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Relationship between Blood Lead Level and Work Related Factors Using the NIIH Questionnaire System

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Abstract: Over an 11-yr period (1990–2000), a questionnaire survey on work environmental management and environmental improvement was conducted on 259 lead-handling factories and 7,623 subjects. Labour Inspection Offices identified these factories as requiring environmental improvement, or possessing a desire to improve their working environment. We analyzed factors affecting blood lead levels (PbBs). These factors were gender, age, employment duration, factory size, work environment control (WEC) class, and job categories. The PbB of men was found to be higher than that of women, and may be due to the differences in job distribution. PbB increased along with increasing age and employment duration. PbB declined as the factory size increased. The odds ratio (OR) of PbB higher than 20 μg/dl according to factory size was significantly high even after adjusting for WEC class. This demonstrates that not only the working environment but also safety management was poorer among small-scale factories that large-scale factories. The rise of PbB along with the increase of WEC class confirmed that the results of work environment measurement are correlated with individual exposure levels. The risk of having a 20 μg/dl or higher PbB was different for various lead handling jobs. Smelting or refining lead had the highest risk for lead exposure while painting or baking had the lowest risk. As our study population was not a randomly selected sample, we are unable to generalize our results for workers across Japan. However, we were able to indicate which jobs pose a high-risk and the effectiveness of using the work environment control class as an index of worksite environment levels.

Key words: Blood lead level, PbB, Lead-handling jobs, Questionnaire, Factory size, Age, Employment duration, Work environment control class

Introduction

Lead has been widely used since early human history because its low melting point, exceptional malleability, and high corrosion resistance are physical and chemical properties beneficial to human activities[1]. However, lead has been recognized as a toxic substance since the Roman Empire[2]. Lead is toxic not only to the hematopoietic organs, but also to the gastrointestinal organs, the central and the peripheral nervous system, and the kidneys[3].

In the year 2000, the demand for lead metal was approximately 239,000 t in Japan[4]. To prevent work site lead poisoning, a policy, under the Ordinance on Prevention of Lead Poisoning, has been carried out in Japan since 1972[5]. The essential elements of this policy are the definition of target work sites (lead handling work sites; LHWS), the reduction of exposure by controlling the concentration of lead in ambient air in work sites (work environment measurement; WEM)[6], and the monitoring of exposure and health effects related to lead toxicity through regular health examinations (lead periodic health examination; LPHE)[5].

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The incidence of individuals demonstrating positive signs of lead toxicity during a LPHE has decreased in recent years from 13.7% in 1965 to 1.9% in 2000[7, 8]. Although this rate is decreasing, in the year 2000 approximately 2000 individuals were found to have lead toxicity. This may be a result of the fact that a large number of workers are still working at LHWS. Accordingly, the issue of preventing lead poisoning remains a priority in Japan. In order to promote the execution of the preventative policy, it is important to regularly assess the number of workers who are exposed to lead and the levels of lead exposure at LHWS. Although WEM and LPHE are carried out regularly and frequently among the target population in Japan, a useful database, such as a "Job-Exposure Matrix"[9] using these results has not yet been constructed in Japan.

Researchers at our institute began conducting yearly questionnaire surveys in 1981 in order to monitor the WEM and LPHE of factories, which were identified by Labour Inspection Offices. These questionnaires collect data concerning work places at which lead or lead-containing substances are used, and workers who have possibly been exposed to lead. Using the results of these questionnaires, we intended to clarify the factors responsible for lead exposure. In the present research, we investigated the association of blood lead levels with demographic factors, work related factors, factory size, working environment, and job categories.

Materials and Methods

Subjects

For each year from 1990 to 2000, a list of factories requiring improvement in their occupational environment and factories concerned with improving their occupational environment has been identified by Labour Inspection Offices.

