximately 98 percent of the volume of the lead oxide powder comprises fine particles between 2 and 76.4 μm[2].

Hand lead loading was shown to be higher in children than in adults. This might be a result of closer contact with the floor or other dusty surface in the home and/or to a lower frequency of washing. Hand lead loading was also higher in males than in females, possibly reflecting a lower fequency of hand washing among males. It is surprising, however, that it was the elderly whose foot lead was most strongly associated with floor lead, whereas children's foot lead was largely independent of floor lead levels. Perhaps the elderly spend more time in the home and therefore have a more intimate exposure to floor lead.

Several studies have been reported showing that the blood lead levels of children of lead-exposed workers are higher than the levels in control children. These include such settings and construction workers[18] and electric-cable factory workers in the United States[19], and lead-zinc-copper mine workers[20] and lead factory workers in Australia[21]. Furthermore, a close relationship between household dust lead and children's blood lead content had been reported in many studies[20, 22–28]. Although our study did not measure blood lead levels, other studies in children and in adults have provided evidence that hand lead loadings are correlated with blood lead levels[29, 30]. Hand lead loading and blood lead levels were obtained from 10 infants aged 2 months born into the lead contaminated environment of Porte Pirie, South Australia. The blood lead levels of infants were well correlated with hand lead loadings (r^2=0.72; p<0.01)[29]. A re-analysis of 11 studies using structural equation modeling to compare lead exposure pathways, reported that interior dust lead and hand-wipe lead were the most important predictors of blood lead in children aged less than three years[26].

With regard to the relative ability of floor lead loading and dust lead content to predict hand and foot lead loading of family members, the results suggest FLL more closely predicts both hand lead loading and foot lead loading. Previous studies of relative predicative ability of various household lead parameters have mostly considered blood lead levels of children. Two studies compared FLL and DLC and found FLL to have better predictive ability[23, 31]. Similarly, in a side-by-side comparison of three dust sampling methods, dust lead loading was found to be a better predictor of children's blood lead levels[32].

Only one study from the United States[33] assessed the differences of the ability of the two dust lead loading methods – the Baltimore Repair and Maintenance (BRM) vacuum method and the wipe lead loading method – to predict blood lead concentration. A log linear model to explain blood lead concentraiton was contructed including both BRM method values and wipe method values of dust lead as independent variables for each surface, including carpeted floors, uncarpeted floors, window sills and window wells. For carpeted and uncarpeted floors, BRM lead loading explained variablility in blood lead concentration above that explained by wipe lead loading. Wipe lead loading, by contrast, explained significant variablility after adjustment for BRM lead loading for uncarpeted floors and window sills. However, including all four surfaces failed to reveal an overall superiority of either dust lead measurement method in predicting blood lead concentration.

Our measurements were made in the setting of the study subjects' regular activities in their home in the afternoon or evening, and subjects' behaviour was intentionally left uncontrolled, so that the lead contamination measurements should well represent the usual levels in these households. The caulker and control groups were matched with respect to distance from the major source of environmental lead contamination, so that geographical bias was largely avoided. However, the study was conducted within a relatively short period, February to April, which coincides with one of the two active boat repairing seasons (highest in April and October). Thus, the absolute levels of lead contamination reported here may be higher than at some other times of the year. An additional limitation may have been introduced by the imbalance in the ages of subjects between the two groups. However, including age group in the multivariate models should have minimized the bias that may otherwise have arisen from this imbalance. It is also to be noted that additional, unmeasured factors are likely to have influenced the levels of hand and foot lead contamination in our study as the R^2 values in both multivariate models, 0.265 and 0.330, were relatively low.

In conclusion, the elevated household lead levels in boat-caulkers' compared with control homes is accompanied by elevated hand and foot lead loading levels in the family members. Foot lead loadings were moderately correlated with floor lead loadings and dust lead content in non-boatyard worker houses but were higher and less well correlated in caulkers' homes. Similarly, hand lead loadings were moderately correlated with floor lead loading only in non-boatyard workers' homes. In all age groups hand lead loading was weakly predicted by FLL, whereas foot lead loading was predicted by FLL only among adults, more strongly in the elderly. As skin lead contamination is likely to result in unintentional ingestion of lead, these findings suggest that this potential health risk to family members, especially serious in children, could be lessened by effective reduction in the levels of household lead contamination. This is of particular significance in the homes of boat-caulkers, who should receive training and encouragement to reduce those behaviours that result in transfer of lead oxide from the workplace to the home.

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