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Metal concentrations in pregnant women and neonates from informal electronic waste recycling

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Abstract

Electronic waste (e-waste) is the fastest growing solid waste stream worldwide and mostly ends up in developing countries where residents use primitive methods for recycling. The most infamous e-waste recycling town, Guiyu in Southeast China, has been recycling since the mid-1990s. E-waste contains several harmful chemicals, including lead (Pb), cadmium (Cd), chromium (Cr), and manganese (Mn). In 2011–12, the e-waste Recycling Exposures and Community Health (e-REACH) Study enrolled 634 pregnant women living in Guiyu and Haojiang, a control site, both in Shantou, China. The women completed a questionnaire and gave maternal blood, cord blood, and maternal urine, which were analyzed for Pb, Cd, Cr, and Mn. Maternal blood Pb, Cd, and Cr concentrations were significantly higher in Guiyu compared to Haojiang. In Guiyu, the geometric mean of Pb concentration in maternal blood was 6.66 µg/dL (range: 1.87 – 27.09 µg/dL) and was 1.74-fold greater than in Haojiang (95% CI: 1.60, 1.89). In cord blood, Pb concentration was 1.53-fold higher in Guiyu (95% CI: 1.38, 1.68). In maternal urine, Cd (ratio: 2.15, 95% CI: 1.72, 2.69) and Mn (ratio: 2.60, 95% CI: 2.04, 3.31) concentrations were significantly higher in Guiyu in comparison to Haojiang. In conclusion, pregnant women in Guiyu were at risk for increased exposure to heavy metals.

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Conflict of Interests

The authors declare no conflicts of interest.

Keywords

Electronic waste; recycling; lead; cadmium; chromium; manganese

Introduction

Electronic waste, or e-waste, describes a wide variety of discarded consumer products that contain electrical or electronic components, including but not limited to televisions, computers, printers, cellular phones, and tablets (1). E-waste is the fastest growing solid waste stream worldwide, expected to exceed 50 million tons in 2017 (2). The United Nations Environment Programme (UNEP) estimates that most e-waste is illegally dumped or traded each year, translating to over US\$ 18 billion (3). Consumer electronic goods contain a number of precious metals, such as gold and silver that can be removed from the products and resold (1). However, they also contain many potentially hazardous components. Lead (Pb), cadmium (Cd), and nickel (Ni) are found in cathode ray tube (CRT) screens; Pb, Cd, Ni, manganese (Mn), and lithium (Li) are used in a various batteries, including rechargeable batteries; floppy disks and data tapes contain hexavalent chromium (Cr[VI]); mercury (Hg) is used liquid crystal display (LCD) screens; and polybrominated diphenyl ethers (PBDEs), tetrabromo-bisphenol-A (TBBPA), and polybrominated biphenyls (PBBs) are added as flame retardants (1, 2).

These chemicals can be harmful when released into the environment and lead to adverse health effects (4–6). In addition to the chemicals in the e-waste, informal (or primitive) e-waste recycling processes can produce harmful byproducts, such as dioxins and polycyclic aromatic hydrocarbons (PAHs) (7). Pb is a known neurotoxicant that distributes in the brain, liver, kidney, and bones (8, 9). Occupational studies of Cd and Cr exposure have identified them as human carcinogens (10–12). Cd exposure has also been associated with renal and skeletal toxicity (10, 11). In children, low level Cd exposure has been associated with learning disabilities, and high levels have been associated with lower birth weight and birth length and decreased IQ (13, 14). Cr irritates the skin and respiratory tract, and there is experimental evidence of its association with adverse renal, hepatic, gastrointestinal, cardiovascular, and reproductive outcomes (e.g., low birth weight, miscarriage), however epidemiological studies are limited (12). Mn is an essential nutrient for normal development; however, workers that were exposed to high levels experienced Parkinson-like symptoms (15–17). Recent studies have shown associations between higher levels of Mn exposure and adverse neurodevelopmental outcomes in children, as well as lower levels of Mn (18–21).

