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ORIGINAL ARTICLE

COMPARISON OF MONOAMINE OXIDASE AND SELECTED HEAVY METALS LEVELS IN THE BLOOD AND THE WORKPLACE AMONG E-WASTE SORTING WORKERS IN UBON RATCHATHANI PROVINCE, THAILAND

Kornwika Harasarn[1], *Nantaporn Phatrabuddha*[1], *Pratchaya Kaewkaen*[2],
Wanlop Jaidee[3], *Anamai Thetkathuek*[1,*]

[1]Department of Industrial Hygiene and Safety, Faculty of Public Health, Burapha University,
Chonburi 20131, Thailand
[2]College of Research Methodology and Cognitive Science, Burapha University, Chonburi 20131, Thailand
[3]Department of Public Health Foundations, Faculty of Public Health, Burapha University,
Chonburi 20131, Thailand

ABSTRACT

Background. E-waste sorting workers usually separate electronic waste. Therefore, they can be exposed to heavy metals.
Objectives. This study compared monoamine oxidase (MAO) levels affected by the levels of lead (Pb), cadmium (Cd), and nickel (Ni) in the blood and their workplace among e-waste sorting workers (EWSW).
Material and methods. The exposed group included 76 EWSW, and the non-exposed group included 49 village health volunteers. An interview form was used to assess the risk factors. We measured Pb, Cd, and Ni on the work surfaces and in the blood, and MAO levels as a neurological enzymes.
Results. Among the EWSW, 42 were males (55.3%), and the mean age (SD) 48.0 (12.64) years, and income were 156.37 ± 88.08 USD. In the work areas of the exposed group, the concentration of Pb, Cd, and Ni were 245.042 (± 613.910), 0.375 (± 0.662), and 46.115 (± 75.740) µg/100 cm2, respectively, while the non-exposed group, the concentration of Pb, Cd, and Ni were 0.609 (± 0.934), 0.167 (± 1.171) and 1.020 (± 0.142) µg/100 cm2. Pb and Ni concentrations in the workplace of the exposed groups were statistically different from that of the non-exposed group. Pb, Cd, and Ni concentrations in serum were 6.411 ± 1.492 µg/dL, 0.9480 ± 0.350 µg/L, 2.568 ± 0.468 µg/L, respectively, while in the non-exposed group, the heavy metal concentrations were 6.411 ± 1.620 µg/dL, 0.909 ± 0.277 µg/L, 2.527 ± 0.457 µg/L. The MAO in the exposed group was 362.060 ± 97.981 U/L, while that in the non-exposed group was 369.771 ± 86.752 U/L. Moreover, MAO concentration was significantly different from Ni concentration ($p < 0.05$).
Conclusion. The electronic waste sorting workers should clean their work areas to reduce the Pb, Cd, and Ni levels on the working surfaces, and health surveillance should be performed.

Key words: *monoamine oxidase (MAO), lead, cadmium, nickel, work area, e-waste sorting workers, Ubon Ratchathani*

INTRODUCTION

Electronic waste sorting workers (EWSW) are informal workers in the northeastern region of Thailand, including Ubon Ratchathani Province. They usually separate electronic waste (EW) around their house for sorting and exporting for further distribution to the EW disposal plant [1]. Therefore, they can be exposed to chemicals and heavy metals [2] such as lead (Pb), cadmium (Cd), and nickel (Ni) [3, 4, 5] during electronic waste sorting [2, 6, 7].

Due to improper hygienic practices, the workers are likely exposed to Pb, Cd, and Ni from e-waste segregation, through inhalation, ingestion, and skin contact [5, 8]. Exposure to these substances causes acute and chronic health implications. If the exposure to these three substances is continued even in low doses, chronic symptoms, especially affecting the central nervous system, will result [9] due to the disruption of neurotransmitters.

The toxicity mechanisms of Pd, Cd, and Ni, as studied in animals with Pb [10], Cd [11], and Ni [12], and in human studies, have shown that Pb [8, 9],

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Corresponding author: Anamai Thetkathuek, Department of Industrial Hygiene and Safety, Faculty of Public Health, Burapha, University, Chonburi, 20131, Thailand, e-mail: anamai@buu.ac.th

Cd [13], and Ni [14] can enter the blood and brain to activate enzymes in the central and peripheral neurotransmitters including monoamine oxidase neurotransmitter type A (MAO-A) and serotonin (Serotonin: 5-Hydroxytryptamine, 5-HT). Pd, Cd, and Ni can also interfere with the mechanism of calcium ion signaling ($Ca2^+$) [15,16] and enter the Raphe nuclei neurons to produce the neurotransmitter serotonin in the hippocampus [17] and secreted from the brain stem by the serotonin messenger which is responsible for controlling the cognitive system, helping in learning and memory [18].