Questionnaires were sent to 3,189 factories identified by Labour Inspection Offices and responses received from 1,889 (response rate, 59.0%) were used for analysis. The cumulative number of factories at which lead or lead-containing substances had been used was 259 (244, excluding duplication), and the cumulative number of workers who were possibly exposed to lead was 7,623 (5,644, excluding duplication; 5,407 men and 2,216 women). The frequency distribution of our sample population, according to industry categories established by the Japan Standard Industrial Classification[10], was compared with that of lead handling worksites in Japan reported in 2001[11] (Table 1).

Questionnaire

Questionnaire items included the type of industry, the type of products, factory size, and WEM classifications, which are discussed later. Further data regarding workers, including gender, age, job category, employment duration, and PbB were obtained if possible. According to the definition of small- and medium-size enterprises, described in the Small and Medium Enterprise Basic Law[12], and the mandatory assignment standards for Health Supervisors, Safety Supervisors, or General Safety and Health Supervisors, described in the Ordinance on Labour Safety and Health[13], factory size was classified into the following four categories: from 1 to 49 employees, from 50 to 99 employees, from 100 to 299 employees, and 300 or more employees.

The concentration of lead in ambient air was classified by the WEM into three work environment control (WEC) classes (I, II, and III) according to the Working Environment Evaluation Standards[14] (see Appendix). Age and employment duration were categorized according to 10-yr intervals. Occupations were classified into 20 categories based on the Ordinance on Prevention of Lead Poisoning[5] and the Enforcement Order of the Industrial Safety and Health Law[15].

According to the Ordinance on Prevention of Lead Poisoning[5], PbBs were classified into category I (PbB $\leq$ 20 μg/dl), II (20 μg/dl < PbB $\leq$ 40 μg/dl), and III (PbB > 40 μg/dl).

Statistical analysis

PbBs were logarithmically transformed and the difference between geometric means was tested by Welch's *t*-test. Further differences between the three groups were tested first by ANOVA, then by Holm's multiple comparisons test[16]. The independency of the contingency table was tested using a χ^2-test. Correlation between age and employment duration of subjects was tested by the Pearson's product-moment correlation.

In order to evaluate which factors had significant effects on exposure to lead, the multiple logistic regression model was constructed with a PbB higher than 20 μg/dl (PbB distribution II or III) or not as the dependent variable and gender (reference: women), age (per 10-yr), employment duration (per 10-yr), factory size (per 100-persons), WEC class (reference: WEC class I), and job categories (reference: soldering) as independent variables.

R version 2.1.1[17] was used for data analysis.

Results

Characterization of subjects

The gender distribution of subjects according to age, employment duration, and WEC class is shown in Table 2.

Table 1. The distribution of lead-handling factories according to industrial categories

Industrial categories	Distribution of factories in the present study		Distribution of lead-handling factories in Japan (2001)[a]
	Number	Percentage	
Manufacturing textile mill products[b]	1	0.4%	0.1%
Manufacturing furniture and fixtures	0	0.0%	0.1%
Manufacturing pulp, paper and paper products	2	0.8%	0.2%
Printing and allied industries	1	0.4%	6.5%
Manufacturing chemical and allied products	30	11.6%	2.9%
Manufacturing petroleum and coal products	0	0.0%	0.0%
Manufacturing plastic products	12	4.6%	1.0%
Manufacturing rubber products	2	0.8%	0.7%
Manufacturing leather tanning, leather products, and fur skins	0	0.0%	0.1%
Manufacturing ceramic, stone and clay products	13	5.0%	3.4%
Manufacturing iron and steel	5	1.9%	0.6%
Manufacturing non-ferrous metals and products	17	6.6%	3.2%
Manufacturing fabricated metal products	13	5.0%	1.4%
Manufacturing general machinery	23	8.9%	6.2%
Manufacturing electrical machinery, equipment and supplies[c]	108	41.7%	59.4%
Manufacturing transportation equipment	13	5.0%	3.1%
Manufacturing precision instruments and machinery	15	5.8%	5.9%
Miscellaneous manufacturing industries	3	1.2%	2.4%
Road freight transport	0	0.0%	0.7%
Waste disposal	1	0.4%	0.0%
Automobile maintenance services	0	0.0%	1.0%
Machine, etc. repair services	0	0.0%	1.2%
Total	259	100.0%	100.0%

[a]Calculated based on the distribution of factories and the percentage of lead-handling factories according to the industrial categories in the Labour Environment Survey (2001).