Although there are methods and technology available that can limit environmental and human exposure during the formal institutionalized e-waste recycling process (e.g., in developed countries), the majority of the world's e-waste collected for recycling ends up in informal e-waste recycling communities in China, India, Ghana, Nigeria, Mexico, and other developing countries (22, 23). Informal e-waste recycling involves sorting, dismantling, heating, burning, using acid baths, and storing improperly, often without the use of personal protective equipment (24). Once referred to as the “e-waste recycling capital of the world,” Guiyu town in the countryside of Shantou city, Guangdong Province of China, has been a

center of informal e-waste recycling since the 1990s (24–26). Of the town's 150,000 residents, approximately 75% of households were involved at the height of its e-waste recycling activity in the late 1990s to mid-2000s, along with an additional 100,000 migrant workers (24, 25).

Several studies have observed elevated levels of heavy metals, flame retardants, and other pollutants in the air, soil, and water samples from Guiyu (25–35). In addition, biological samples, including whole blood, serum, cord blood, and placenta, from Guiyu were found to have levels of Pb, Cd, Cr, PBDEs, and other pollutants higher than those from comparison sites within China (36–42). The majority of these studies measured exposure from neonates and children, however many of the chemicals found in e-waste are known to cross placenta during pregnancy so evaluating the mother's exposure will play a crucial role in understanding the exposure profile in the infants and targeting prevention in pregnant women (43).

Recognizing the complicated and unique exposure scenario from informal e-waste recycling, we conducted the e-waste Recycling Exposure And Community Health (e-REACH) study by simultaneously collecting environmental and biological samples in Guiyu and an unexposed control site (Haojiang), with the aim to investigate the scope of metal exposure in residential environment and community residents. The methods and results from the environmental samples have been published (44, 45), suggesting widespread exposure to Pb and Cd via inhalation, ingestion of soil and road dust, and possibly, dermal contact. This article will focus on heavy metal concentrations in maternal blood, maternal urine, and cord blood to examine the extent to which pregnant women and newborns are exposed to a mixture of potentially hazardous environmental contaminants.

Subjects and Methods

Study population

The e-REACH Study enrolled 634 pregnant women at delivery from local hospitals in Guiyu (n=314) and a control site, Haojiang (n=320), from September 2011–August 2012. Haojiang is located approximately 25 miles east of Guiyu within the same Shantou jurisdiction area and has no history of informal e-waste recycling. The women had to be ≥ 18 years, have a singleton pregnancy, and have lived in Guiyu or Haojiang during their pregnancy. Women with multiple pregnancies, a pregnancy from assisted reproductive technology, history of psychiatric disorders, history of thyroid disorder, or who lived outside of Guiyu or Haojiang for more than three months during pregnancy were excluded. The women were consented by study nurses and asked to complete a questionnaire to capture demographic, health status, family history, pregnancy, and exposure information. In addition to questions about e-waste exposure, participants were asked if they smoked during pregnancy, drank alcohol during pregnancy, and if they lived in a household where someone smoked at least 3 times a week. Questionnaire data were entered into the Remote Electronic Data Capture (REDCap) program, a secure, web-based application designed to aid in capturing data from research studies, using double entry and validation check (46). Study protocols were reviewed and approved by the Institutional Review Boards (IRBs) at Shantou University Medical College and the University of Cincinnati.

Sample Collection and Analysis

Maternal whole blood sample was drawn using 6mL Vacutainer tubes containing 10.8 mg of K₂-EDTA (dipotassium-ethylene diaminetetraacetic acid) as an anticoagulant and stored at -20°C (47). Umbilical cord blood was collected shortly after delivery with an EDTA-containing tube and stored at -20°C (39, 48, 49). Maternal urine samples were collected in the morning into polypropylene conical centrifuge tubes during the hospital stay (50). Concentrations of Pb, Cd, Cr, and Mn in maternal whole blood, cord blood, and maternal urine was determined by graphite furnace atomic absorption spectrometry (GFAAS) (Jena Zenit 650), which consists of an auto sampler (MPE60), with an injection volume set at 10 µL, using previously reported methods (51, 52). The parameters for measuring Pb, Cd, Cr, and Mn in maternal blood, cord blood, and maternal urine are described in Supplemental Table 1, including wavelength, lamp current, slit width, and temperatures for the drying, ashing, and atomization processes. Urine creatinine concentrations were determined by using commercially available kits (Cayman Chemical Company, China). For quality control, a spiked sample for each metal (15 µL at 100 ppb for Pb, Cr, and Mn, and 10 ppb for Cd) was added to a randomly chosen blood or urine sample (5 µL) for determination of recovery rate and recovery standard deviation with three repeats, using the quality control procedures for AAS. The mean and standard deviation of the recovery rate are shown in Supplemental Table 2.