Exposure to Pd, Cd, and Ni may increase the activation of the enzyme MAO-A in the neurotransmitter [19], which regulates metabolism and catalyzes oxidizing reactions into the metabolism of neurotransmitters. Monoamines include doptopinephrine, epinephrine, and serotonin [20,21] by *Jaya Parasanthi* et al. [22]. In mice, damage to serotonin-producing neuron tissues was found, so MAO-A may play an essential role in activating several neurotransmitters, including serotonin [23]. When exposed to Pd, Cd, and Ni for longer, these heavy metals affect neurotransmitters damaging the central and peripheral nervous systems responsible for perception, comprehension, and memory [24, 25, 26].

Many risk factors may affect the biological indicators and the health effects of EWSW exposed to Pd, Cd, and Ni. These include personal characteristics such as gender, age, monthly income, education level, and body mass index (kg/m^2) [3, 5, 27, 28, 29, 30]; behavioral factors such as smoking and drinking alcohol [31]; and job characteristics factors such as year of working [32] number of working hours [33], and working area size [34]; personal hygiene factors such as improper hand washing, delay to change their clothes after work, washing the body immediately after home arrival [32, 35], lack of wearing personal protective equipment [36], and the amount of exposure to Pd, Cad, and Ni [4, 37].

Environmental and health monitoring must provide appropriate and timely health care for these workers. Moreover, health surveillance should be performed by collecting dust samples to assess these contaminated substances in the air in working areas [38] by measuring the surface wipe [39,40]. Therefore, we conducted the health surveillance study and primary health screening, such as detecting Pd, Cd, and Ni levels in the blood among the EWSW in the Bangkok Subdistrict Khueang Nai District, Ubon Ratchathani Province [5].

Recent studies that measured blood Pb levels among the EWSW in Ghana [41] found that the effects of Pd, Cd, and Ni exposure caused acute and chronic neurologic symptoms [15]. Moreover, a study of Pb blood levels of rats in India showed that low Pb levels activate neurotransmitter enzymes such as monoamine oxide (MAO) [10]. However, no similar study in humans was documented [8]. Similarly, no data have been reported on exposure to Pd, Cd, and Ni and their effects on the nervous system among the EWSW in Thailand. Therefore, this study compared the monoamine oxidase (MAO) levels in the nervous system classified by Pb, Cd, and Ni levels in the blood among EWSW in Ubon Ratchathani Province.

MATERIALS AND METHODS

Study site and population

For this analytical cross-sectional study, data were collected from November 2020 to April 2021. The study population included an exposure group, EWSW whose nature of work was sorting, disassembling, and incinerating parts, and electronic waste collection to wait for distribution within the housing area, and the group was out of reach by village volunteers in the Ubon Ratchathani Province. We calculated the sample size according to the following formula, $n = (Z_2\alpha/2\ \sigma_2)/e^2$ in which the exact population of *Dupont* and *Plummer* [42] is unknown, the confidence level ($Z\alpha$) = 1.96, e = 0.05, and the variance (σ) = 0.22 according to the findings of *Kshirsagar* et al. [43]. The required sample size was at least 74.37. Therefore, we used the estimated error of less than 5% at the 95% confidence level to prevent discrepancies in data collection by purposive sampling and analysis. Therefore, our study included 76 people in the exposure group and 49 non-exposed village health volunteers.

Data collection procedures

In this study, we used questionnaires and sample collection to quantify Pb, Cd, and Ni substances in the work surface. Blood samples were also collected to measure the levels of Pb, Cd, Ni, and MAO enzymes.

1. *Questionnaire:* It included five personal factors such as gender, age (years), monthly income (in USD), educational level, body mass index (BMI), congenital disease; three behavioral health factors, and job characteristics factors such as the number of working years, working hours, working area size. The legitimacy and validity of the structure and content of the interview questionnaires were verified by three independent experts. Moreover, the index of concordance (IOC) was determined using the formula $IOC = \sum R/N$. The interview form of this study had a coefficient of conformity of 0.726.

