Evaluation of an Intervention to Reduce Childhood Lead Exposure in a Vietnamese Battery Recycling Village

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Abstract

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Battery recycling and manufacturing are major sources of occupational exposure to lead. Residents of Dong Mai village in northern Vietnam have been involved in battery recycling since the 1970s. To address pervasive lead contamination a remediation plan was developed by Blacksmith Institute in collaboration with Vietnamese national and local authorities. This is an ongoing study with the primary aim of determining changes in child lead exposures after lead remediation activities and a secondary aim of identifying risk factors for childhood lead exposure.

All children in the village 6 years of age and younger were eligible and invited to participate in the study. A total of 231 children participated in baseline measurements in December 2013; 203 (88%) of the 231 children participated in follow-up assessment in September 2014. Written informed consent was collected

from parents/guardians of participants. Parents or guardians of participants also responded to interviewer-administered household survey on involvement in recycling activities, use of personal protective equipment, and personal hygiene of household members including children. For data analysis BLL was categorized based on U.S. CDC recommendations for treatment (≥45 μg/dL). BLL was categorized as ≥45, 30-44.9, and <30 μg/dL. Bivariate analysis was conducted between categorized BLL and covariates using chi-square, Fisher exact tests, or one-way ANOVA.

At baseline, all children tested with Lead Care II had elevated BLLs : 24% had BLL >65 μg/dL; other values had mean 35.2 μg/dl (sd 11.5), with lowest value, 6.9 μg/dL. Current recycling at home, involvement of household members in recycling, duration of home-based recycling activities, and proximity to a recycling operation were all significantly associated with very high BLLs. Time spent by child in outdoor environment was also significantly associated with very high BLLs. At the follow-up assessment BLLs displayed a downward trend: >65 (5% follow-up versus 24% baseline), 45-65 (11% versus 17%), 20-44 (56% vs 53%), and 10-19 (26 % vs 6%).

Follow-up BLLs, though still high, point towards favorable impact of lead remediation activities in Dong Mai village. However, this study evaluates remediation activities in only one village. We do not have a control group for external comparison, but we consider this unlikely to be a secular trend.

BACKGROUND AND SIGNIFICANCE

According to the World Health Organization (WHO), lead poisoning accounts for 0.6% of the global burden of disease (WHO 2010a). Lead occurs naturally in earth's crust, most commonly in the form of lead sulfide (IPCS 1995). Human exposure to lead is mainly a result of anthropogenic activities. Once introduced in the environment, lead persists for a long time, making it a major public health risk. Owing to its abundance, low cost, and physical properties such as corrosion resistance, waterproof nature and malleability, it is has a wide range of uses like paint, lead petrol, plumbing materials, and lead-acid batteries.

Global demand of lead has been on a steady rise primarily driven by the lead-acid battery industry (ILA 2013). Unfortunately, exposure from lead-acid battery recycling also puts an estimated one million people worldwide at risk of lead toxicity (Blacksmith Institute 2012). Workplace reforms and technological advances in developed nations have lead to decline of lead exposure and environmental lead levels; however, it remains a growing problem in developing countries.

Recycling of used lead acid batteries (ULAB) is a profitable business and contributes to 50% of global lead production (Thornton 2001). Demand for lead batteries is bound to increase disproportionately in developing countries because of its multiple uses especially in backup power sources for solar installations and primary power source for cell phone towers. The growing market of computers in the developing world combined with frequent power cuts further necessitates the use of lead batteries for power back up. Shortened life of recycled batteries due to poor quality control and tropical climate also add to this demand. (Gottesfeld & Pokhrel 2011). One review of studies in 37 developing countries found that exposure of workers in battery recycling facilities is much higher than for workers in developed countries. A plausible reason for the higher exposure is the lack of large-scale used battery collecting programs, which would provide the economic incentive for initial investment in construction of relatively expensive environmentally sound recycling facilities.

Most of the ULAB recycling in developing countries is done in informal settings and in low-income homes with no pollution control because of either ignorance of health risks and/or lack of economically viable alternatives (Blacksmith Institute 2012). Lead is extracted manually by breaking the batteries with an axe or hammer, and melting the lead within homes sometimes in kitchens, thus intimately and heavily contaminating the household environment. Various pathways of exposure arise from informal recycling processes including but not limited to:

1) Dumping battery acid containing lead particles into soil or water.

2) Lead ash from melting plates can collect on clothing, skin, and soil.

3) Hand-to-mouth activities of children playing/living near a recycling site.

4) Lead containing soil can be airborne and inhaled.

Biological fate of lead

Upon uptake lead is sequestered into three different compartments in the body – blood, bone, and soft tissue (Barry 1975). Nearly all (99%) of blood lead content is stored in red blood cells. Half-life of blood lead in adults with acute or short-term exposure ranges from 28 to 36 days. In cases of chronic occupational exposure in adults, 95% of total lead body burden is stored in bones and teeth with very slow elimination with half-life of 25-30 years. Thus, lead in bone is a biomarker for cumulative lead exposure over an adult's life. However, certain conditions like injury, pregnancy, and advancing age can induce lead release back into the blood stream (ASTDR 2007). Lead metabolism differs substantially with age. Children absorb up to 70% of an ingested dose and retain as much as one third of the absorbed dose. In contrast, adults absorb 10% and retain only 1% of their ingested dose (Barry 1975). Inhalation can also be an important route of uptake. In general, lead is not absorbed across skin unless it is an organic form of lead; however, skin contamination and hand to mouth behavior can be an important pathway leading to ingestion.

Lead exposure and children's health

Children are especially susceptible to environmental exposures because of their higher metabolism relative to body weight, ongoing neurological development, dust and soil intake through extreme hand-to-mouth activities, poor hygiene status, and lack of control over their environment (WHO 2010b). Poor nutritional status of children in developing countries can also lead to higher lead uptake through increased absorption from the gastrointestinal tract (Mahaffey 1995). The frequency and severity of health effects in children, and the major target organs differ with the level of lead exposure, but there is evidence of adverse health effects at the lowest levels studied (Bellinger 2008). Lead exposure is most often measured in blood lead levels (BLLs) expressed in μg/dL, although other tests have been used commonly in the past, e.g., urine lead, blood "ZPP" (zinc protoporphyrin). The current reference level, for childhood lead exposure at which CDC recommends initiation of public health action, has been set at BLL of 5 μg/dL (CDC 2012). This level represents BLLs of U.S. children aged 1-5 years in the highest 2.5% category. It is estimated that for preschoolers with blood lead levels between 10-20μg/dL, each

1μg/dL rise in BLL is associated with a lower IQ of up to 1 point (WHO 2010b). Lead exposure is also associated with behavioral changes, lower test scores, absenteeism, and hyperactivity. The negative association between IQ and BLL combined with adverse behavioral changes can have noteworthy implications at a population level. Lead's neurotoxicity is based on its ability to mimic bivalent ions like calcium and zinc and interfering with normal cell signaling and subsequent neurodevelopment by competitively attaching to protein binding sites with a higher affinity than the polyvalent ions it mimics (Godwin 2011).

A review of 37 studies of lead exposure of children living near battery recycling facilities in developing countries reported 13-fold higher mean BLLs in developing countries compared to those of children in the U.S. (Gottesfeld and Pokhrel 2011). The potential for severe lead intoxication at informal ULAB recycling facilities was recently reported in a study from Dakar, Senegal (Haefliger 2009). BLLs of tested children ranged from 39.8 μg/dL to 613.9 μg/dL at the site where death of 18 children was connected to lead contamination. Soils and homes were also heavily contaminated affecting about 950 households.

Lead recycling in Vietnam

Lead recycling is one of many important economic activities that are carried out at a village level in Vietnam. A government initiative for market-oriented economic reforms in 1986 led to the creation of "craft villages" (Dang 2010). A craft village is one in which more than 30% of households engage in "off-farm" activities. Today, Vietnam has 1450 craft villages that engage in industries like textiles, construction materials, plastics, and recycling metals including lead. While these activities have resulted in rapid economic growth, the progress has come at the cost of largely unchecked environmental degradation (Korea-World Bank 2014). Residents of these villages often suffer from poor health status while living in continuously polluted environments. The village of Dong Mai in Hung Yen province of Northern Vietnam is one such example of a lead recycling craft village involved in battery recycling since 1978 (Tung 2011). Of the 2300 village residents, 500 villagers are involved in battery recycling activities in some capacity.