[b]Includes manufacturing textile mill products, except apparel and other finished products made from fabrics or similar materials.

[c]Includes manufacturing information and communication electronics equipment, and manufacturing electronic parts and devices.

The mean age of subjects was 38.9 yr (men: 38.7, women: 39.2). The mean employment duration among subjects was 8.6 yr (men: 9.6, women: 6.3). A weak positive correlation was observed between age and employment duration (r=0.52, p<0.001). In terms of WEC class, 78.8% of subjects were employed in class I, 15.3% were employed in class II, and 5.9% were employed in class III. In addition, the proportion of men working in WEC class II and III worksites was significantly higher than that of women (p<0.001 by χ^2-test).

The frequency distribution of subjects according to job categories by different gender is shown in Table 3. A significant difference was observed between the distributions of men and women by job categories (p<0.001 by χ^2-test).

PbB according to gender, age, employment duration, factory size, and WEC class

The distribution and geometric means of PbB by gender, age, employment duration, factory size, and WEC class are shown in Table 4. According to gender, the percentage of PbB category III workers was 5.5% among men and was 0.2% among women. The geometric means of PbB (PbB_{GM}) was found to be significantly higher among men than women (p<0.001). In addition, the level was observed to increase with a rise in age and significant differences were observed between all age categories, expect between the 19 yr or younger category and the 20 to 29 yr category (p<0.001). The PbB_{GM} increased in accordance with the duration of employment and significant differences were seen between all categories (p<0.001). According to factory size, the percentage of high PbB workers was found to decrease with an increase in factory size. The differences in PbB_{GM} between each category of factory size were also significant (p<0.001). According to working environment, the percentage of PbB category III workers increased in accordance with the increase

Table 2. The frequency distribution of subjects according to age, employment duration, and WEC level by gender

Categories	Men	Women	Total
Age (yr)			
–19	125 (2.3%)	86(3.9%)	211 (2.8%)
20–29	1,439 (26.6%)	467(21.1%)	1,906 (25.0%)
30–39	1,265 (23.4%)	463(20.9%)	1,728 (22.7%)
40–49	1,293 (23.9%)	751(33.9%)	2,044 (26.8%)
50–59	1,166 (21.6%)	432(19.5%)	1,598 (21.0%)
60–	119 (2.2%)	17 (0.8%)	136 (1.8%)
Average (yr)	38.7	39.2	38.9
Employment duration (yr)			
–9	3,094 (57.2%)	1,636 (73.8%)	4,730 (62.0%)
10–19	993 (18.4%)	392 (17.7%)	1,385 (18.2%)
20–29	582 (10.8%)	87 (3.9%)	669 (8.8%)
30–39	227 (4.2%)	11 (0.5%)	238 (3.1%)
40–	38 (0.7%)	0 (0.0%)	38 (0.5%)
Unknown	473 (8.7%)	90 (4.1%)	563 (7.4%)
Average (years)	9.6	6.3	8.6
WEC class[a)]			
I	3,619 (74.6%)	1,484 (91.2%)	5,103 (78.8%)
II	850 (17.5%)	142 (8.7%)	992 (15.3%)
III	384 (7.9%)	1 (0.1%)	385 (5.9%)
Subtotal (I–III)	4,853 (100.0%)	1,627 (100.0%)	6,480 (100.0%)
Unknown	554	589	1,143
Total	5,407	2,216	7,623

[a)]The difference between men and women; significant at $p < 0.001$ using a chi-square test.

of WEC class I to WEC class II and to WEC class III. The differences in PbB_{GM} between each WEC class were significant ($p<0.001$).