2. *Surface wipes:* We used the set of equipment comprised of heavy metal dust sampling paper such as Pb, Cd, Ni (Ghost wipes), sample tube, paper frame (Template), size 10 × 10 cm, powder-free rubber gloves label paper, permanent pen, plastic bag, adhesive tape, scissors, shoe cover bag storage box. Ghost wipes

sample submission form was sent to the lab every time with the collected samples. Every batch of the samples included quality control (field blank). We wiped to collecting samples in the work area. The sample collection per field blank was 10 to 1 by opening the wipe paper envelope, then unfolding the sample collection area and packing it back in a tightly closed plastic tube, amounting to one sample per sample collection. We collected eight blank field samples and 76 samples in the EW sorting sites. In the comparison group of 5 samples, field blanks were collected for a total of 49 samples [44].

Pb, Cd, and Ni in the working surface were measured by surface wipe. We collected the samples at the waste sorting area by using paper to wipe in an S-shape from left to right and around the edge of the paper frame (Template), then folded the paper in half, ensuring the sample inside, then placed sampling papers in the sample tube, labeled and sent the samples for particulate composition analysis to determine the content of Pb, Cd, Ni according to method ID-125G metal and metalloid particulates in workplace atmospheres (ICP Analysis) [45] at a laboratory in Bangkok.

3. *Blood sample collection to measure the levels of Pb, Cd, Ni, and monoamine oxidase (MAO) in the blood:* The registered nurse collected the blood samples from the participants at THPH according to the guideline provided [46]. The collected blood 8 mL was divided into two tubes: 5 mL in EDTA tubes for analysis of Pb, Cd, and Ni in the blood, and tubes without EDTA (3 mm doses) to analyze MAO type A.

After proper labeling, the samples were kept at 4°C. Then, the blood samples for analysis of Pb, Cd, and Ni in blood were sent to Khueang Nai Hospital Khueang Nai District, Ubon Ratchathani Province, within 24 hours after collection [35]. Blood samples for MAO-A level [8] were delivered to the laboratory in Chonburi Province within 24 hours [47]. For quality control, the analysis of heavy metals and MAO-A was repeated triplicate, with 10% of all samples re-analysis. However, the results of all field blank heavy metal content analyses must be lower than the Limit of detection.

Data analysis

Descriptive statistics included number, percentage, arithmetic mean, geometric mean, and standard deviation for personal factor, behavioral health factor, working factor, and Pb, Cd, and Ni concentration. Moreover, the median concentration of Pb, Cd, and Ni were analyzed between the exposure and non-exposure groups. We used multivariate analysis of variance to compare the mean Pb, Cd, and Ni concentration in the working surface waste sorting between the exposed and the non-exposed group and the concentrations of Pb, Cd, and Ni between their work surface and these in their blood, and the MAO-A level between the exposed and non-exposed groups or risk factors.

RESULTS

Demographic data

Of the 76 participants in the exposed group, most (55.3%) were male with mean age (SD) of 48 (± 12.645) years. Most of them completed primary school education (55, 72.4%). The average monthly income (SD) was 156.37 (± 88.08) USD, and the mean BMI was 23.00 (± 5.124) kg/m^2. Among them, 34.2% used medication that included diabetes (9, 11.8%), lipid reduction (9, 11.8%), and hypertension (6, 7.9%).

Health behaviors and job characteristics

Among the participants, 51.3% drank alcohol, smoking of 1.276 ± 0.450 cigarettes per day, and ate in the workplace (92.1%). In the exposed group, the average number of working years for EW sorting was 6.08 ± 3.973 years, and the average working hours per day was 7.80 ± 0.980 in the average area of e-waste sorting of 180.16 ± 306.185 squared meters. Most of their past work was farming (77.6%). Moreover, 92.1% and 96.1% wore gloves and arm protection while sorting EW.

The concentration of Pb, Cd, and Ni in the surface wipe (µg/100 cm^2) of the exposed and non-exposed groups

We measured the Pb, Cd, and Ni in dust content in the working surface (µg/100 cm^2) of 76 exposed groups and 49 in the non-exposed group. The median amount of particulate matter containing Pb greater than 2.0 µg/100 cm^2 was observed in 62 samples (49.6%) with the mean concentration of 149.224 (± 492.250) µg/100 cm^2. The standard value by OSHA [48] defines the Pb value in the operating surface area as 500.00 µg/100 cm^2.

The median Cd concentration in the operating surface area less than or equal to 0.000 µg/100 cm^2 was found in 89 samples (71.2%), with a mean concentration of 0.293 (± 0.898) µg/100 cm^2. At the same time, OSHA defines the Cd value in the operating surface area as 50.00 µg/100 cm^2.