PRELIMINARY STUDIES

A 2006 cross-sectional study by the National Institute of Occupational and Environmental Health (NIOEH) of Vietnam found elevated levels of lead in environmental samples (air, soil, surface water, wastewater) and >80 µg/dL urine lead levels in 28% of school children (Tung 2011). These findings prompted attempts to discourage home-based lead recycling and move ULAB recycling activity to a new communal recycling facility outside the village. As a result, recycling activities within the village declined. However, according to a recent study by NIOEH and UW researchers, household lead activity still persists and so does lead exposure of children (Wallace 2012). The 2012 study reported 44% of 109 tested children had BLLs ≥ 45µg/dL. This is the BLL threshold that, in the U.S., would trigger consideration of medical (chelation) therapy, assuming that the lead exposure could be eliminated or controlled (CDC 2002).

In response to the persistent lead contamination reported by UW and NIOEH researchers, a lead remediation plan was developed by Blacksmith Institute in collaboration with local authorities, a Vietnamese non-government organization (Center for Environment and Community Development, CECoD), and the Vietnam

Environment Administration (VEA). The Vietnam NIOEH and UW served as advisors for the remediation and have evaluated child BLLs before and after the remediation. The key components of this remediation included:

1) Community engagement, education and training
2) Constructing changing facilities at lead recycling centers.
3) Clean up or capping of contaminated sites including waste sites, soils, roads, and heavily contaminated households.

SPECIFIC AIMS

The overall aim of this study was to determine whether child lead exposures decrease after lead remediation activities in the battery recycling village of Dong Mai, Vietnam. Most of the initial remediation efforts were conducted between December 2013 and March 2014, and other efforts were conducted intermittently thereafter. We measured child lead exposure in form of blood lead levels (BLLs) of children under the age six years. Our team had already collected baseline BLLs data and household-level survey on lead-based activities in December 2013 and this data was available to me for analysis and comparison. The first follow-up evaluation was conducted in September 2014. My hypothesis was that the lead remediation will lead to lowered childhood exposure, which will be reflected in form of lower follow-up BLLs when compared to baseline values.

Specific Aim 1: Conduct a preliminary analysis of Baseline BLLs with data from a household survey questionnaire.

Specific Aim 2: Conduct follow-up measurements of blood lead levels of young children (under age six) in Dong Mai village.

Specific Aim 3: Compare baseline and post-remediation child BLLs in order to assess the effect of lead mitigation activities on child lead exposure in Dong Mai village.

METHODS

This study was conducted in continuing collaboration with Vietnam NIOEH. Study protocols were reviewed and approved by University of Washington's Institutional Review Board (IRB) and by NIOEH. This report describes the second phase of the project for evaluating the effectiveness of lead mitigation activities in the village of Dong Mai conducted by Blacksmith Institute. The first phase of this study (December 2013) involved collecting baseline level data on child BLL measurements, home-based lead activities, and household observations "before" (actually concurrent with) the start of the remediation. In the second phase (September 2014), follow-up BLL measurements were performed and were compared with the baseline to evaluate the effect of lead remediation activities on child lead exposure.

The study population constitutes all households in Dong Mai village with children less than six years of age at the time of baseline measurements. No potentially eligible children were excluded. These households were recruited at the time of baseline evaluation. The recruitment team consisted of NIOEH researchers and provincial and community health workers who visited each household to invite participation. Families were offered monetary incentive of $10 per child for participation. A parent or guardian provided consent, and participating children provided assent. At each participating household, a parent or guardian responded to an interviewer-administered questionnaire about current or past home-based lead recycling activities, household members involved in lead recycling, use of personal protective equipment, personal hygiene, and health and hygiene status of their children. The questionnaire also collected information about household floor surfaces, yard surfaces, and any domestic uses of battery casings.

The follow-up time-point in September 2014 was chosen in order to capture any possible transient effect that might otherwise be missed if we waited too long. A second follow-up is tentatively planned for December 2015. Participating households were interviewed once again to determine if the job status of household members had changed, i.e., if someone left battery recycling, or someone from the household started working in battery recycling. Information on remediation activities at or near the household, and knowledge assessment regarding lead toxicity and exposure were also collected at the time. Follow-up BLL measurements were performed on the children who participated in baseline evaluation.

A total of 231 eligible children were recruited for baseline, out of whom 203 (88%) participated in the follow-up assessment.

Blood lead level measurements

BLL measurements were performed at the Dong Mai commune health building. Prior to BLL measurements, all subjects proceeded through wash stations with three separate basins each for scrubbing, soap application and removal and a final rinsing. Lead-removal wipes, Hygenall LeadOff®, were used to ensure maximal lead removal from skin. Each child underwent a single BLL measurement using aseptic finger-stick blood sample collection. The child's finger was wiped with an alcohol swab, and a sterile lancet was used to collect 50µl of blood in a capillary tube after wiping off the first blood drop from the finger-stick. BLL samples were analyzed using a portable screening device, LeadCare® II (Magellan Diagnostics).

The blood sample was mixed with a treatment reagent that lyses red blood cells releasing their lead content. Blood lead content deposits on a lead sensor when a potential is applied. The analyzer displays results in μg/dL within three minutes. The detection limits are 3.3μg/dL to 65μg/dL. Higher values are reported as "High."

The recommended temperature range for LeadCare is 54°-97°F (12°-36°C) and relative humidity 12% - 80%. At the time of follow up data collection in September, temperature and humidity were relatively high, necessitating the use of air conditioning to house the test kit and for BLL measurement. Since, the commune building did not have air conditioning, we used a combination of de-humidifier and air conditioning inside a car to house the testing apparatus in optimal ambient conditions. Temperature and humidity were checked regularly to ensure that we were operating in the manufacturer-recommended range.

Test results were reported to the parent or guardian at the time of testing. The parent or guardian was also provided an interpretation of the result along with education on exposure reduction. Current CDC guidelines were used for case management recommendations, since no international or Vietnamese guidelines exist for lead poisoning case management (CDC 2002).

Families of children with measured BLLs ≥ 45 μg /dL were immediately notified of the test results and it was recommended that the child have a venipuncture sampling for further, confirmatory laboratory analysis. This retesting was covered by the research budget. These samples were then analyzed using Graphite Furnace Atomic Absorption Spectrometry (GFAAS) by the NIOEH laboratory. Local staff emphasized urgent removal of child from contamination sources and recommended clinical follow-up and possible chelation therapy.

Families of children with BLLs between 10μg/dL and 44μg/dL were provided counseling on exposure reduction methods.

Data Analysis

All data analyses used STATA, version 13. MS-Excel was used to manage the database and prepare figures and tables.

Variable transformations

Numeric variables were examined both in numeric and categorical form. Categories were based on overall sample distribution, with preference for category cut-offs based on external conventions (e.g., CDC's BLL treatment threshold, 45μg/dL), and categories with similar subsample sizes and cut-off values rounded to integers or multiples of five. BLL was categorized as ≥45, 30-44.9, and <30 μg/dL. Change in BLL (follow-up minus baseline) was categorized as increased (>+5 μg /dL), no change (+5 to -5 μg/dL), medium decrease (-5 to -20μg/dL) and large decrease (-20 to –52.6 μg/dL). These categories were chosen after carefully examining the frequency distribution of change in BLL in smaller 5 μg/dL intervals. The threshold for no change was chosen, keeping in mind the manufacturer-reported error margin of LeadCare II, which is ± 3 μg/dL. For the large decrease category, 20μg/dL or higher change was considered a substantial difference in baseline and follow-up (n=53, 26% of participants).