PbB according to job categories

The distribution of PbB_{GM} according to job categories are shown in Table 5. The overall mean for the percentage of workers in PbB category III was 3.9%. Job categories in which the percentages of workers in PbB category III were higher than the overall mean included crushing, welding, or cutting in lead-using facilities (33.3%), smelting or refining lead (15.4%), manufacturing products from lead or lead alloys (10.9%), lead lining (9.0%), and workplace cleaning (8.6%). In contrast, job categories in which the percentages of workers in PbB category III were lower than the overall mean included painting or baking with lead-containing colors (0.0%), working in a lead-using facility (0.0%), smelting or refining copper or zinc (0.0%), soldering (0.1%), and hardening, tempering, or sand-bathing using molten lead (0.8%).

Job categories in which the mean PbB_{GM} was higher than overall mean of 7.1 μg/dl included crushing, welding, or cutting in lead-using facilities (27.1 μg/dl), manufacturing, repairing, or disassembling lead-acid batteries (20.7 μg/dl), smelting or refining lead (17.8 μg/dl), smelting or refining copper or zinc (17.0 μg/dl), and glazing or baking with lead-containing glaze (15.9 μg/dl). In contrast, job categories in which the mean PbB_{GM} was lower than the overall mean included soldering (3.4 μg/dl), working in a lead-using facility (4.8 μg/dl), and painting or baking with lead-containing colors (5.4 μg/dl).

Odds ratios for PbB higher than 20 μg/dl by factors

The odds ratios (ORs) for PbB higher than 20 μg/dl by gender, age, employment duration, factory scale, WEC class, and job categories are shown in Table 6. Odds ratios for men compared with women were 4.48 (95% confidence interval (95%CI); 3.42–5.58). For age (per 10-yr), the OR was 1.16 (1.08–1.26). For employment duration (per 10-

Table 3. The frequency distribution of subjects according to job categories by different gender (sorted by number of total subjects)

Job categories	Men	Women	Total
Soldering	916	1,458	2,374
Manufacturing products from rubber, plastics, lead-containing paint, colors, glaze, pesticide, or glass	1,187	51	1,238
Smelting or refining lead	598	0	598
Manufacturing, repairing, or disassembling lead-acid batteries	357	207	564
Manufacturing lead compounds	509	17	526
Manufacturing products from lead or lead alloys	347	64	411
Hardening, tempering, or sand-bathing using molten lead	265	0	265
Glazing or baking	100	41	141
Manufacturing electrical wires	43	51	94
Painting or baking	63	19	82
Lead lining	65	3	68
Crushing, welding, cutting, riveting, heating or rolling substances lined with lead or coated with lead-containing paints	33	17	50
Working in a lead-using facilities	30	16	46
Smelting or refining copper or zinc	42	0	42
Workplace cleaning	24	11	35
Crushing, welding, or cutting in lead-using facilities	12	0	12
Other work using lead	452	127	579
Other work in a lead-handling workplace	334	129	463
Unknown	30	5	35
	5,407	2,216	7,623

The difference between men and women was significant at $p < 0.001$ using a chi-square test.

yr), the OR was 1.22 (1.11–1.35). For factory size (per 100 persons), the OR was 0.84 (0.81–0.87). For WEC class II, the OR was 2.75 (2.24–3.37), and the OR for class III was 7.01 (5.34–9.20), compared with WEC class I. The job categories with significantly high ORs compared with soldering work were 91.55 (47.13–177.83) for lead smelting or refining, 12.73 (2.79–58.04) for crushing, welding, or cutting in lead-using facilities, 12.30 (7.87–19.21) for glazing or baking, 10.34 (7.29–14.65) for manufacturing, repairing, or disassembling lead-acid batteries, 5.27 (2.51–11.04) for lead lining, 4.75 (3.30–6.84) for manufacturing products from lead or lead alloys, 3.95 (1.78–8.75) for manufacturing electrical wires, 2.82 (1.84–4.32) for hardening, tempering, or sand-bathing using molten lead, 2.00 (1.42–2.80) for manufacturing rubber or plastic products with lead-containing paint, colors, glaze, pesticide, or glass, and 1.94 (1.31–2.87) for manufacturing lead compounds.