The median Ni concentration in the operating surface area was within the standard range according to the OSHA, i.e., the amount was greater than 1 µg/100 cm^2 (49.6%), with a mean concentration of 28.1970 (± 63.022). However, there is no standardized value for Ni in the operating surface area (Table 1).

The blood level of heavy metals and monoamine oxidase (MAO-A)

The mean blood levels of Pb in the exposed and non-exposed groups were 6.4112 ± 1.49274 µg/dL and

Table 1. Concentration of Pb, Cd, and Ni in the surface wipe of the exposed and non-exposed groups

Concentration of heavy metals in dust at operating surface (µg/100cm^2)	Exposed group		Non-exposed group		Total		Standard (µg/100cm^2)	F	*p*-value
	n	%	n	%	n	%			
	76	100	49	100	125	100			
Lead (Pb)							500.00	19.512	<0.001*
≤ 2	17	22.4	46	93.9	63	50.4			
> 2	59	77.6	3	6.1	62	49.6			
Mean ± SD	245.042±613.910		0.609±0.934		149.224±492.250				
Min-Max	0.170-3,412.00		ND-3.80		ND -3,412.00				
GM ± GSD	24.888±12.159		0.3877±3.886		6.3694±18.839				
Cadmium (Cd)							50.00	0.675	0.207
≤ 0.00	41	53.9	48	98.0	89	71.2			
> 0.001	35	46.1	1	2.0	36	28.8			
Mean ± SD	0.375±0.662		0.1673±1.171		0.2938±0.898				
Min-Max	ND -3.20		ND -8.20		ND -8.20				
GM ± GSD	0.565±2.375		8.199±1		0.608±2.617				
Nickel (Ni)							No standardized value for Ni in the operating surface area.		
≤ 1	16	21.1	47	95.9	63	50.4		35.802	<0.001*
> 1	60	78.9	2	4.1	62	49.6			
Mean ± SD	46.115±75.740		1.020±0.142		28.1970±63.022				
Min - Max	0.180-368.0		1-2		ND -368.00				
GM ± GSD	11.040±7.555		0.3071±2.984		3.0262±11.608				

Note *Standard values are determined by the OSHA Tech manual method [48] because the amount of Cd on the surface of the workplace was below all standard values, and there is no standard value for nickel exposure on surfaces. Therefore, we grouped them according to the median values for these substances as follows: Pb = 2.00 µg/100 cm^2, Cd = 0.00 µg/100 cm^2, Ni = 1.00 µg/100 cm^2.

6.411 ± 1.620 µg/dL, respectively. Similarly, the mean blood Cd values of exposed and non-exposed groups were 0.974 ± 0.389 µg/dL and 0.909 ± 0.277 µg/dL, respectively. The mean blood Ni values of the exposed and non-exposed groups were 2.5958 ± 0.476 µg/dL and 2.527 ± 0.457 µg/dL, respectively. Moreover, the mean serum MAO in exposed and non-exposed groups were 362.060 ± 97.981 µg/dL and 369.771 ± 86.752 µg/dL, respectively (Table 2).

Factors influencing the blood Pb, Cd, and Ni levels

We compared the levels of Pb, Cd, and Ni in the blood of exposed and non-exposed groups classified by personal factors, health behavior, nature of work, and the concentration of these metals in the dust at the work surface.

Demographic factors: Income (USD) was significantly associated with the blood Pb level (F = 1.818, *p* = 0.041). However, behavioral health factors and job characteristics were not significantly different with blood Pb, Cd, and Ni concentrations. Similarly, the concentration of heavy metals in the dust on work surfaces (µg/100 cm^2) showed no significant difference with blood Pb, Cd, and Ni (Table 3).

Comparison of the concentration of monoamine oxidase (MAO) classified by factors

We compared the participants' MAO enzyme levels with their demographic factors, health behavior, job characteristics, and the concentration of Pb, Cd, and Ni in the dust at the operating surface (µg/100 cm^2). All variables, including sex, age, monthly income, education level, and BMI, were not statistically significantly associated with MAO enzyme level.

Moreover, the multivariate covariance analysis indicated that the MAO level in the blood was significantly different from the blood concentration of Ni (F = 4.282, Sig. = 0.041) (Table 4).