The numeric BLL values had limited statistical robustness, because of truncation by the LeadCare II and its 65 μg/dL upper limit of detection. Therefore, BLL values (and change in BLL values) were analyzed both as numeric variables and also categorically. Above-threshold BLL values were assigned a value of 65μg/dL for numeric analyses. Sensitivity analyses examined whether using a higher assigned value had substantial influence on results.

Children (and not households) were treated as the unit of analysis, except in specific analyses examining possible within-household effects.

Participation Analysis

The major baseline dependent variable (BLL) and independent variables were compared between the group of children (n=28) who participated in the baseline but not follow-up evaluation and the group (N=203) who participated in both evaluations. After affirming similarity between the two groups, all subsequent analyses used the subset of children who participated in both evaluations.

Univariate Analysis

Preliminary comparison of baseline and follow-up data was performed by comparing frequency distributions at both time points and decline in individual BLLs from baseline to follow-up. Results from knowledge assessment survey were tabulated in form of percentage of people who responded yes to survey questions, with the denominator being the entire study sample or applicable subgroup.

Bivariate Analysis

The categorical BLL variables (baseline BLL and change in BLL) were examined relative to the major independent variables for identification of risk factors for high BLLs at baseline and factors associated with decline in BLL at follow-up. Analyses for categorical variables (e.g., age, household recycling, hygiene, remediation activities) used a contingency table and chi-square test or Fisher exact test. Between-group comparison for numeric variables like BMI used a Student t-test or one-way ANOVA. Non-parametric tests were used for paired ordinal data or numeric data with skewing or truncation.

In addition, change in protective worker practices was characterized using chi-square test of proportions. Correspondence between LeadCare II measurements and GFAAS measurements were visualized using scatter plots at baseline and follow-up.

Multivariate Analysis

Multivariate analyses used linear regression models. The regression models were developed separately using two different outcome variables, follow-up BLL or change in BLL, and all models controlled for baseline BLL. Models with the two different outcome variables yielded similar results, and follow-up BLL was chosen as the outcome variable for ease of reporting and interpretation (negative regression co-efficient corresponded to greater decline in BLL at follow-up).

The analysis was stratified by developing separate regression models for participants with BLLs ≥45 and those < 45μg/dL at baseline. This reduced potential bias from the wide range of baseline BLL values (i.e., children with higher baseline BLL can potentially have a greater decrease in BLL over time than children with lower baseline BLL). It also allowed for the possibility that changes in BLL might show different patterns of association with independent variables, depending on whether the child's baseline BLL was relatively high or lower.

Independent variables identified as statistically significant in the bivariate analyses were singly and sequentially examined for statistical significance as covariates in the regression model (while always controlling for Baseline BLL), selecting variables to retain in the model based on strongest additional contribution to the model (significance and change in R-squared). We individually tested variables related to demographics (age, numeric and categorized), exposure sources (e.g., household or nearby recycling or remediation), exposure pathway (e.g., household member practices at work and home), parent knowledge about lead, and child hygiene and practices. Other variables that did not show significance in bivariate analysis were ultimately entered in the finalized model one by one to test for associations that might have been missed in the bivariate analysis.

RESULTS

Participation Analysis

Of the 231 participants at baseline, 203 (88%) participated in follow-up assessment. There was no significant difference between the mean baseline BLLs between participants (45.7μg/dL) and non-participants (42.1 μg/dL; t-test, $p=0.2$), and no substantial differences in major household characteristics (not shown). All subsequent results are reported only for the 203 fully participating children.

Study sample

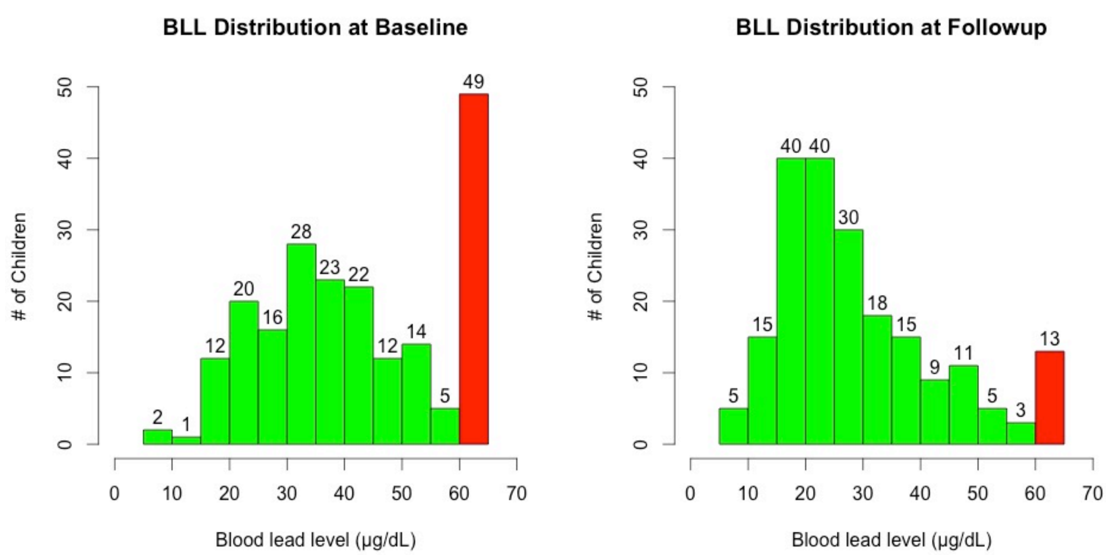
The study sample consisted of 108 (53%) male and 95 female children with a mean age of 3.2 years (standard deviation, s.d. 1.6). The children represented 147 households, including 37 households (25%) with two participating children, one with three participating children, and one with four participating children. Participating children had a mean height or length of 91.3 cm (s.d. 14.3) and mean weight of 13.4 kg (s.d. 3.5). Mean BMI of study participants was 16.2 kg/m^2 (s.d. 2.4) with a minimum of 9.5 kg/m^2 and a maximum of 27.2 kg/m^2. Almost one-third of the children (32%) had BMIs that met US CDC criteria for underweight (CDC 2015).

At the time of baseline assessment, 109 (54%) participating children lived in 84 (57%) households where one or more household members were involved in recycling activities, including 13 (6%) children residing in 11 (7%) households that conducted recycling at the home. At follow-up, eight fewer households had members involved in recycling (at any location, $n=76$), including half as many home-based recycling households ($n=5$) as at baseline.

Blood lead levels

As shown in figure 1, all children in the study had elevated BLLs at baseline and follow-up, relative to US reference values (CDC action level, 5 µg/dl) (CDC 2012). The lowest recorded value at baseline was 6.9 µg/dL and only two children had a BLL <10 µg/dL (at follow-up, 6.4 µg/dL and five children, respectively). Many children had BLLs exceeding 65 µg/dL (upper detection limit of LeadCare II), although this was less prevalent at follow-up (5.4%) than at baseline (23.7%; p<0.001, chi-square). Overall, BLLs were significantly lower at follow-up than at baseline with median of 40.8 and 25.6 µg/dL, respectively; p<0.001, Wilcoxon Rank Sum test).