Statistical Analysis

The geometric mean (GM) was calculated for Pb, Cd, Cr, and Mn concentrations in maternal blood, cord blood, and maternal urine. Maternal urine metal concentrations were adjusted for creatinine (µg/g creatinine). For participants without biospecimens or not tested, we treated them as missing. For concentrations that were below the lowest level of detection, we used the machine reading values (53). The metal concentrations were natural log transformed before data analysis. We calculated the ratio between metal concentrations in cord blood and maternal blood to assess placental transfer of these metals. The ratio of metal concentrations in Guiyu vs. Haojiang was calculated using the exponential values of the regression coefficients from general linear models with ln-metal concentrations as the dependent variable and site indicator as the independent variable. We adjusted for maternal age, maternal education, maternal occupation, maternal body mass index (BMI), gravidity, environmental tobacco smoke (ETS), and baby sex (only for cord blood metal concentrations).

We used generalized linear models with log link and binary distribution to calculate unadjusted and adjusted relative risks of elevated maternal blood Pb levels (BPb) 5 µg/dL, 10 µg/dL, and blood Cd levels (BCd) 1.7 µg/L. These cutoffs reflect United States Centers for Disease Control and Prevention (CDC) 2012 BPb reference levels (5 µg/dL) and 1991 blood lead “level of concern” (10 µg/dL), and the 95th percentile of US adult BCd levels in 2007–2008 (1.7 µg/L) (54, 55). We parsimoniously adjusted for maternal age, maternal BMI, gravidity, and ETS in the generalized linear models to achieve model convergence.

We completed an analysis in Guiyu participants only to compare those who responded that either or both parents of the newborn worked in the informal e-waste recycling during the pregnancy with those without direct parental involvement in informal e-waste recycling, with crude and covariates-adjusted analysis. All statistical analyses were performed using SAS 9.4 (SAS Institute Inc., Cary, NC, USA). We report regression coefficients and 95% confidence intervals (CIs) from regression models. All statistical tests are two-sided with an alpha level of 0.05.

Results

The demographic characteristics of the participants are shown in Table 1. The average age of the mothers was 26.5 years (standard deviation [SD] ± 4.36) in Guiyu and 28.3 years (SD ± 4.34) in Haojiang. This was the first pregnancy for 44.7% of the participants in Haojiang, compared to 20.4% in Guiyu. The mothers in Guiyu were less educated than those in Haojiang with about 88% in Guiyu with junior high school or less and 68.5% in Haojiang (Table 1). Maternal occupation was similar in both sites. Although nearly all the women from Guiyu and Haojiang reported no active smoking during pregnancy, 52.9% and 47.2% reported exposure to ETS during pregnancy, respectively.

In Guiyu, GM of maternal BPb concentrations (6.66 $\mu\text{g/dL}$), BCd (1.72 $\mu\text{g/L}$), Cr (BCr) (13.78 $\mu\text{g/L}$) were significantly higher than in Haojiang (BPb: 3.81 $\mu\text{g/dL}$; BCd: 1.43 $\mu\text{g/L}$; BCr: 8.90 $\mu\text{g/L}$) (Table 2). After adjusting for covariates, maternal BPb was 1.74-fold higher in Guiyu mothers compared to Haojiang mothers (95% Confidence Interval [CI]: 1.60, 1.89), BCd concentration was 1.21-fold higher (95% CI: 1.09, 1.34), and BCr concentration was 1.55-fold higher (95% CI: 1.37, 1.75). Conversely, BMn concentration in maternal blood was significantly higher in Haojiang, with the ratio of Guiyu vs. Haojiang at 0.83 (95% CI: 0.77, 0.90) (Table 2).