Table 2. Blood levels of Pb, Cd, and Ni and monoamine oxidase in the exposed and non-exposed groups

Levels of Pb, Cd, and Ni in blood	Exposed group		Non-exposed group		Total		OSHA Standard	Unit
	n	%	n	%	n	%		
	76	100	49	100	125	100		
Lead (Pb)							0-20	μg/dL
≤6.31	40	52.6	23	46.9	63	50.4		
>6.32	36	47.4	26	53.1	62	49.6		
Mean ± SD	6.411±1.492		6.411±1.620		6.411±1.537			
GM ± GSD	6.235±1.272		6.1972±1.310		6.2201±1.286			
Median IQR	6.285 (7.412)		6.670 (7.690)		6.310 (7.475)			
Min-Max	3.01 - 10.84		3.61-9.74		3.01-10.84			
Cadmium (Cd)							0-5	μg/L
≤ 0.91	38	50.0	28	57.1	66	52.8		
> 0.91	38	50.0	21	42.9	59	47.2		
Mean ± SD	0.974±0.389		0.909±0.277		0.948±0.350			
Median IQR	0.915 (1.152)		0.870 (1.050)		0.910 (1.130)			
Min-Max	0.20-2.10		0.30-1.15		0.20-2.10			
GM± GSD	0.894±1.545		0.865±1.387		0.883±1.484			
Nickel (Ni)							0-10	μg/L
≤2.53	37	48.7	26	53.1	63	50.4		
>2.53	39	51.3	23	46.9	62	49.6		
Mean ± SD	2.5958±0.476		2.527±0.457		2.568±0.468			
Median IQR	2.545 (2.817)		2.520 (2.720)		2.53 (2.785)			
Min-Max	1.55-4.05		1.24-3.61		1.24-4.05			
GM± GSD	2.555±1.1953		2.481±1.220		2.525±1.205			
Monoamine Oxidase (MAO)							< 650	U/L
≤353.000	42	55.3	24	49.0	66	52.8		
>353.001	34	44.7	25	51.0	59	47.2		
Mean ± SD	362.060±97.981		369.771±86.752		365.083±93.457			
Median IQR	340.95(415.30)		364.00(417.85)		353.800(415.30)			
Min-Max	175.30-615.20		153.80-610.10		153.80-615.20			
GM± GSD	349.462±1.308		359.666±1.274		353.427±1.294			

Table 3. Comparison of blood Pb, Cd, and Ni with personal factors, behavioral health factors, job characteristics, and the concentration of heavy metals in the dust at the operating surface

Factors	n	Blood Pb (μg/L)		Blood Cd (μg/dL)		Blood Ni (μg/dL)	
		GM ± GSD	F, p-value	GM ± GSD	F, p-value	GM ± GSD	F, p-value
Income (USD)			1.818, 0.041*		1.394, 0.163		0.367, 0.985
≤151.68	73	6.085±1.315		0.168±1.487		2.520±1.223	
>151.68	52	6.h415±1.240		0.942±1.472		2.533±1.179	
Concentration of heavy metals in the dust at the operating surface (μg/100 cm^2)							
Pb			0.750, 0.861				
≤ 2	63	6.231±1.293					
> 2	62	6.208±1.281					
Cd					1.483, 0.079		
≤ 0	89			0.874±1.440			
> 0.001	36			0.903±1.594			

Ni							0.888, 0.681
≤ 1	58					0.388±3.376	
> 1	62					54.663±7.47	

Remark: Independent variables that are insignificant to dependent variables are 1) individual factors such as sex, age (year), educational level, weight, and height; 2) health behavior factors such as alcohol consumption, smoking, and eating at the workplace; 3) job characteristics factors such as the number of working years, working hours working area size, past work history and use of personal protective equipment.

Table 4. Comparison of monoamine oxidase enzymes level with personal factors, behavioral health factors, job characteristics, and the concentration of heavy metals in the dust at the operating surface

Factors (µg/dL)	Monoamine oxidase: MAO (U/L)				
	SS	df	MS	F	*p-value*
Blood Pb	0.135	1	0.135	0.538	0.465
Blood Cd	0.102	1	0.102	0.406	0.525
Blood Ni	1.077	1	1.077	4.282	0.041*
Blood Pb and Cd	0.340	1	0.340	1.352	0.247
Blood Pb and Ni	0.021	1	0.021	0.083	0.773
Blood Cd and Ni	0.007	1	0.007	0.030	0.863
Blood Pb, Cd and Ni	0.092	1	0.092	0.364	0.547
Error	29.440	117	0.252		
Total	317.00	125			

Note Sig, $p < 0.05$*

Independent variables that are insignificant to dependent variables are as follows: personal factors, including sex, age, educational level, and BMI; behavioral health factors such as alcohol consumption, smoking, and eating at their workplace. The job characteristics included the number of working years, working hours, working area size, past working history, use of personal protective equipment, and Pb, Cd, and Ni contamination on work surfaces.