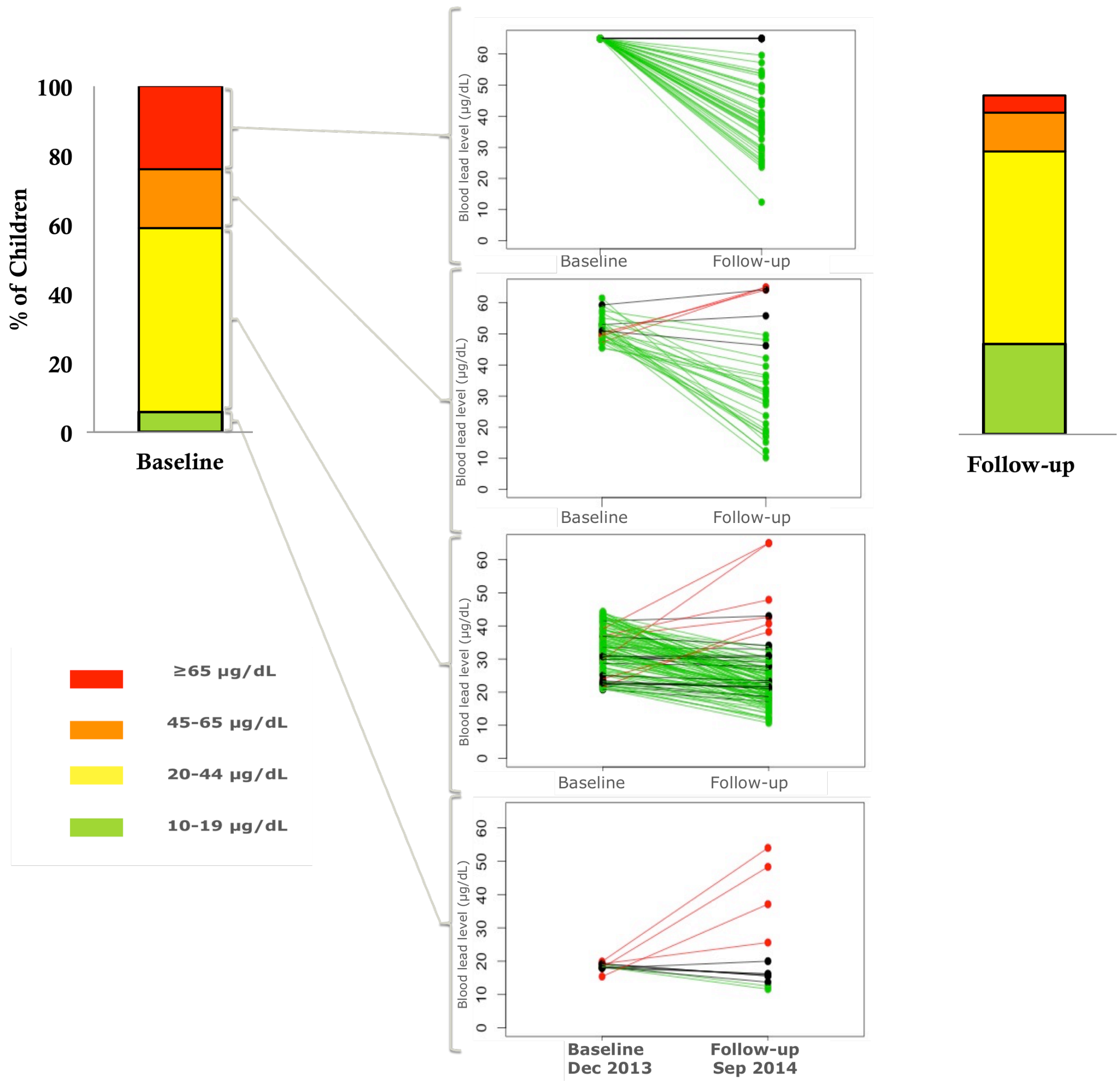
Figure 1. Blood lead level (BLL) distribution at baseline and follow-up, determined by fingerstick sample and LeadCare II analysis (n=203). Red columns denote all subjects with BLLs ≥ 65 µg/dL, the LeadCare II upper analytic limit.



Change in BLLs for individual participants is shown in Figure 2, separately for children in each Baseline BLL category. Overall, 37 children (18.2%) showed no

/dL" for above-threshold BLL values). Most children showed a medium decrease (n=100, 49.3%) or large decrease (n=53, 26%) in BLL, and only 13 (6.5%) showed >5 µg /dL increase in BLL (*p*=<0. 01, chi-square). All but one child with BLLs in the highest BLL category at baseline had lower BLLs at follow-up. The decreases were most evident among children in the highest Baseline BLL category (≥65 µg/dL: mean change, -22.5 µg/dL, assuming baseline BLL; standard deviation, s.d., 13.6; p<.001, Wilcoxon signed rank test). However, substantial decreases also occurred in the intermediate Baseline BLL categories (45-64 µg/dL: mean –18.1, s.d. 16.9, p<.001, paired t-test; 20-44 µg/dL, mean –9.7, s.d. 9.7, p<.001). The children with relatively lowest Baseline BLLs, however, showed no overall decrease (10-19 µg/dL: mean change 4.7, s.d. 14.4, p=0.8), and a few children (6.5%) had Follow-up BLLs that were substantially higher than their baseline.

Figure 2. Change in Blood Lead Levels (BLLs) for individual subjects from baseline to follow-up (using fingerstick samples and LeadCare II analysis; n=203).



Footnote: Red lines denote worsening by >5 μg /dL, Green lines denote improvement by >5 μg /dL, Black lines denote changes ranging from -5 to +5 μg /dL.

Confirmatory BLL retesting

Children with very high Baseline or Follow-up BLL values ≥ 45 μg/dL were offered confirmatory BLL retesting using a venipuncture blood sample and GFAAS analysis at the Vietnam NIOEH laboratory. Most children participated: baseline, n=67/80 (84%); follow-up, n=17/32 (56%). Retesting was conducted on the same day after the LeadCare II testing. The field (LeadCare II) and laboratory measurements are compared in Figures 3-5. The laboratory measurements were generally lower than field LeadCare II measurements at both time points as indicated by most points being below the 45 degree line in the scatterplot (Figure 5). Although nearly all of the retested children still had substantially elevated BLLs (≥20 μg /dL) on retesting, only 40% of re-tested children at baseline and 20% at follow-up had BLLs ≥45 μg/dL on retesting. Considering only the quantifiable LeadCare II values (i.e., <65 μg /dL), the retested laboratory values were on average 8.6 μg /dL (s.d. 11.4) lower during the baseline evaluation, and 9.3 μg /dL (s.d. 9.9) lower during the follow-up evaluation, with a noteworthy amount of variation (coefficient of variation, s.d./mean: 1.3 and 1.1, respectively).

Figure 3. Comparison of baseline BLL distribution measured by LeadCare II (finger-stick) and GFAAS (venipuncture)

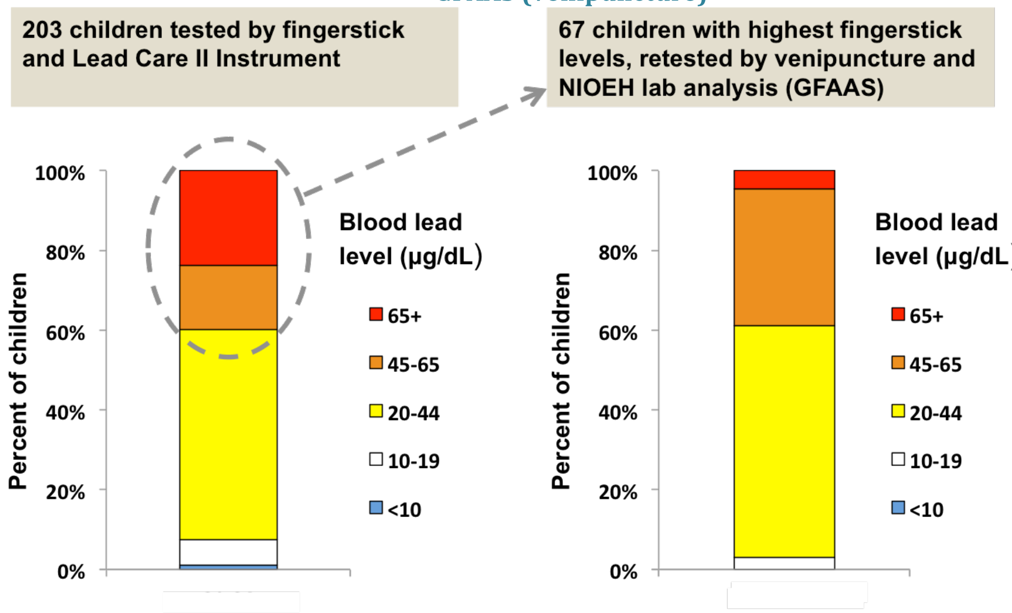


Figure 4. Comparison of follow-up BLL distribution measured by LeadCare II (finger-stick) and GFAAS (venipuncture)

