Self-Reported Health and Metal Body Burden in an Electronic Waste Recycling Community in Northeastern Thailand

Rita Seith, MPH, Aubrey L. Arain, PhD, Kowit Nambunmee, PhD, Sara D. Adar, ScD, and Richard L. Neitzel, PhD

Objective: This study aims to summarize electronic waste (e-waste) worker health; examine associations between health and sociodemographic characteristics; and metal body burden. **Methods:** In 2016, 131 e-waste recycling workers were enrolled in the study, completed a questionnaire, and gave blood and urine samples for heavy metal concentration assessment (lead, cadmium, copper, zinc, nickel). The relationship between symptoms, general health, and metals is assessed via generalized estimating equation models (adjusted for age, education, sex, and village). **Results:** Cadmium in blood and copper in serum were most consistently associated with higher odds of poor health and prevalence of symptoms. We found inconsistent results between general health, symptom severity, and urinary nickel. Higher blood lead levels (BLL) were associated with fewer self-reported symptoms. **Conclusions:** Exposure to certain metals in e-waste recycling communities may adversely impact health status.

Keywords: cadmium, e-waste, health outcomes, lead, metals

Due to the rapid development of the electronics industry, electronic waste (e-waste) has become one of the fastest growing waste streams worldwide. In the year 2016, 44.7 million metric tons of e-waste were produced, including laptops, dishwashers, cell phones, and printers.[1] E-waste recycling work in the informal sector is not taxed or regulated by the government.[2] Methods of recovering valuable materials like copper, steel, and precious metals include open burning, physical dismantling, and desoldering. These activities, which sometimes occur inside the home, can lead to a variety of direct and indirect metal exposures among workers and those living nearby.[3,4] Although some metals like nickel, zinc, manganese, and copper are essential trace elements, others like lead and cadmium have adverse health consequences such as increased risk of cancer and organ damage.[5] Metals can also accumulate in the soil, food, air, and water—chronically exposing those residing near e-waste recycling sites.[6] For example, cadmium, linked with renal failure, persists in rice, a staple food item worldwide.[7] Through environmental and other pathways of exposure, community and family members are affected by recycling work. A review on health effects of e-waste in China reported heavy metals in blood, urine, serum, hair, and even placenta and umbilical cord blood.[8] Blood lead levels have been most thoroughly studied, but metal levels are overall elevated in those more exposed to recycling work.[8,9]

Estimates suggest 50% to 80% of the world's e-waste ends up in China[10] and informal e-waste recycling is now a major cause of metal contamination.[11] Consequently, much of the e-waste research is China-specific. E-waste recycling has spread globally, including in countries like Thailand. Despite recent efforts to regulate e-waste with legislation, Thailand lacks a suitable national e-waste management strategy, and is therefore not sufficiently equipped to monitor or address the short- and long-term hazards associated with e-waste recycling, including metal exposures.[12] The amount of e-waste in Thailand is predicted to increase annually at a rate of 12% which calls for a need to protect workers from negative health impacts of heavy metal exposures.[13]

Examination of early health effects from metal exposure in e-waste allows for the planning of prevention activities in workers and community members. Those aware of early signs and symptoms of illness are known to be more likely to engage in self-care behaviors.[14] Protecting community health in the informal e-waste sector relies heavily on behavior changes and self-care; hence, the importance of understanding the relationship between short-term health effects and metal exposure. This study focuses on a relatively new e-waste recycling site in Thailand, and examines the relationship between metal levels in the body and self-reported health and symptoms among e-waste workers.

MATERIALS AND METHODS

This study was reviewed and approved by the Institutional Review Boards of the University of Michigan (UM) (approval number HUM00114562) in the United States and Mae Fah Luang University (MFU) in Thailand (approval number REH-59104).

Study Population and Design

Four villages in a subdistrict of one province of Thailand have been selected for the study due to their e-waste processing activities. Each of the villages was within 4 km of the other villages, and all were less than 2 km away from a shared mixed-waste landfill where some e-waste processing and disposal occurs. The physical environments of all four villages, which have historically relied on rice farming for income and sustenance, were quite similar.