The concentration of Pb in cord blood was 1.53-fold higher (95% CI: 1.38, 1.68) and Mn was 1.11-fold higher (95% CI: 1.03, 1.21) in Guiyu than in Haojiang after covariate adjustment. Cd concentration in cord blood was significantly higher in Haojiang with the ratio of Guiyu vs. Haojiang at 0.78 (95% CI: 0.71, 0.87). Cr concentrations were also higher in Guiyu, but without statistical significance (Guiyu vs. Haojiang 1.32 [95% CI: 0.98, 1.78]). The cord to maternal blood ratio of metal concentrations was 0.84 for Pb, 0.13 for Cd, 0.46 for Cr, and 2.27 for Mn in Guiyu and 0.91, 0.18, 0.77, and 2.00, respectively, in Haojiang.

Maternal urinary metal concentrations were significantly higher in Guiyu after covariates adjustment with a Guiyu vs. Haojiang ratio of 2.15 (95% CI: 1.72, 2.69) for urinary cadmium (UCd). The ratio for urinary chromium (UCr) was 1.63 (95% CI: 1.09, 2.45) and for urinary manganese (UMn) was 2.60 (95% CI: 2.04, 3.31), indicating higher concentrations in Guiyu.

The Pearson correlation of each metal within the biospecimens was mostly not correlated at either site. We also observed moderate correlation between the metal concentrations in cord blood and maternal urine at both sites (Supplemental Table 3). For the same metal in

different biological samples, we observed a mild-to-moderate correlation between maternal and cord blood Pb: $r = 0.27$ ($p < 0.01$) in Guiyu and $r = 0.40$ ($p < 0.01$) in Haojiang.

Approximately 74% of the mothers in Guiyu had a BPb ≤ 5 $\mu\text{g/dL}$ and 16% had BPb ≥ 10 $\mu\text{g/dL}$ compared to 20% and 1.6% in Haojiang, respectively. The adjusted relative risk (RR) of mothers living in Guiyu was 4.03 (95% CI: 3.07, 5.29) for having an elevated BPb ≤ 5 $\mu\text{g/dL}$ and 8.75 (95% CI: 2.85, 26.86) for having an elevated BPb ≥ 10 $\mu\text{g/dL}$. Analogously, 51% of Guiyu participants had BCd concentrations ≥ 1.7 $\mu\text{g/L}$ compared to 36.6% in Haojiang. The adjusted RR for elevated BCd was 1.49 (95% CI: 1.16, 1.91) (Table 3).

Among Guiyu participants, 87 (27.7%) reported that either or both parents of the newborn worked with e-waste: 12.4% reported using the home to store e-waste, and 11.2% reported using the home to recycle e-waste on the questionnaire. We only found a slightly significant difference in maternal and cord BPb between parents involved in e-waste recycling and parents not involved with e-waste recycling after adjusting for covariates (Table 4). There were no other significant differences between the two groups in for metal concentrations in maternal blood, cord blood, and maternal urine.

Discussion

In this study with multiple metal exposure assessment in mother-neonate dyads, we identified significantly higher levels of heavy metals in maternal blood (Pb, Cd, Cr), maternal urine (Cd), and cord blood (Pb) in Guiyu in comparison to the control site, similar to the reported higher levels of Pb and Cd in the environmental samples of soil and road dust in Guiyu when compared to Haojiang (44, 45). Guiyu mothers had 1.74-fold higher levels of Pb and 1.21-fold higher levels of Cd in whole blood, after adjusting for covariates. Pb concentrations in cord blood were 1.53-fold higher in Guiyu compared to the control site.