DISCUSSION

In this study, the majority of the exposed group was male (42; 55.3%), with a mean age of 48.00 ± 12.645 years, which was consistent with the study of *Thanthisawapop* et al. [27], who found that the mean age of the exposed group was 48.07 ± 13.19 years. Moreover, most participants completed primary school education (55, 72.4%), consistent with the study by *Kuntawee* et al. [3], which found that most of the EWSW in Thailand were primary school level. *Suraraks* and *Nawwan* [49] described that different education levels affect employees' financial compensation. As a result, workers who segregated EW took a longer working time to increase their monthly income, with an average monthly income of 156.37 (± 88.08) USD.

The minimum wage of Ubon Ratchathani Province is 325 baht (9.09 USD) per day [50], which was consistent with the findings of *Amankwaa* et al. [5]. Their study observed that the average daily income was approximately 6.96–18.10 USD among the EWSW in Ghana.

The mean BMI of the participants was 23.00 (± 5.1247) kg/square meter, which was the lower margin for obesity according to the World Health Organization's body mass index standard of 23.0–24.99 kg/square meter [51]. Therefore, a weight loss program should be considered for obese workers to minimize the risk of non-communicable diseases. Despite no history of underlying diseases in 50 participants (55.8%), 26 (34.2%) had drug treatment for metabolic diseases such as diabetes 9 (11.8%), blood pressure 6 (7.9%), and lipid-lowering 9 (11.8%). This is consistent with the report by *Burns* et al. [52] that found potential cardiovascular damage with abnormal heart rate in a group of workers exposed to e-waste.

In this study, 39 participants (51.3%) drank alcohol and smoked an average of 1.276 ± 0.450 cigarettes per day, which may impair cognitive abilities among these groups [53]. Moreover, EWSW is prone to exposure to toxins that enter the body and may have several adverse health effects, disrupting biochemical mechanisms and affecting decreased brain command. Therefore, educational programs are needed to raise awareness among these workers to abstain from alcohol and smoking. Moreover, 70 participants (92.1%) reported eating in the workplace, and 75 (98.7%) ate breakfast, lunch, and dinner in their workplace.

The exposure group had an average of 6.08 (± 3.9736) years in EW sorting with an average working hour per day of 7.80 (± 0.980) hours, which was consistent with the study of *Akormedi* et al. [33] that found the average working hour of 10 to 12 per day.

In this study, the average e-waste sorting work area was 180.16 (± 306.185) square meters. Although no study observed the relationship between working area size and the health status of the EWSW, a study by *Xue* et al. [54] indicated that heavy metal contamination was found elsewhere in their working area. Due to the diversity of the electronic e-wastes, the workers had to separate and organize e-waste into categories and clean the working area after every operation to minimize exposure to threats.

Regarding their working history, most were farmers (59, 77.6%) and mainly engaged in farming, but e-waste was also sorted throughout the year [55]. Interestingly, 70 participants (92.1%) wore hand protection such as gloves, 73 (96.1%) wore arm protection such as armbands or long-sleeved shirts 67 (88.2%) used safety shoes, such as sneakers or sneakers while working.

Comparison of Pb, Cd, and Ni exposure in a surface wipe (µg/100 cm^2) of exposed and non-exposed groups

The median of all levels of Pb, Cd, and Ni from a surface wipe (µg/100 cm^2) of 76 exposed groups and 49 in the non-exposed groups did not exceed the US OSHA standard [48]. However, a statistically significant difference in the Cd and Ni concentrations in the surface wipe was observed between the exposed and non-exposed groups ($p < 0.001$). Workers may be exposed to Cd and Ni long term, resulting in multi-system illnesses [56]. In the past decade, informal e-waste processing and disposal have taken place in many parts of Thailand [57]. This causes environmental contamination and threatens the health of EW sorters. Therefore, measures for health surveillance in these workers should be conducted according to the Occupational and Environmental Diseases Control Act B.E. 2562 [58]. Additionally, some measures on environmental management, such as cleaning the working area, should be performed regularly after completing their work to reduce Pb, Cd, and Ni contamination [59].