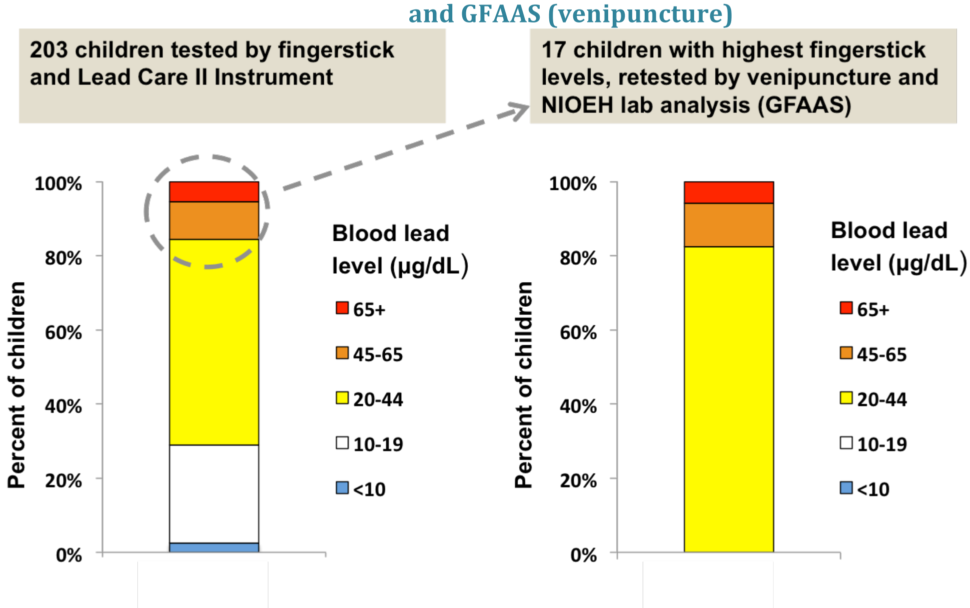
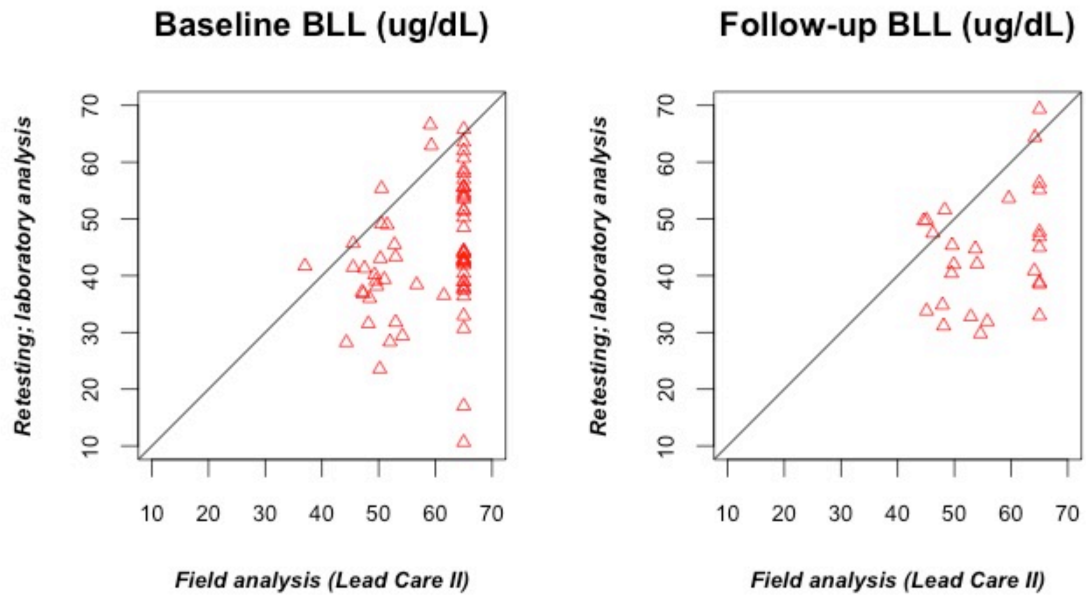


Figure 5. Scatterplots comparing "very high" quantifiable LeadCare II values (45 to >65 μg /dL) and re-tested laboratory measurements, shown separately for baseline and follow-up.



Footnote*:* Line shown is at 45-degree angle and passing through the origin.

Associations with Baseline BLL

Findings from baseline household surveys and bivariate analysis with categorized Baseline BLLs are listed in Table 3. Involvement of household members in current recycling, either at the house or a separate recycling facility, was significantly associated with very high BLL (≥45 μg/dL; $p<0.001$). At the time of baseline survey 13 out of 203 respondents reported active recycling at the household. Moreover, the specific home-based recycling activities of lead removal, burning waste, and separating dross were significantly associated with very high BLLs. All children (n=11) who spent time near these home-based recycling activities had BLLs over 30 μg/dL.

BLLs also tended to be higher in households closer to recycling facilities particularly if lead removal and waste burning occurred within 50 m of the house (Table 3). Bare soil surface at the house was also significantly associated with very high BLLs. All of the children (n=5) with bare soil surface at home had BLLs over 30 μg/dL. Time spent by child in outdoor environment was also associated with higher BLL ($p=0.002$) with all children (n=23) who spent more than six hours daily displaying BLLs over 30 μg/dL. Some other variables showed significant associations but in the opposite direction from predicted trend (use of battery casing inside the house and vacuum cleaning at home). BLLs differed significantly between age levels (0-1, 2-4, 4-6 years) but there was no clear single pattern. There was no evident association between baseline BLL and child health, hygiene or behavior.

Table 3. Survey and observation results for 203 children at baseline, relative to blood lead level (BLL)

Table 3	Blood Lead Levels (µg/dL)*			
	10-29.9 n= 51	**30-44.9** n= 71	**≥45** n= 81	**Signif** (p)**
Child Characteristics				
Age (years)				0.03
0-1	16 (31%)	24 (34%)	20 (25%)	
2-4	12 (24%)	19 (27%)	38 (47%)	
5-6	23 (45%)	28 (39%)	23 (28%)	
Gender				0.67
Male	28 (55%)	40 (56%)	40 (49%)	
Female	23 (45%)	31 (44%)	41 (51%)	
BMI (SD)	16.2 (2.4)	15.9 (2.0)	15.5 (2.5)	0.41
Household involvement in				
HH members involved in reycling				<.001
Never	14 (27%)	23 (32%)	9 (11%)	
Past	18 (35%)	24 (34%)	6 (7%)	
Current	19 (37%)	24 (34%)	66 (81%)	
No. of household members involved				
one	*11*	*8*	*27*	
two	*2*	*8*	*26*	
>2	*6*	*8*	*13*	
Recycling at household				0.01
Never	26 (51%)	34 (48%)	54 (67%)	
Past	24 (47%)	33 (46%)	19 (23%)	
Current	1 (2%)	4 (6%)	8 (10%)	
Lead removal from batteries	*0*	*0*	*8*	
Cooking lead	*0*	*0*	*4*	
Buring waste	*0*	*0*	*6*	
Separating dross	*0*	*0*	*7*	
Recycling for 10+ years	*0*	*0*	*6*	
10+ years since past recycling conducted at the house	16 (31%)	17 (24%)	6 (7%)	0.50
Household Conditions				
Floor surface inside house				0.05
Bare soil	0 (0%)	1 (1%)	4 (5%)	
brick	1 (2%)	7 (10%)	6 (7%)	
cement	5 (10%)	1 (1%)	3 (4%)	
tile	41 (80%)	56 (79%)	65 (80%)	
Type of surface in yard				
Soil	8 (16%)	4 (6%)	13 (16%)	0.12
Brick	32 (63%)	54 (76%)	58 (72%)	0.12
Cement	22 (43%)	26 (37%)	41 (51%)	0.37
Battery casing use inside house	14 (27%)	27 (38%)	12 (15%)	0.001
Method of cleaning floors				0.08
Sweeping	4 (8%)	4 (6%)	12 (15%)	
Mopping	40 (78%)	58 (82%)	66 (81%)	
Vacuum cleaning	3 (6%)	2 (3%)	0 (0%)	
Method of washing clothes				0.76
Wash clothes by hand	25 (49%)	34 (48%)	46 (57%)	