In August 2016, a team of Thai nurses, Thai health volunteers, and students, staff, and faculty from UM, MFU, and Kasetsart University (Thailand) enrolled 144 participants via a convenience sample of community residents. Study inclusion criteria were age over 18 years and residence in the studied e-waste recycling community. For the present study, 14 participants were removed from the data set because they were not employed in e-waste recycling. Following enrollment, participants completed a technician-administered questionnaire and provided blood and urine samples (described in detail below). Participants also completed a battery of environmental and health measurements, which will be described elsewhere (manuscript in preparation). The health volunteers explained all procedures of the study in Thai to interested

From the Department of Epidemiology, School of Public Health, University of Michigan, Ann Arbor, Michigan (Mrs Seith and Mrs Adar); Department of Environmental Health Sciences, School of Public Health, University of Michigan, Ann Arbor, Michigan (Dr Arain and Dr Neitzel); Department of Occupational Health and Safety, School of Health Science, Mae Fah Luang University, Chiang Rai, Thailand (Dr Nambunmee).

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Address correspondence to: Richard L. Neitzel, PhD, University of Michigan, Ann Arbor, MI 48109-2029 (rneitzel@umich.edu).

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individuals before an informed consent form was signed and participants enrolled.

Questionnaire

Each participant was given a 100-question survey that had been translated from English to Thai and then back-translated to English for validation before collection of data. Select questions used from this survey (translated to English) are included in Appendix 1, http://links.lww.com/JOM/A630. Questions addressed basic demographic characteristics (sex, age, income, education, marital status, residential history, and so on), work-related activities, and a series of health outcome-related questions. These included self-reported overall health status reported on a five-category scale (ie, poor, fair, good, very good, and excellent) and self-reported presence and severity of nine general symptoms (rash, headache, cough, blood in the urine, blood in the stool, nausea, fever, watery stools, and abnormal heart beat). We asked participants to report if each of these symptoms occurred ‘‘rarely or never,’’ ‘‘occasionally,’ or ‘‘always or frequently.’’

Biological Sample Collection and Analysis

Participants provided freshly voided urine samples in 50 mL acid-washed propylene sampling containers. After collection, two 15 mL subsamples were drawn using a transfer pipette and placed into two separate BD Vacutainer Plus Urinalysis tubes. Trained Thai nurses collected samples of whole blood from participants by trained Thai nurses using one sterilized 4 mL plastic blood collection tube with lithium heparin (for whole blood analysis) and two 6 mL sterilized plastic blood collection tubes with increased silica act clot activator (for serum analysis). Heparin tubes were inverted 8 to 10 times, whereas silica tubes were inverted 5 times and allowed to sit for 60 minutes before the samples were centrifuged. Sample processing and centrifuging took place in the village within several hours of sample collection. Using a transfer pipette, as much of the serum as possible was removed and placed into separate 5 mL containers. Samples were transported on dry ice to the Thai Ministry of Public Health Central Laboratory in Bangkok for analysis within 3 days after samples were collected.

Urine samples were stored at 4°C before analysis. Concentrations of lead, zinc, manganese, copper, and nickel in urine samples were measured using an Agilent 7500 ce inductively coupled plasma mass spectrometer and previously described methods[15] (Appendix 2, http://links.lww.com/JOM/A631). Samples were diluted by a factor of 10 using a 2% HNO_3 solution. We determined urinary cadmium concentration through graphite furnace atomic absorption spectrometry (GF-AAS) using a Agilent 280Z AA spectrometer using methods detailed previously.[16] Samples were diluted by a factor of 10 using a solution of 0.1% Triton X-100, 0.2% $(NH_4)2HPO_4$. For all urine analytes, blanks were taken at a rate of 10% of the total sample number. All urinary metal levels were creatinine-adjusted to account for differences in urinary generation rates and hydration.

Blood samples for heavy metal analysis were stored at −20°C before analysis. Concentrations of manganese, and nickel in whole blood were measured using an Agilent 7500 ce ICP mass spectrometer (Appendix Table 3, http://links.lww.com/JOM/A632). Concentrations of lead and cadmium were measured in whole blood samples with GF-AAS using an Agilent 280Z AA spectrometer and a Spectr AA 880 Varain Spectrometer, respectively. Both elements were analyzed using previously described methods.[16] Zinc and copper concentrations in were measured in serum using ICP-MS. For all blood analytes, blanks were measured at a rate of 5% of the total number of samples. The sample volumes collected did not allow for duplicate analysis. We replaced nondetectable whole blood, serum, and urine concentrations with the limit of detection value divided by the square root of 2.[17]