The comparison of concentrations of Pb, Cd, and Ni in the blood between the exposed and the non-exposed groups

In our study, the mean concentrations of the blood Pb, Cd, and Ni in 76 exposure groups and 49 non-exposed groups were within the standard [58]. Moreover, the concentrations of the three substances in the blood were not significantly different between the two groups (F = 1.830, 3.966, 0.535; p = 0.999, 0.284, 0.426).

The concentration of Pb in the blood was consistent with the study by *Kuntawee* et al. [3], which examined the blood lead levels of the exposure group, EWSW in Thailand, and the non-exposed group, farmers. In this study, no statistically significant difference in the blood lead concentrations was identified between the exposed and non-exposed groups. The e-waste sorting area in Ban Kok and Ban Klang in Thailand had insufficient levels of Pb to be assessed, or villagers in the area may be exposed to Pb because of the fertilizers used for agriculture.

Similarly, the serum Cd concentration in this study was consistent with the findings by *Wittsiepe* et al. [41]. They examined the blood Cd concentration of 75 e-waste segregation workers and 40 controls in Ghana. Their study had limitations on the exposed groups because of different food and preparation related to their religion. As the food habits differ among different ethnicities, the cross-sectional study design was not adequate to assess the relationship of Cd exposure in EWSW.

Sirichai et al. [57] examined the blood levels of cadmium in the exposed group, workers sorting EW in Daeng Yai Subdistrict Ban Mai District of Buriram Province, Thailand, and found that the mean blood cadmium level (exposed group vs. non-exposed group) was 1.00±0.33 µg/L vs. 1.17±0.39 µg/L. Separating EW, the EWSW had Cd concentrations slightly lower than those in the no-exposure group.

A study in Ubon Ratchathani Province found the blood concentration of Ni in EWSW was deficient, which was similar to the results by *Li* et al. [60], that observed no significantly different in the blood concentration of the median (range) of Ni between two groups (exposed group vs. non-exposed group): 4.49 (2.64–10.55) vs. 1.88 (0.6–22.22). However, the blood concentration of Ni was higher in the exposed group than in the non-exposed group.

In this study, we observed the normal range of the mean concentrations of neurotransmitter MAO levels (<650 U/L) in the exposed and non-exposed groups (exposed group vs. non-exposed group: 362.060±97.981 vs. 369.771±86.752). Moreover, Comparisons of neurotransmitter MAO concentrations between the exposed and non-exposed groups were not significantly different, consistent with the study by *Shin* et al. [61].

A similar finding was reported by *Marianti* et al. [8], which measured the MAO level among brass workers with heavy metal contamination in Indonesia. However, in their study, heavy metal contamination of Pb was found in the air below the OSHA standard (2005) among the workers with over 8 hours of work daily. In our study, the blood

Pb levels of brass technicians were 24.21± 98.61 µg/dL, which was within 80% of the standard range. Brass technicians had average MAO (SD) levels of 6.72±5.78 IU/ml or 6,720 ± 5,780 U/L. Moreover, elevated MAO-A level was significantly associated with blood lead levels.

The MAO enzyme levels in the nervous system of EWSW can indicate exposure to Ni. However, health screening should be done among EWSW for confirmation. Therefore, further analytical studies should be conducted to explore a cause-and-effect relationship.

Risk factors for serum Pb, Cd, and Ni concentrations

We performed the risk factor assessment for blood Pb, Cd, and Ni levels. Health behaviors, work characteristics, and concentrations of heavy metals in the dust at the operating surface (µg/100 cm^2) were included in this analysis. The monthly income (USD) and the blood Pb level (F = 1.818, p = 0.041) were significantly different. The workers received an average daily wage of 9.09 USD (321.28 baht), which was comparable to the minimum wage rate of Ubon Ratchathani, Thailand, 9.19 USD (325 baht). However, the workers may have an average daily income lower than the minimum wage rate [62], which is consistent with the study by *Amankwaa* et al. [5]. They found that EWSW earned approximately 6.96–18.10 USD per day or 169–450 USD per month. The longer time of working in e-waste sorting may result in higher exposure to lead, cadmium, and nickel.