Table 3 (continued)	Blood Lead Levels (µg/dL)*			
	10-29.9 n= 51	**30-44.9** n= 71	**≥45** n= 81	**Signif** (p)**
Recycling operations near the home				
Recycling within 50m anytime	26 (51%)	42 (59%)	39 (48%)	0.17
Currently recycling within 50m	11 (22%)	17 (24%)	27 (33%)	0.02
Lead removal from batteries	9 (18%)	14 (20%)	23 (28%)	0.04
Cooking lead	14 (27%)	22 (31%)	22 (27%)	0.93
buring waste	5 (10%)	6 (8%)	14 (17%)	0.07
separating dross	18 (35%)	28 (39%)	27 (33%)	0.94
Child Health, Hygiene and Behaviour				
Child's Symptoms				
Overall poor health	11 (22%)	8 (11%)	10 (12%)	0.21
abdominal pain	23 (45%)	26 (37%)	45 (56%)	0.15
constipation	25 (49%)	39 (55%)	54 (67%)	0.12
Frequency of handwashing				0.35
low (1-2 times)	8 (16%)	9 (13%)	9 (11%)	
moderate (3-4 times)	25 (49%)	35 (49%)	54 (67%)	
high (more than 4 times)	12 (24%)	19 (27%)	14 (17%)	
Handwashing with soap	32 (63%)	50 (70%)	53 (65%)	0.26
Timing of handwashing				
before meals	39 (76%)	50 (70%)	68 (84%)	0.34
after meals	26 (51%)	34 (48%)	45 (56%)	0.87
before snacks	12 (24%)	13 (18%)	17 (21%)	0.83
after snacks	10 (20%)	15 (21%)	17 (21%)	0.93
after using toilet	31 (61%)	45 (63%)	62 (77%)	0.19
before going to bed	34 (67%)	44 (62%)	50 (62%)	0.61
after coming from outside	13 (25%)	10 (14%)	11 (14%)	0.14
Time spent outdoors per day				0.002
low (0-3h)	23 (45%)	23 (32%)	24 (30%)	
moderate (4-6h)	20 (39%)	33 (46%)	33 (41%)	
high (> 6h)	0 (0%)	6 (8%)	17 (21%)	
Children near current recycling activity	0 (0%)	3 (4%)	8 (10%)	1.00
Child near past recycling activity	3 (6%)	6 (8%)	4 (5%)	0.89

* Blood lead level (BLL) determined by fingerstick blood sample and Leadcare II instrument
**Significance determined by chi-square, Fisher exact test, or one way ANOVA. P value shown
Percentages are column percentages, using the entire column sample as denominator

Associations with change in BLL

Findings from follow-up household survey and bivariate analysis of change in BLL are displayed in Table 4. Only five households were still involved in home-based recycling, compared to 13 at baseline. No households were burning waste at the home at follow-up. Current household involvement in recycling activities tended to be associated with larger decrease in BLL, but was not statistically significant

(p=0.09). There was also unclear direction of association in child hygiene behavior: washing hands after coming from outside and after snacks. Change in BLLs varied significantly with age but once again there was no clear single trend

Table 4. Survey and observation results at follow-up, relative to change in BLL

Table 4.	Change in Blood Lead Levels (ug/dL)			
	No change (or increase) n= 50	**Medium decrease** (- 6 to -20) n= 100	**Large decrease** (-20 or more) n= 53	**Signif** (p)**
Child Characteristics				
Age (years)				0.03
0-2	22 (44%)	22 (22%)	18 (34%)	
2-4	16 (32%)	32 (32%)	18 (34%)	
4-6	12 (24%)	46 (46%)	17 (32%)	
Current Household Involvement in Recycling				
Household members involved in recycling	22 (44%)	38 (38%)	30 (57%)	0.09
Total No. of household members involved				0.47
one	14	25	18	
two	4	7	10	
>2	4	6	2	
Recycling at the house	0 (0%)	4 (4%)	3 (6%)	0.32
Lead removal from batteries	0	2	2	
Cooking lead	0	0	2	
burning waste	0	0	0	
separating dross	0	0	2	
Recycling operations near the home	33 (66%)	57 (57%)	25 (47%)	0.12
Nearby recycling happening now	15 (30%)	32 (32%)	12 (23%)	0.58
Lead removal from batteries	10	20	8	
Cooking lead	17	30	8	
burning waste	5	12	2	
separating dross	17	28	14	
Remediation at Household	12 (24%)	12 (12%)	6 (11%)	0.09
Removing soil	0	0	0	
covering soil	4	4	2	
tiles/cement in yard	5	6	4	
cleaning inside home	5	3	1	
Remediation nearby	22 (44%)	31 (31%)	19 (36%)	0.15
Household Conditions				
Type of surface in yard				
Soil	3 (6%)	1 (1%)	0 (0%)	0.09
Brick	36 (72%)	74 (74%)	44 (83%)	0.40
Cement	13 (26%)	32 (32%)	12 (23%)	0.45
Method of cleaning floors				0.36
Sweeping	8 (16%)	7 (7%)	7 (13%)	
Mopping	38 (76%)	87 (87%)	45 (85%)	
Vaccum cleaning	2 (4%)	5 (5%)	1 (2%)	

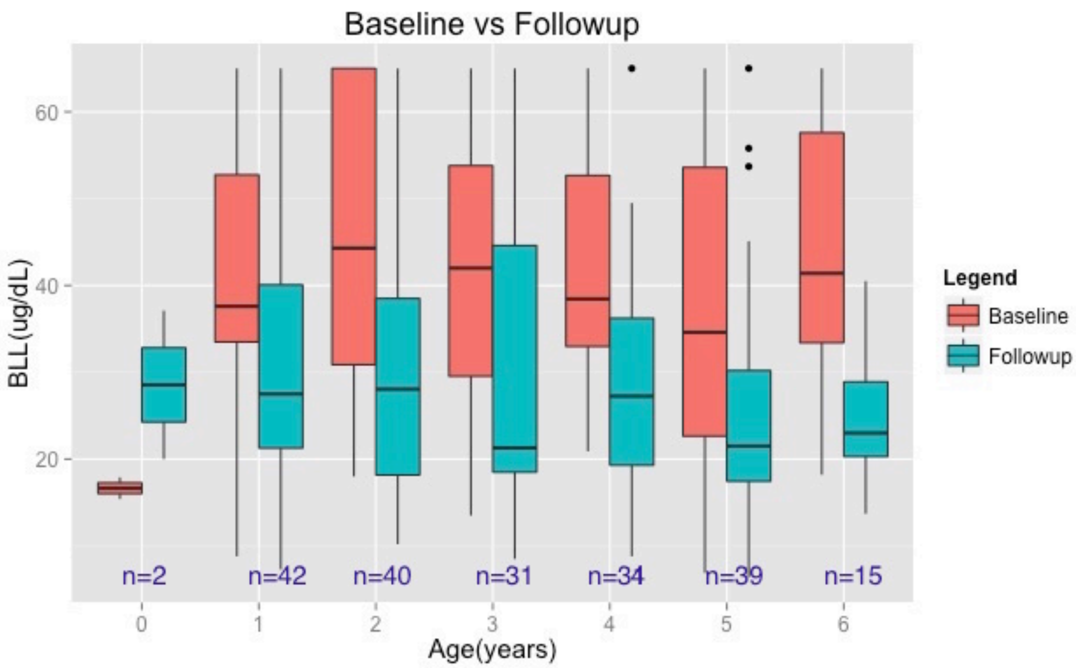
Table 4.(continued)