Statistical Analysis

All data analysis was performed with SAS software version 9.4 (SAS Institute, Cary, NC). Basic descriptive statistics were estimated for demographic, health, and work-related characteristics, and heavy metal concentrations for the entire study population, as well as stratified by village. Distributions of continuous variables were examined visually and skewed data were log-transformed to produce a log-normal distribution. Categorical variables were compared using chi-squared and Fisher exact test, when counts were less than 5. Differences in heavy metal concentrations by demographic variables and village were compared. Blood and urine levels were also compared with relevant health standards recommended by the US Centers for Disease Control and Prevention (5 μg/dL for blood lead)[18] and the US Occupational Safety and Health Administration (5 μg/L for blood cadmium, 3 μg/g creatinine for urinary cadmium)[19] to determine exceedance fractions.

Two outcome variables are used in modeling: a three-category overall health status indicator (‘‘excellent or very good,’’ ‘‘good,’’ ‘‘fair or poor’’) and a binary variable for the presence of any symptoms (0=rarely or none for all symptoms, 1=otherwise). Generalized estimating equation models are used to assess the relationships metal biomarkers with both outcome measures, with village as a clustering variable. For models using the binary symptom severity variable, we performed a logistic regression model, whereas a multinomial logistic regression is performed for the three-category health status. Three demographic variables (age, education, and sex) are selected a priori as confounders for inclusion in all models as well as the random effect for village. The six heavy metals evaluated are evaluated as potential predictors in their native concentration values. We use the metal's corresponding interquartile range (IQR) in interpretation.

RESULTS

General Characteristics of Population

A total of 130 participants completed the questionnaires, with two villages (B and D) providing the most participants (Table 1). The sample had a mean age of 45 years (SD 13), was predominantly male (54%), and lived in households with children (89%). Most participants had only completed primary school (75%). There were significant differences in income and marital status between the villages ($P = 0.004$). Village A had the highest percentage with income between 5K and10K Baht and village D had the highest percentage with income greater than 10K Baht.

Village C reported the worst general health and experienced the most symptoms; village D reported the best general health and experienced the fewest symptoms. Of all of the symptoms evaluated, rash was the most commonly reported, followed by headache and coughing. Blood in urine was the least frequent (Table 2). These individual symptoms were compared with metals in the biological samples. The only one to show a significant relationship was coughing and blood cadmium via the GEE models. Those with higher levels of blood cadmium reported more frequent coughing ($P = 0.0092$).

Metal Biomarker Levels

A significant difference is observed in manganese levels in whole blood between males and females (Table 3); no significant differences in whole blood lead or cadmium levels were observed for any demographic variable. There were significant differences between groups in serum levels for some metals (Table 3). Females, low-income participants and low-educated participants had higher levels of both zinc and copper in serum. Thirty percent of participants had whole blood lead levels that exceeded the American Conference of Governmental Industrial Hygienists (ACGIH)

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TABLE 1. Participant Characteristics by Village

Variable and Category	Count (*n*)	Total (*N* = 130)	Village A (*n* = 25)	Village B (*n* = 39)	Village C (*n* = 22)	Village D (*n* = 45)	*P*
Mean age (SD), y	129	45.2 (13.5)	46.1 (16.0)	46.1 (11.4) (12)	41.0 (11.0)	46.9 (14.3)	0.388
Number of children in household (SD)	119	2.1 (1.0)	1.9 (1.2)	2.2 (0.8)	1.8 (0.4)	2.1 (1.2)	0.336
	Count (*n*)				*N* (%)		
Male sex	130	71 (54.6)	14 (56)	19 (48.7)	13 (59.1)	25 (58.1)	0.832
Households w/children	130	118 (90.1)	22 (88.0)	37 (94.9)	15 (68.2)	44 (97.8)	0.0004
Marital status	130						0.004
Single		9 (6.9)	3 (12.0)	1 (2.6)	5 (22.7)	0 (0)	
Married		115 (88.5)	20 (80.0)	37 (94.9)	17 (77.3)	41 (91.1)	
Divorced		2 (1.5)	0 (0)	0 (0)	0 (0)	2 (4.4)	
Widowed		4 (3.1)	2 (8.0)	1 (2.6)	0 (0)	1 (2.2)	
Education	130						0.745
Primary		97 (74.6)	19 (76.0)	28 (71.8)	15 (68.2)	35 (79.5)	
Secondary and up		33 (25.4)	6 (24.0)	11 (28.2)	7 (31.8)	9 (20.5)	
Monthly income	130						0.018
<5K Baht (143 USD)	36 (27.7)	6 (24.0)	13 (34.2)	10 (45.5)	7 (15.6)		
5–10K Baht (143–286 USD)	45 (34.6)	14 (56.0)	11 (29.0)	3 (13.6)	17 (37.8)		
10K+ Baht (286 USD)	49 (37.7)	5 (20.0)	14 (36.8)	9 (40.9)	21 (46.7)		
General health	130						<0.0001
Poor health		32 (24.6)	6 (24.0)	10 (25.6)	2 (9.1)	14 (31.8)	
Good health		64 (49.2)	13 (52.0)	29 (74.4)	8 (36.4)	14 (31.8)	
Excellent health		34 (26.2)	6 (24.0)	0 (0)	12 (54.6)	16 (36.4)	
Symptom prevalence	126						0.0003
No symptoms		62 (49.2)	10 (43.5)	13 (35.1)	20 (90.9)	19 (43.2)	
Occasional to always	64 (50.8)	13 (56.5)	24 (64.9)	2 (9.1)	25 (56.8)		