Guiyu is a more rural community than Haojiang, as the latter is closer to a larger city (Shantou). The Guiyu participants were younger and less educated than the participants from Haojiang. Guiyu was traditionally a rice-growing community but switched to recycling e-waste in the 1990s, which is reflected in the relatively small group of self-reported farmers, 8.3% of mothers and 4.8% of fathers (24). The level of unemployment was similar between the two sites among the mothers, 37.6% and 35.9%, respectively. Most participants from both sites were exposed to ETS during pregnancy (52.9% in Guiyu, 47.2% in Haojiang), with only a handful reporting smoking during pregnancy.

Previous studies from Guiyu have found elevated levels of blood Pb, Cd, and Mn in children (37, 52, 56, 57). One of the first studies to determine exposure levels in children observed increased blood Pb (mean: 15.3 $\mu\text{g/dL}$, range: 4.4 – 32.67 $\mu\text{g/dL}$) in preschoolers under age 6 years (36). The BPb increased with age from a mean of 12.88 $\mu\text{g/dL}$ for ages 1–4 to 16.54 $\mu\text{g/dL}$ at ages 5–6, which is concerning since Pb concentrations typically decrease after age 2–3 years as children grow out of mouthing behaviors (36, 58). Another study confirmed the increasing concentrations of blood Pb with age observing that one year old children had a mean of 9.893 $\mu\text{g/dL}$ and gradually increased to 16.72 $\mu\text{g/dL}$ in 7–8 year old children (37). The same study determined a mean blood Cd concentration of 1.58 $\mu\text{g/L}$ (range: 0.00 – 9.72

µg/L). An additional study found elevated concentrations of Pb in cord blood with a mean of 11.59 µg/dL (range: 0.40 – 47.46 µg/L) (49). An analysis of Cd concentration in cord blood samples from 2004–2007 found a mean of 4.84 µg/L (range: 0.00 – 51.43 µg/L), which is much higher than our observations (41). This may be from the overall decline of informal e-waste recycling activity in Guiyu from 2007 to 2011. Within the same study, they observed decreasing concentrations of Cd in cord blood from 5.86 µg/L in 2004/2005 to 3.47 µg/L in 2007. Most of these studies focused on children 1–13 years old. A few investigators collected cord blood samples from neonates; however, they did not collect biological samples from the mothers. There have been a handful of studies that collected adult hair samples, which is a good biomarker for chemicals like Mn but not for Pb (59, 60). This study incorporates the mother's exposure to better characterize the biological exposure matrix of metals from informal e-waste recycling.

The cord to maternal blood metal ratios from our study were similar to literature. We observed a cord:maternal BPb ratio of 0.84 in Guiyu and 0.91 in Haojiang, which agrees with previous studies that observed ratios between 0.7 – 0.9 (61–63). The cord:maternal BCd ratio was similar between Guiyu (ratio: 0.13) and Haojiang (ratio: 0.18). Although Cd can pass through the placenta, it does not do so as easily as other metals (63, 64). Similarly, BCr had a cord:maternal ratio Guiyu at 0.46 and 0.77 in Haojiang. There is not much literature on the transfer of Cr from maternal to cord blood, but we found a similar ratio to Cr concentrations in patients who became pregnant after hip resurfacing with a ratio of approximately 0.30 (65). In contrast to BCd and BCr, we observed higher BMn in cord blood with a cord:maternal BMn ratio of 2.27 in Guiyu and 2.00 in Haojiang, which align with reported values of higher levels of Mn in cord blood than the mother in previous studies (63, 66, 67). The differences in BCd and BCr ratios between Guiyu and Haojiang could be based on other factors, like metallothionein, or the higher levels of metal concentration in Guiyu could have influenced the permeability of the placenta and the transport of metals in fetal circulation (68).

Although the BPb concentrations in Guiyu were significantly higher than in the control site, concentrations in Haojiang were high when compared to the United States. A recent analysis of 5000 participants across China determined that, though BPb concentration have been dropping in recent years, Chinese adults have BPb twice as high as US adults (range: 2.51 – 6.22 µg/dL) (69). The mothers in Guiyu have higher risk of having elevated BPb and BCd concentrations compared with Haojiang. Prenatal exposure to Pb and Cd has been associated with low birth weight, preterm birth, and delays or deficits in neurodevelopment (70–79).