	Change in Blood Lead Levels (ug/dL) No change (or increase) n= 50	Medium decrease (- 6 to -20) n= 100	Large decrease (-20 or more) n= 53	Signif (p)**
Child Health, Hygiene and Behaviour				
Child's Symptoms				
Overall poor health	7 (14%)	8 (8%)	3 (6%)	0.28
abdominal pain	17 (34%)	28 (28%)	18 (34%)	0.62
constipation	18 (36%)	41 (41%)	18 (34%)	0.69
seizure	47 (94%)	96 (96%)	52 (98%)	0.79
chronic problems	3 (6%)	14 (14%)	3 (6%)	0.20
recent illness	22 (44%)	36 (36%)	17 (32%)	0.38
Frequency of handwashing				0.98
low (1-2 times)	6 (12%)	10 (10%)	7 (13%)	
moderate (3-4 times)	20 (40%)	38 (38%)	19 (36%)	
high (more than 4 times)	14 (28%)	28 (28%)	14 (26%)	
Timing of handwashing				
before meals	40 (80%)	73 (73%)	34 (64%)	0.67
after meals	25 (50%)	33 (33%)	20 (38%)	0.21
before snacks	7 (14%)	8 (8%)	7 (13%)	0.43
after snacks	11 (22%)	7 (7%)	7 (13%)	0.04
after using toilet	38 (76%)	66 (66%)	31 (58%)	0.59
before going to bed	18 (36%)	33 (33%)	19 (36%)	0.76
after coming from outside	11 (22%)	10 (10%)	11 (21%)	0.08
Handwashing with soap	42 (84%)	82 (82%)	41 (77%)	0.60
>6h spent outdoors per day	1 (2%)	4 (4%)	1 (2%)	0.87
Child near recycling	0 (0%)	3 (3%)	3 (6%)	0.99

* Blood lead level (BLL) determined by fingerstick blood sample and Leadcare II instrument
**Significance determined by chi-square, Fisher exact test, or one way ANOVA. P value shown
Percentages are column percentages, using the entire column sample as denominator

At both time points child age showed a significant association with Baseline BLL or change in BLL. As with the analysis of Baseline BLL (Table 3), there was no clear pattern in the association. We examined whether this might be a misclassification artifact based on our choices for age categorization. Figure 6 below demonstrates the patterns in BLL at baseline and follow-up over the age range of the participants in the study. All age groups display a decrease in overall BLLs, except the youngest age group where the follow-up BLLs were higher than at baseline. That youngest age group, however, only represented two children.

Figure 6. Distribution of Blood Lead Levels (BLLs) according to age at baseline and follow-up.



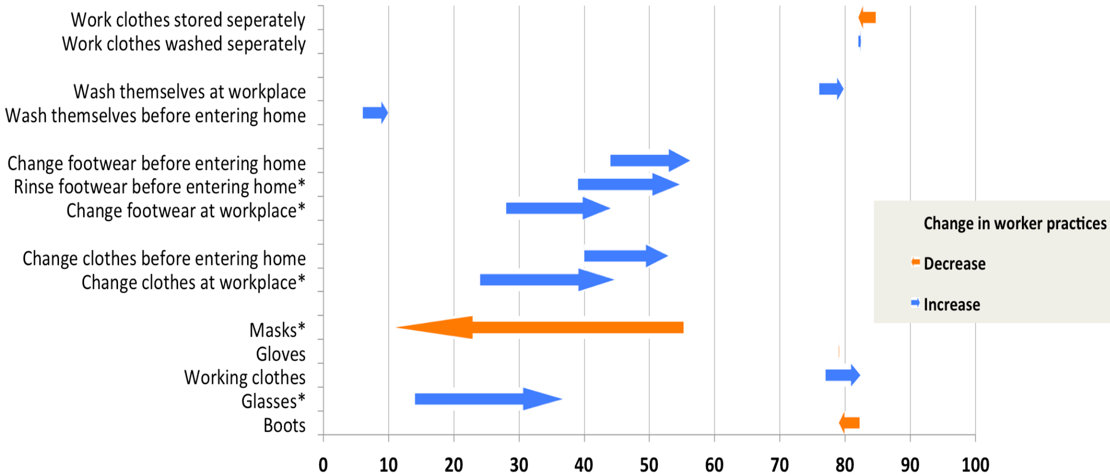
Households involved in recycling

The household questionnaire inquired about protective practices followed by workers involved in recycling. In the 109 households where family members were involved in recycling (either at home or a separate recycling facility), most members used some form of personal protective equipment at baseline. Almost all members reported use of boots (98%), gloves (96%), and work clothes (87%). More than half (57%) wore masks while only 11% reported wearing glasses. In most but not all households these work clothes were washed (72%) and stored (62%) separately from other clothes at home.

Only 20% of the participants changed clothes at the recycling facility before coming home. Half of the subjects (47%) change clothes right before entering home. Only 23% used to take off their work footwear and put on different footwear before going home. Half (48%) reported rinsing and most (58%) reported changing footwear before entering home. Very few (7%) reported washing themselves at the workplace, before coming home. Most of the subjects (86%) wash themselves right after getting home.

Figure 7 shows the change in protective worker practices from baseline to follow-up. An increase (improvement) was observed in all practices except use of masks. There was a significant increase in workers who rinsed footwear before entering home, changed footwear at workplace, and used glasses. In contrast, use of masks decreased significantly over this period.

Figure 7. Change in worker practices from baseline to follow-up (* significant change p<.05)



As shown in table 5, use of personal protective equipment like wearing boots, glasses, and gloves while engaging in recycling activities was significantly associated with larger decrease in BLL. Furthermore, factors related to worker hygiene like changing or rinsing shoes before entering home, washing themselves right after entering home, and storing work clothes separately were associated with favorable change in BLL.

Table 5. Work practices at households where one or more person was involved in recycling activities (at home or elsewhere), at follow-up, relative to change in BLL

	Change in Blood Lead Levels (ug/dL)			
	No change (or increase) n= 21	**Medium decrease** (- 6 to -20) n= 37	**Large decrease** (-20 or more) n= 30	**Signif** (p)**
PPE used				
Boots	18 (86%)	36 (97%)	30 (100%)	0.05
Glasses	4 (19%)	11 (30%)	15 (50%)	0.07
Work clothes	19 (90%)	33 (89%)	30 (100%)	0.15
Gloves	18 (86%)	36 (97%)	30 (100%)	0.05
Mask	2 (10%)	3 (8%)	7 (23%)	0.19
Worker hygiene				
Change clothes before leaving work	6 (29%)	18 (49%)	11 (37%)	0.32
Change clothes before entering home	10 (48%)	15 (41%)	18 (60%)	0.25
Change shoes before leaving work	7 (33%)	19 (51%)	10 (33%)	0.25
Rinse shoes before entering home	7 (33%)	17 (46%)	18 (60%)	0.02
Change shoes before entering home	9 (43%)	18 (49%)	19 (63%)	0.03
wash at work	1 (5%)	3 (8%)	3 (10%)	0.89
wash after coming home	17 (81%)	34 (92%)	29 (97%)	0.10
work clothes washed seperately	20 (95%)	37 (100%)	30 (100%)	0.25

Multivariate analysis

Results of multiple linear regressions are shown in Table 6. Multivariate analysis restricted to children with baseline BLL values >45 μg /dL (Model 1) revealed that nearly half of variation in follow-up BLLs (model R^2 0.54) can be explained by child age, baseline BLL, remediation status of home or nearby, living near a functioning recycling operation and childhood hygiene. When the same model was applied to children with baseline BLL <45 μg /dL, the model R^2 was much smaller (0.15) and except for age and child hygiene, the other aforementioned variables showed no association with follow-up BLL. The regression model developed specifically for children with Baseline BLL <45 μg /dL, however, showed a slightly higher model R2 (0.23; Model 2) plus significant associations between Follow-up BLL and child age, involvement of household members in recycling and child's hand washing habits (washing after coming home).

Table 6. Results of multiple linear regressions with follow-up BLL as the dependent variable. Reference age category is 0-2 years of age.