P values are taken from chi-square tests looking at associations between villages.

Biological Exposure Index (BEI) level of 20 μg/dL[20]; no participants had whole blood cadmium levels more than 5 μg/L or urinary cadmium levels more than 3 μg/g creatinine (data not shown).

Participants with excellent self-reported health had lower blood lead, log blood manganese, serum zinc, and urinary nickel levels and higher serum copper levels in comparison with those with poor self-reported health (Table 3). These trends are inconsistent, however, when compared with whether or not people reported symptoms. Those with fewer self-reported symptoms had lower levels of serum copper but higher levels of blood lead and serum zinc.

Associations Between Metal Biomarker Levels and Health

After adjustment for education, age, sex, and village, greater levels of cadmium in blood were most strongly and consistently associated with adverse health (Table 4). For example, a 0.8 μg/L higher blood cadmium level was associated with an 80% greater odds of poor general health (95% confidence interval [CI] of odds ratio [OR]: 1.2 to 2.0) and a 50% increased odds of symptoms (95% CI of OR: 1.0 to 1.9). Greater blood lead levels were unexpectedly associated with lower prevalence of symptoms but greater odds of poor health, though these findings could not be distinguished from no association. For the remaining biomarkers in Table 4 (serum zinc and copper, urinary nickel, and blood manganese), the odds ratios for prevalence of symptoms and poor general health were in opposite directions. No associations were found for cadmium in the urine and zinc in serum.

TABLE 2. Specific Symptom Prevalence

Symptom	Symptom Prevalence (%)* Rarely or Never	Occasionally, Always or Frequently
Rash	73.0	27.0
Headache	73.8	26.2
Blood in urine	100.0	0
Blood in stool	97.6	2.4
Cough	82.5	17.5
Abnormal heartbeat	92.9	7.1
Watery stool	94.4	5.6
Fever	88.9	11.1

*$N = 126$ for all symptoms.

DISCUSSION

The goal of this study was to examine the relationship between metal levels in the body and self-reported health among workers of a community engaging in e-waste recycling. A sizeable fraction of participants were found to exceed the CDC's recommended exposure limits for lead in adults (5.0 μg/dL),[21] but no participants had concentrations higher than exposure limits for workers (20.0 μg/dL). In addition, no worker had concentrations of blood or urinary cadmium in excess of AGCIH BEI[20] limits. Blood cadmium was most strongly and consistently associated with adverse health, with more mixed results for other metals. BLL was counter to expectation, predictive of a lower prevalence of symptoms. In contrast, high BLL was predictive of worse general health, though this was not statistically significant. Like lead, urinary nickel and blood manganese had contradictory findings between the prevalence of severe symptoms and odds of poor general health models. These inconsistencies highlight the need for further research, including dietary intake considerations. In addition, the latency period for symptoms and general health impact from exposure to metals at lower levels may be on the order of many years.[22]

Blood lead has been a focus of much of current e-waste research, finding e-waste workers with higher BLL than control groups.[5,9] Research has shown a number of negative health outcomes associated with higher levels of blood lead; however, low-

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TABLE 3. Heavy Metals Biomarker Levels by Demographics and Health Status