Within Guiyu, there was little to no difference in metals concentrations between women with family involvement in e-waste recycling and those without such involvement, possibly suggesting widespread contamination by heavy metals. Decades of recycling e-waste using informal methods has created a community highly contaminated with heavy metals and other chemicals. Since the end of this study, many of the workshops within Guiyu have been shut down by the government or moved to a central recycling facility. On a recent trip to Guiyu, Greenpeace found limited recycling activities visible to a visitor, leaving people to wonder where the e-waste is going now (80). There is evidence that it is moving further into mainland China, Hong Kong, and other countries in Southeast Asia (80–82).

This study has several limitations. At the time of the study, the Chinese government was in the process of shutting down the local e-waste recycling workshops, creating a suspicious atmosphere in Guiyu towards outsiders. This may have prevented participants from completing the questionnaires to save their livelihood. Although we were able to include maternal biological samples, we were only able to collect them at delivery and could have missed opportunities to describe trimester-specific exposure levels. Some other relevant chemicals were not measured in this study, such as mercury (Hg), arsenic (As), PBDEs, polychlorinated biphenyls (PCBs), PAHs, and dioxin. We also did not measure metal concentrations in the placenta, which could explain some of the differences in the cord to maternal blood ratios. Despite the limitations, this study provides a unique cohort of pregnant women to determine the exposure levels from informal e-waste recycling in the community's vulnerable population. This is one of the first studies to comprehensively capture maternal and neonate biological samples from a community with intensive informal e-waste recycling and test for metals exposure. In addition, the simultaneous collection of environmental and biological samples confirmed the widespread contamination of heavy metals in Guiyu.

Informal e-waste recycling produces a mixture of exposures that are unique to each recycling site and depend on the recycling methods that are used and the type of e-waste that is recycled. This complex mixture is potentially harmful, not only to the recyclers, but also to the surrounding community. The amount of e-waste generated each year continues to grow and recycling is a profitable industry; therefore, steps should be taken to protect the workers and the surrounding community without taking away the economic benefits. Workers must be educated on the risks associated with exposures to chemicals, to not only themselves but also their families and the surrounding community.

Supplementary Material

Refer to Web version on PubMed Central for supplementary material.

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Table 1Demographics of study participants in Guiyu (recycling site) and Haojiang (non-recycling site)^a

Characteristics	Guiyu n (%)	Haojiang n (%)
	n = 314	n = 320
Age (mean $\pm$ SD, years)	26.5 $\pm$ 4.36	28.3 $\pm$ 4.34
Education		
Elementary school or less	96 (30.6)	61 (19.1)
Junior high school	181 (57.6)	158 (49.4)
High school	17 (5.4)	56 (17.5)
College or above	4 (1.3)	33 (10.3)
Occupation		
Farmer	26 (8.3)	47 (14.7)
Industrial Worker	71 (22.6)	55 (17.2)
Managerial/Professional	29 (9.2)	31 (9.7)
Unemployed	118 (37.6)	115 (35.9)
Other	30 (9.6)	42 (13.1)
Father's Occupation		
Farmer	15 (4.8)	42 (13.1)
Industrial Worker	82 (26.1)	91 (28.4)
Managerial/Professional	61 (19.4)	83 (25.9)
Unemployed	18 (5.7)	25 (7.8)
Other	71 (22.6)	64 (20.0)
Gravidity		
0 pregnancies	64 (20.4)	143 (44.7)
1 pregnancy	105 (33.4)	132 (41.3)
2–3 pregnancies	110 (35.0)	43 (13.4)
>4 pregnancies	32 (10.2)	1 (0.3)
Maternal alcohol drinking during pregnancy	8 (2.6)	6 (1.9)
Maternal smoking during pregnancy	2 (0.6)	1 (0.3)
Environmental tobacco smoke	166 (52.9)	151 (47.2)
Baby Sex male	174 (55.4)	168 (52.5)
Frequency of cleaning home		
Less than once a week	18 (5.7)	40 (12.5)
1–2 times a week	87 (27.7)	79 (24.7)
More than 2 times a week	118 (37.6)	142 (44.4)
Mother and/or Father involved in e-waste recycling	87 (27.7)	0 (0)
Used home to store e-waste	39 (12.4)	0 (0)
Used home to recycle e-waste	35 (11.2)	0 (0)
Distance from home to e-waste recycling workshop		
1km	49 (15.6)	228 (71.3)
200–999 m	65 (20.7)	0 (0)
< 200m	66 (21.0)	0 (0)