	BLL (ug/dL)	Covariates	R-squared	Coefficient	95% CI		p value
Model 1	≥45ug/dL	Age (2-4 years)	**0.54**	1.46	0.83	2.08	<.001
		Age (4-6 years)		-6.21	-18.08	5.67	0.290
		Baseline BLL		-24.06	-39.32	-8.81	0.003
		Remediation at/near home		-15.16	-24.34	-5.97	0.002
		Living near current recycling		18.88	8.13	29.63	0.001
		Wash hands 4+ times/day		-13.56	-22.27	-4.85	0.004
*Model 1**	<45ug/dL	Age (2-4 years)	**0.15**	0.12	-0.18	0.42	0.43
		Age (4-6 years)		-7.67	-14.57	-0.78	0.03
		Baseline BLL		-9.71	-15.46	-3.97	0.001
		Remediation at/near home		-1.86	-6.91	3.20	0.46
		Living near current recycling		-1.35	-6.44	3.74	0.60
		Wash hands 4+ times/day		-1.49	-7.44	4.45	0.62
Model 2	<45ug/dL	Age (2-4 years)	**0.23**	-5.01	-9.44	-0.58	0.03
		Age (4-6 years)		-5.76	-9.62	-1.90	<.001
		Baseline BLL		0.28	0.09	0.47	0.01
		Household members in recycling		-3.41	-7.05	0.23	0.07
		Wash hands after coming from outside		-5.63	-10.10	-1.16	0.01

** Using variables from the best fit model for ≥45ug/dL group*

Sensitivity analysis for Model 1 was done by replacing truncated values (≥ 65 μg/dL) with 70 μg/dL or 80 μg/dL. These substitutions gave results identical to the original model. In another sensitivity analysis the child hygiene variable originally selected for Models 1 and 2 was replaced individually and sequentially with other hygiene variables and worker protective practices. This too did not yield any further contribution to the model and instead resulted in reduced R^2. For Model 2, three similar child hygiene variables made comparable contributions: washing hands before snacks (p=0.009), after snacks (p=0.001), and before going to bed (p=0.04).

Parent knowledge

Of the 203 participating children, 97 of the parent (or guardian) survey respondents had attended at least one educational session, which was one component of lead mitigation activities. Table 7 below summarizes the responses from the knowledge assessment survey conducted at the follow-up evaluation. Note, there was no knowledge assessment at the baseline evaluation.

Table 7. Responses from knowledge assessment survey (n=93)

Knowledge Assessment	% of correct responses
Which will reduce lead exposure at home	
Cleaning with broom (no)	54%
Cleaning with wet mop (yes)	88%
Which will protect against lead contamination	
Boiling drinking water (no)	26%
Wash fruits/veg (yes)	79%
Wash hands before eating (yes)	85%
Which will protect against lead contamination	
Change work clothes at work (yes)	74%
Change work shoes at work (yes)	59%
Wash yourself at work (yes)	70%
Children are exposed to lead by	
Playing near current lead battery work (yes)	84%
Playing near past recycling work (yes)	75%
Eating in contaminated areas (yes)	83%
Small children are more susceptible to lead poisoning because	

Kids put everything in their mouth (yes)	86%
They crawl around and play on floor (yes)	82%

DISCUSSION

All children in the study had elevated BLLs at baseline. The most substantial decline in BLL was observed for children who had the highest BLLs at baseline (Figure 2), although BLLs generally decreased among all children except those with the lowest baseline BLLs (10-19 µg/dL). However, when compared to the CDC's reference level of action, 5 µg/dL, the follow-up BLLs were still very high. Although this study cannot establish causality, the findings provide encouraging evidence of an early beneficial effect of the lead mitigation intervention, within nine months after beginning educational and cleanup initiatives. It is further reassuring that study participation was high at baseline and follow-up, thus enhancing the generalizability of our observations

The findings suggest that both components of the intervention, community education and cleaning up of contaminated sites and households, might have played roles in the overall decline in BLLs. Regression analysis revealed that BLL reduction was significantly associated with remediation near or at the home and hand washing practices. Continued recycling near the home and household member involvement in recycling showed unfavorable associations with BLL change over time. However, it is noteworthy that both became less common among study households across the study period. In addition, an overall improvement in protecting worker practices was also observed.

We had anticipated doing a stratified analysis because children with higher BLLs at baseline have more room for change over time. The cut off of 45μg/dL was chosen to align with CDC's reference value for clinical intervention. Within these strata we continued controlling for baseline BLL. Multivariate analysis (Table 6) shows that when controlled for hygiene practices, remediation and recycling activities older kids (4-6 years) are expected to have significantly lower BLL than their younger counterparts (approx. 17 unit decrease compared to 4 units). This could probably be explained by the fact that older kids adopt more complex behaviors as compared to kids in the younger age groups who are more dependent on the parent/caregiver for their hygiene habits and are ignorant about hand-to-mouth activities. Children in this age group are relatively more mobile and likely to wander and play out of the home, thus being affected by changes in outdoor environments (nearby recycling, remediation at nearby homes, etc.).

These associations were less pronounced in children who had BLLs lower than 45μg/dL at baseline. However, the association with age persisted as seen in the earlier model. Further analysis revealed that in this stratum, involvement of household member in recycling activities and a different hygiene behavior (washing hands after coming home) showed significance.

Interestingly, none of the protective practices that showed significance in bivariate analysis showed significant contribution towards above models. Given that use of PPEs and protective practices are relatively distant factors in the exposure pathway of the child compared to child's personal hygiene (washing hands), this is plausible. To test this explanation, we substituted the child hygiene variable with individual protective practices and most of them showed no significant association with BLL change over time.

Change in worker practices

Favorable changes were observed with respect to use of personal protective equipment and protective worker practice, with the exception of mask use (Figure 7). It is possible that the observed decrease in mask use was due to the follow-up assessment being in summer, making it inconvenient to wear masks for an extended period of time. This secular trend explanation is plausible since use of masks was the only practice that declined during this period. Notably, use of mask other than a proxy for use of PPEs is not a predictor of child BLL unless the worker is a pregnant expecting mother. Use of masks will only reduce the parent 's exposure and not the child's.

Even though, there was a significant increase in workers changing footwear and clothes at workplace, the frequency at follow-up was still less than 50%. As part of the intervention activities, new changing facilities have been constructed at the private recycling facility in the centralized industrial area. The construction was completed after the data collection period in November 2014. In absence of changing facilities, workers do not have a choice but to wear the clothes and shoes to home thus increasing the amount of take-home exposure. We hope that the use of changing facilities will reduce take-home exposure in future.

Study Limitations

This study had some obvious limitations. A primary limitation in measurement was due to the upper detection limit of the LeadCare II instrument (65 μg/dL). To address this issue we used categorized BLLs for baseline assessment instead of numeric values. In order to expand our ability to detect differences between baseline and follow-up BLLs using numeric analysis, we assumed a value of 65 μg/dL for all values equal to or greater than 65 μg/dL (Table 2). Assigning a constant value of 65 is an underestimate, which may have lead to conservative estimates of associations between covariates and change in BLLs. However, substituting higher presumed values for above-limit BLLs showed no effect in our sensitivity analyses.

A second and more worrisome limitation is the use of field instruments (LeadCare II) that while being more affordable and practical may not be as accurate as using a lab instrument (GFAAS). Both baseline and follow-up BLL measurements show that GFAAS BLLs tended to be lower than LeadCare II BLLs. This was also evident in our earlier evaluation that preceded the intervention (Daniell 2015). It is reassuring that the upward bias was comparable at these three different points in time (Figure 5), suggesting that the field BLL measurements at least have value as relative measurements, and unclear value as absolute measurements. Thirdly, depending on our follow-up timeline, it is possible that we could miss a transient decrease in BLL, or we might be too soon to detect a slower decrease of BLLs (gradual effect of remediation). This is further complicated by longer half-life of decrease in BLL with chronic exposure. Finally, this study evaluates remediation activities in only one village. We do not have a control group for external comparison or provision for adjustment for secular changes. However, we think it is unlikely that the observed trends are of secular nature.

CONCLUSION

We observe promising decline in childhood BLLs within nine months of lead are still high when compared to CDC reference level for action. Our analysis reveals that modifiable environmental factors and personal hygiene practices are associated with significant improvement in BLLs. This warrants following the cohort further into future for evidence of sustained effect and ongoing improvement.

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