The concentration of Pb in the dust at the operating surface was a statistically significant difference with the blood Cd levels (p = 0.028) that was consistent with a study by *Ceballos* et al. [63]. The worker touched the scraps of electronic components containing metal during their work, and heavy metal dust on the work surface contaminated the skin and clothing of workers' Pb blood level of more than 10 µg/dL. In addition, a high Ni blood level between the exposed group and the non-exposed group was not exposed to blood cadmium dust on work surfaces

However, the tendency of heavy metal contamination in EW sorting among these workers is higher than that in the general population. Therefore, the Department of Disease Control, Ministry of Public Health, Thailand [59], should establish proper e-waste management by adopting clean and easy-to-implement e-waste processing technology. Additionally, the working area should always be kept clean, and the workers should be aware of the importance of personal hygiene such as bathing, not re-dressing, wearing masks, and appropriate personal protective equipment [44].

Multivariate covariance analysis of the monoamine oxidase (MAO) enzyme level related to the serum heavy metals levels

The multivariate covariance analysis of the activity of levels of MAO enzymes in neurotransmitters indicated no significantly different synergistic effect of the Pb and Cd blood concentrations (F=1.045, *p*=0.426). The combined analysis of quantitative blood concentrations of Pb and Ni with MAO enzymes in the neurotransmitter found that the blood Pb and Ni levels significantly differed from neurotransmitter MAO levels (Pb: F = 2.5553, *p* = 0.098 and Ni F = 3.89587, Sig. = 0.040, respectively). However, as a cross-sectional study, the results cannot assume causality.

MAO is a neurotransmitter used as a biomarker for monitoring neurochemical effects. The lead, cadmium, and nickel in the blood cause inflammatory changes and affect the balance of neurotransmitters. MAO can be used to assist in the diagnosis of brain abnormalities in combination with brain imaging [64]. The MOA-B analysis identifies changes from the molecular level to the effect of altered behavior. Moreover, the MAO-A/B ratio was an indicator of Alzheimer's disease [65].

The results of the study are consistent with an investigation by *Zhicheng* et al. [14] that assessed the activity of MAO enzymes in neurotransmitters. The workers exposed to nickel carbonyl results in acute toxicity, causing respiratory and nervous systems damage [66]. The prolonged exposure to nickel carbonyl may cause abnormal symptoms such as excitement, insomnia, variable dreams, headache, dizziness, weakness, poor memory, tightness in the chest, excessive sweating, hair loss, and decreased sexual desire.

In humans, high levels of the neurotransmitter MAO affect the central and peripheral nervous system, especially in nerve endings, where MAO is located on the outer membrane of the mitochondria, to catalyze oxidative deaminization reactions of monoamine and 5-hydroxytryptamine. Therefore, workers exposed to nickel carbonyl over the long term result in biochemical and electrical changes in the nervous system [67].

Our findings on the activity of MAO enzymes among the EWSW in Ubon Ratchathani Province working with Pb, Cd, and Ni, were consistent with *Martínez-Martínez* et al. [68] who studied the behaviors change in exposed individuals. Exposure to Ni^{2+} can change (both inhibition and activation) neurotransmitters serotonin which alters behavior. Similarly, exposure to Ni^{2+} in rodents altered motor activity, learning, and memory and caused anxiety and depression-like symptoms. However, no dosedependent relationship was analyzed between these effects [69].

One of the limitations of this study is a cross-sectional design. We only collected the information from the EWSW during the survey period. Moreover, there are limitations in describing other information. Similarly, the quantitative assessment of the heavy metals and MAO were performed only for a certain period. However, the data obtained from this study can be used for future health surveillance in EWSW in Thailand. Additionally, further studies should be investigated the relationship between heavy metal exposure and neurological health conditions in these workers.

CONCLUSION AND RECOMMENDATIONS

In this study, blood levels of heavy metals such as Pb, Cd, and Ni and MAO among the EWSW did not exceed the standard. Moreover, Pb, Cd, and Ni levels in the operating surface did not exceed the normal values. However, a statistical difference in the Pb and Ni concentrations was identified between exposed and non-exposed groups. Similarly, the concentrations of MAO were significantly different from blood Ni levels. Therefore, these workers should promote personal hygiene, and their working areas should be cleaned to reduce the Pb, Cd, and Ni content. Moreover, health surveillance should be encouraged by examining the blood heavy metal levels among the EWSW in Thailand.

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Authors' contributions:
Kornwika Harasarn and Anamai Thetkathuek decided to conduct this study and collected data. Kornwika Harasarn wrote the first draft of the manuscript. Anamai Thetkathuek, Wanlop Jaidee, Nantaporn Phatrabuddha, and Pratchaya Kaewkaen planned the design of the study. Wanlop Jaidee also helped with the research methodology. All authors read and approved the final manuscript.

Disclosure statement
All authors declare that they have no competing interests in this work.

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