Characteristics	Guiyu n (%)	Haojiang n (%)
	n = 314	n = 320
Visits to e-waste recycling workshop		
Never	176 (56.1)	289 (90.3)
Once a week	30 (9.6)	0 (0)
2–6 times a week	40 (12.7)	0 (0)
Daily	24 (7.6)	0 (0)

^aTotal numbers may vary due to missing data

Table 2
Concentrations of Pb, Cd, Cr, and Mn in maternal blood, cord blood, and maternal urine in Guiyu and Haojiang

Metal	LOD ^a	Guiyu n=314						Haojiang n=320						Guiyu vs. Haojiang Concentration Ratio			
		n Missing	n<LOD	GM	Min	Max	CB:MB Ratio	n Missing	n<LOD	GM	Min	Max	CB:MB Ratio	Unadjusted		Adjusted ^b	
														Ratio	95% CI	Ratio	95% CI
Maternal Blood																	
Pb (µg/dL)	0.20	0	0	6.66	1.87	27.09		0	0	3.81	0.86	16.12		1.75	1.64, 1.86 [*]	1.74	1.60, 1.89 [*]
Cd (µg/L)	0.20	0	0	1.72	0.26	4.83		6	6	1.43	0.10	7.03		1.20	1.11, 1.29 [*]	1.21	1.09, 1.34 [*]
Cr (µg/L)	1.67	1	0	13.78	2.35	189.40		0	0	8.90	4.38	175.40		1.55	1.42, 1.69 [*]	1.55	1.37, 1.75 [*]
Mn (µg/L)	1.12	1	0	25.93	8.38	320.50		0	0	28.51	4.41	170.90		0.91	0.86, 0.96 [*]	0.83	0.77, 0.90 [*]
Cord Blood																	
Pb (µg/dL)	0.20	20	0	5.03	1.53	26.36	0.84	6	0	3.18	0.59	12.70	0.91	1.58	1.48, 1.70 [*]	1.53	1.38, 1.68 [*]
Cd (µg/L)	0.20	21	171	0.18	0.06	1.96	0.13	16	124	0.23	0.10	2.25	0.18	0.80	0.75, 0.86 [*]	0.78	0.71, 0.87 [*]
Cr (µg/L)	1.67	108	39	4.02	0.10	24.53	0.46	87	60	3.52	0.03	19.94	0.77	1.14	0.93, 1.41	1.32	0.98, 1.78
Mn (µg/L)	1.12	28	0	52.93	20.66	165.90	2.27	29	0	49.69	16.60	131.20	2.00	1.07	1.01, 1.13	1.11	1.03, 1.21 [*]
Maternal Urine (µg/g creatinine) ^c																	
Cd	0.04	68	2	1.06	0.05	18.71		75	6	0.54	0.03	16.47		1.94	1.65, 2.29 [*]	2.15	1.72, 2.69 [*]
Cr	0.08	107	8	1.66	0.01	114.67		103	18	0.97	0.01	35.12		1.72	1.29, 2.29 [*]	1.63	1.09, 2.45 [*]
Mn	0.06	82	0	7.62	0.84	158.26		54	0	3.14	0.13	40.47		2.43	2.05, 2.88 [*]	2.60	2.04, 3.31 [*]

^aWe used the machine reading values of those below LOD

^bAdjusted for maternal age, maternal BMI, maternal education, maternal occupation, gravidity, ETS