		Serum		Urine Creatinine-Corrected			Blood	
Variable	Category	Zinc (μg/L)	Copper (μg/L)	Cadmium (μg/g Cr)	Nickel (μg/g Cr)	Lead (μg/dL)	Cadmium (μg/L)	Log Manganese (μg/L)
ACGIH BEI[20]				3.0	N/A	20.0	5.0	N/A
Total *N*		101	101	99	94	63	29	101
Total		1019.1 (183.7)	1084.2 (244.7)	0.8 (0.3)	4.7 (3.9)	4.9 (1.9)	1.7 (0.6)	2.7 (0.4)
Sex	Male	1007.2 (186.6)	1013.5 (162.3)***	0.8 (0.3)	4.4 (3.4)	5.0 (1.9)	1.8 (0.6)	2.7 (0.4)
	Female	1034.1 (183.1)	1173.2 (298.5)***	0.8 (0.3)	5.0 (4.3)	4.7 (1.9)	1.6 (0.5)	2.7 (0.4)
Monthly income	< 5K Baht	1051.0 (207.7)	1027.9 (135.1)	0.8 (0.4)	5.2 (4.1)	5.3 (2.7)	1.3 (0.6)	2.6 (0.2)
	5–10K Baht	1001.1 (153.8)	1171.5 (334.6)	0.8 (0.2)	5.0 (3.7)	4.7 (1.4)	1.8 (0.3)	2.7 (0.5)
	10K+ Baht	1022.8 (194.3)	1033.0 (167.1)	0.8 (0.3)	4.1 (3.8)	4.8 (1.7)	1.8 (0.7)	2.7 (0.3)
Education	Primary	1022.2 (199.6)	1080.8 (200.2)	0.8 (0.3)	5.2 (4.1)	5.1 (2.1)	1.7 (0.5)	2.7 (0.4)
	Secondary	1013.8 (135.2)	1099.9 (348.2)	0.7 (0.1)	3.5 (2.7)	4.3 (1.2)	1.8 (0.7)	2.6 (0.4)
General health	Poor health	1023.3 (242.0)	1052.8 (266.4)	0.9 (0.4)	6.7 (4.1)***	5.2 (2.9)	1.6 (0.6)	2.6 (0.3)
	Good health	1021.7 (136.9)	1108.2 (201.7)	0.8 (0.2)	4.5 (3.3)***	5.0 (1.8)	1.8 (0.6)	2.7 (0.3)
	Excellent health	1002.2 (208.1)	1067.7 (308.3)	0.8 (0.2)	3.2 (4.2)***	4.5 (1.5)	1.6 (0.5)	2.7 (0.6)
Symptom	No symptoms	1032.2 (206.9)	1058.2 (260.3)	0.8 (0.4)	4.9 (4.2)	5.1 (2.1)	1.6 (0.5)	2.6 (0.4)
	Occasional to always	1021.2 (166.3)	1104.1 (243.2)	0.8 (0.2)	4.5 (3.6)	4.8 (1.7)	1.8 (0.7)	2.7 (0.4)

*Significant at $P<0.05$.
**Significant at $P<0.005$.
***Significant at $P<0.001$.

level chronic exposures are not expected to produce symptoms.[23] Therefore, our findings may indicate chronic, low-level exposures rather than no exposure to lead in e-waste.

In comparison to samples taken from a recycling site in Ghana, the Thai worker population had a higher mean level of blood manganese, lower levels of blood lead, and comparable levels of blood cadmium.[24] Further highlighting the variation between e-waste worksites, another study of 75 workers in Accra, Ghana found higher levels of blood lead, similar levels of urinary nickel, and lower levels of blood and urinary cadmium.[25] In comparison with US and German background levels, our Thai population of individuals in a community with e-waste recycling had higher levels of urinary nickel, urinary cadmium, and blood lead, but lower levels of blood cadmium.[25] Levels of blood cadmium were higher in this study than in most studies on Chinese e-waste workers, though blood lead was lower in the Thai population than studies completed in China.[25] E-waste recycling workers in more established sites like Ghana and China may have a different body burden of metals that are a result of a greater cumulative exposure, different recycling activities, work practices, or background levels from other sources. In addition, e-waste sites in these countries are likely older and may therefore have a higher environmental load of metals from recycling activities than is found in the Thai study community. In future research of this site, body burden of metals should be compared with a background population elsewhere in Thailand. Nonetheless, this work adds to a nascent literature on the human health impacts of e-waste recycling.