Discussion

In a LPHE survey conducted by Kawamoto *et al.*, it was reported that 96.0% of workers had a category I PbB, 3.7% had a category II PbB, and 1.1% had a category III PbB[18]. These values may be similar to national LPHE statistics because these values were obtained from a population comprising approximately 90% of the workers who participated in LPHE from 1991 to 1995. The percentages of workers in the present study with category II and category III PbBs were 3.2 and 3.5 times higher, respectively, than the previously published values. This suggests that the subjects of the present research were sampled from a population that consists of workers with higher PbBs compared with the national population of workers in LHWS. This difference could be explained by our sampling method, which may have distorted our study population in comparison to the general population. When comparing the percentage of industry types in the present study to data from the Labour Environment Survey[11], the percentage for manufacturing electrical machinery, equipment, and supplies was highest in both data sets. However, significant differences were observed in several categories. The percentages of some industry types, such as manufacturing chemical and allied products, and manufacturing plastic products, were high; although, the percentages for printing and allied industries were low in the present study. Therefore, we do not insist that our results accurately represent work environments in

Table 4. The frequency distributions of PbB and PbB_{GM} by gender, factory size, age, employment duration, and WEC class

Category	PbB Distribution				PbB_{GM} (μg/dl) (Range)
	–20 μg/dl (I)	20–40 μg/dl (II)	40 μg/dl– (III)	Total	
Gender[a, b]					
Men	4,037 (74.7%)	1,075 (19.9%)	295 (5.5%)	5,407	9.2 (0.4–100.0)
Women	2,106 (95.0%)	106 (4.8%)	4 (0.2%)	2,216	3.7 (0.1–48.1)
Age (yr)[a, c, e]					
–19	191 (90.5%)	17 (8.1%)	3 (1.4%)	211	4.7 (0.9–74.0)
20–29	1,682 (88.2%)	174 (9.1%)	50 (2.6%)	1,906	5.3 (0.1–79.6)
30–39	1,445 (83.6%)	235 (13.6%)	48 (2.8%)	1,728	6.4 (0.1–91.2)
40–49	1,640 (80.2%)	339 (16.6%)	65 (3.2%)	2,044	7.5 (0.1–79.5)
50–59	1,109 (69.4%)	377 (23.6%)	112 (7.0%)	1,598	9.9 (0.2–100.0)
60–	76 (55.9%)	39 (28.7%)	21 (15.4%)	136	15.9 (1.6–79.9)
Employment duration (yr)[a, c, d]					
–9	3,974 (84.0%)	605 (12.8%)	151 (3.2%)	4,730	6.1 (0.1–100.0)
10–19	1,052 (76.0%)	275 (19.9%)	58 (4.2%)	1,385	7.7 (0.1–79.9)
20–29	469 (70.1%)	153 (22.9%)	47 (7.0%)	669	9.8 (0.2–78.4)
30–39	142 (59.7%)	68 (28.6%)	28 (11.8%)	238	13.2 (1.0–83.2)
40–	8 (21.1%)	17 (44.7%)	13 (34.2%)	38	28.2 (0.4–67.8)
Unknown	498	63	2	563	
Factory scale (persons)[a, c, d]					
–49	189 (56.4%)	68 (20.3%)	78 (23.3%)	335	14.7 (0.1–83.2)
50–99	619 (69.9%)	207 (23.4%)	60 (6.8%)	886	9.3 (0.2–91.2)
100–299	2,463 (77.0%)	611 (19.1%)	124 (3.9%)	3,198	7.3 (0.1–100.0)
300–	2,871 (89.6%)	295 (9.2%)	37 (1.2%)	3,203	5.8 (0.1–63.0)
Unknown	1	0	0	1	
WEC class[a, c, d]					
I	4,321 (84.7%)	633 (12.4%)	149 (2.9%)	5,103	6.4 (0.1–100.0)
II	599 (60.4%)	342 (34.5%	51 (5.1%)	992	13.2 (0.4–76.6)
III	126 (32.7%)	168 (43.6%)	91 (23.6%)	385	24.0 (1.0–91.2)
Unknown	1,097	38	8	1,143	
Total	6,143 (80.6%)	1,181 (15.5%)	299 (3.9%)	7,623	7.1 (0.1–100.0)