^cThe unit of limit of detection in maternal urine was 1 µg/L. LOD: limit of detection; CB: Cord blood; MB: Maternal blood

^{*}p<0.05

Table 3

Unadjusted and adjusted relative risk for elevated blood lead ($\geq 5 \mu\text{g/dL}$ and $\geq 10 \mu\text{g/dL}$) and cadmium levels ($\geq 1.7 \mu\text{g/L}$)^b

Variable	Guiyu n (%)	Haojiang n (%)	Unadjusted RR [RR (95% CI)]	Adjusted RR ^a [RR (95% CI)]
BLL $\geq 5 \mu\text{g/dL}$	232 (73.9)	64 (20.0)	3.70 (2.94, 4.64) *	4.03 (3.07, 5.29) *
BLL $\geq 10 \mu\text{g/dL}$	50 (15.9)	5 (1.6)	10.19 (4.12, 25.22) *	8.75 (2.85, 26.86) *
BCd $\geq 1.7 \mu\text{g/L}$	160 (50.9)	117 (36.6)	1.39 (1.16, 1.67) *	1.49 (1.16, 1.91) *

^a Adjusted for maternal age, maternal BMI, gravidity, ETS

^b Cadmium levels from the CDC Fourth Report 95th percentile of adults in the United States

* p<0.01

Table 4
Exposure differences in the parents involved in e-waste recycling compared to those who are not

Guiyu Parents Involved with Informal E-waste Recycling				Guiyu Parents Not Involved with Informal E-waste Recycling				Involved vs. Not Involved Metal Ratio			
n = 87				n = 227				Unadjusted	Adjusted ^a		
	LOD ^a	n Missing	GM	Min	Max	n Missing	GM	Min	Max	[Ratio (95% CI)]	[Ratio (95% CI)]
Maternal Blood											
Pb (µg/dL)	0.20	0	6.99	3.08	27.09	0	6.54	1.87	25.97	1.07 (0.96, 1.19)	1.14 (1.01, 1.30)*
Cd (µg/L)	0.20	0	1.65	0.26	4.52	0	1.74	0.27	4.83	0.95 (0.85, 1.05)	0.87 (0.77, 1.00)
Cr (µg/L)	1.67	0	14.30	5.07	189.40	1	13.59	2.35	140.70	1.05 (0.90, 1.23)	0.99 (0.80, 1.22)
Mn (µg/L)	1.12	0	26.88	8.38	320.50	1	25.58	11.19	50.42	1.05 (0.97, 1.14)	1.03 (0.92, 1.13)
Cord blood											
Pb (µg/dL)	0.20	9	5.84	2.35	16.99	11	4.77	1.53	26.36	1.22 (1.08, 1.38)*	1.29 (1.11, 1.51)*
Cd (µg/L)	0.20	9	0.18	0.07	0.76	12	0.19	0.06	1.96	0.96 (0.86, 1.07)	1.00 (0.87, 1.15)
Cr (µg/L)	1.67	35	3.64	0.10	18.42	73	4.16	0.32	24.53	0.88 (0.66, 1.16)	0.87 (0.60, 1.27)
Mn (µg/L)	1.12	10	51.04	25.33	101.70	18	53.64	20.66	165.90	0.95 (0.88, 1.03)	0.95 (0.86, 1.05)
Maternal Urine (µg/g creatinine)											
Cd	0.04	15	1.05	0.05	18.71	53	1.06	0.08	16.47	0.99 (0.77, 1.28)	1.25 (0.91, 1.72)
Cr	0.08	31	1.73	0.01	96.75	76	1.64	0.01	114.67	1.05 (0.66, 1.68)	0.94 (0.50, 1.77)
Mn	0.06	21	7.21	1.03	72.77	61	7.79	0.84	158.26	0.93 (0.70, 1.22)	0.80 (0.54, 1.17)

^aWe used the machine reading values of those below LOD

^bAdjusted for maternal age, maternal BMI, maternal education, maternal occupation, gravidity, and ETS

* p<0.05