This study differs from the collection of e-waste research already published in a number of ways. First, the recycling site selected is newer than the other sites commonly studied, and the workers from this study are older and have a higher representation of female workers. A cohort study done in Ghana found their worker

TABLE 4. Adjusted Associations Between Metal Biomarker Levels and Indicators of Health in Four E-Waste Communities in Thailand*,†

Prevalence of Any Symptoms	Interquartile Range	Odds Ratio (95% Confidence Interval)	*P*
Serum zinc (μg/L)	179.0 (909.0–1088.0)	1.1 (0.8–1.5)	0.613
Serum copper (μg/L)	217.6 (944.0–1161.0)	1.0 (0.9–1.2)	0.565
Urinary nickel (μg/g Cr)	3.7 (2.3–5.96)	1.7 (1.2–2.2)	0.047
Blood lead (μg/dL)	1.7 (3.5–5.2)	1.2 (0.9–1.5)	<0.001
Blood cadmium (μg/L)	0.8 (1.2–2.0)	1.5 (1.0–1.9)	0.508
Blood manganese (μg/L)	0.5 (2.4–2.9)	0.8 (0.6–1.0)	0.309
Odds of Poorer General Health	**Interquartile Range**	**Odds Ratio (95% Confidence Interval)**	***P***
Serum zinc (μg/L)	179.0 (909.0–1088.0)	0.9 (0.7–1.2)	0.507
Serum copper (μg/L)	217.6 (944.0–1161.0)	1.2 (0.6–1.7)	0.740
Urinary nickel (μg/L)	3.7 (2.3–5.96)	0.8 (0.6–1.0)	0.001
Blood lead (μg/dL)	1.7 (3.5–5.2)	0.7 (0.5–0.9)	0.222
Blood cadmium (μg/L)	0.8 (1.2–2.0)	1.8 (−0.5 to 4.0)	0.053
Blood manganese (μg/L)	0.5 (2.4–2.9)	1.6 (0.4–2.8)	0.095

*All models were adjusted for sex, age, and education level while accounting for clustering by village.
†Urinary Cadmium was not reported here due to the high number of nondetectable samples.

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population ($n = 69$) to be largely male (58 males, 11 females) and much younger (average age = 26 years) than the cohort in this study.[24]. Asante et al reported an average age of 20 in 40 e-waste workers.[26,27] Another important difference is that much of the previous e-waste research concerning human health outcomes is specific to children, developmental outcomes, or cellular changes[5]. Research on worker's knowledge of health hazards in Ghana asked workers about health issues similar to the symptoms reported in this study, but did not include quantifiable results. They found workers complained of coughing, fever, and abdominal pain, but that these symptoms were present before the workers began participating in e-waste recycling work.[28] Research done in Guiyu, China, on a group of children showed higher levels of cadmium and manganese in blood to be associated with coughing and wheezing, but touched on no other symptoms.[29] With our focus on early health indicators in an e-waste exposed population, our research contributes to an existing research gap in the field.

Our study has a number of limitations. We were only able to examine a few metals for this study. In addition, our study design was cross-sectional, raising issues of reverse causality, selection bias, and potentially increasing the measurement error in our estimates. Similarly, self-reported symptoms experienced by workers may not be indicative of true long-term self-reported health status and may not be a representative reflection of a worker's entire exposure history. In addition, we do not have a local background group to qualify differences between the e-waste workers and the general Thai population. Finally, our sample size was restricted by available funding and the size of the community we studied. The relatively small sample size of the study limited our statistical power to detect differences between groups, and it is likely that we have underestimated the adverse health effects associated with metal exposures from e-waste recycling activities.

This study is one of the first to investigate health and heavy metals in e-waste recycling workers in Thailand, a growing e-waste destination. A number of participants exceeded US occupational health limits for lead in blood, and for cadmium in both urine and blood. We found a number of inconsistencies in the relationships between nonserum heavy metals reporting severe symptoms, and general health. This could suggest a distinction between self-reported symptoms and self-reported health, or a need for more understanding of the body burden of these metals. The variation between the four villages in demographics, health, and work should be addressed in future research at this site and an intervention created. Workers in e-waste recycling locations may be subject to chronic occupational and environmental exposures to metals, and should be explored in future studies on recycling in Thailand.

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