[a]Significant difference using a chi-square test (p<0.001), [b]Significant difference using Welch's t-test (p<0.001), [c]Significant difference using an ANOVA (p<0.001), [d]Significant differences between groups using Holm's multiple comparison (p<0.001), [e]Significant differences between groups, except –19 and 20–29 (p<0.001) and no significant difference between –19 and 20–29 (p>0.05) using Holm's multiple comparison.

Japanese LHWS. However, despite the bias in our results, these data at least offer useful information regarding the associations between work environments in LHWS in Japan and factors related to these environmental conditions.

Our study demonstrated that PbB_{GM} of men was significantly higher than that of women, which is consistent with several previous studies[19, 20]. This may be explained by the fact that more men are employed in high-exposure work environments, such as smelting or refining. In contrast, more women are employed in relatively low-exposure working environments, such as soldering (Table 2, 3). This finding supports the prohibition of pregnant women and nursing mothers from engaging in jobs at LHWS according to the Ordinance on Labour Standards for Women[21]. Conversely, an investigation of French citizens indicated that the mean PbB for men and women were 17.2 μg/dl and 12.7 μg/dl, respectively[19], while a population-based study of Swedish elderly urban residents indicated that the mean PbB for men and women were 4.6 μg/dl and 3.5 μg/dl, respectively[20]. Although this significant gender difference of PbBs might be explained by a genetic difference in lead metabolism rather than by the difference of the exposure

Table 5. The frequency distributions of PbB and PbBGM according to job categories (sorted by PbB_{GM})

Job categories	PbB Distribution				PbB_{GM} (μg/dl)	
	–20 μg/dl (I)	20–40 μg/dl (II)	40 μg/dl– (III)	Total	[Range]	
Crushing, welding, or cutting in lead-using facilities	4 (33.3%)	4 (33.3%)	4 (33.3%)	12	27.1 [10.1–53.8]	***
Manufacturing, repairing, or disassembling lead–acid batteries	254 (45.0%)	274 (48.6%)	36 (6.4%)	564	20.7 [5.4–67.3]	***
Smelting or refining lead	355 (59.4%)	151 (25.3%)	92 (15.4%)	598	17.8 [1.5–100.0]	***
Smelting or refining copper or zinc	23 (54.8%)	19 (45.2%)	0 (0.0%)	42	17.0 [1.5–38.6]	***
Glazing or baking	78 (55.3%)	55 (39.0%)	8 (5.7%)	141	15.9 [2.0–55.6]	***
Manufacturing products from lead or lead alloys	257 (62.5%)	109 (26.5%)	45 (10.9%)	411	15.1 [0.9–78.4]	***
Lead lining	41 (60.3%)	21 (30.9%)	6 (8.8%)	68	12.8 [1.9–49.7]	***
Hardening, tempering, sand–bathing using molten lead	195 (73.6%)	68 (25.7%)	2 (0.8%)	265	12.5 [2.0–44.0]	***
Manufacturing lead compounds	381 (72.4%)	129 (24.5%)	16 (3.0%)	526	9.7 [1.0–79.5]	***
Workplace cleaning	31 (88.6%)	1 (2.9%)	3 (8.6%)	35	9.0 [2.0–58.6]	NS
Manufacturing products from rubber, plastics, lead–containing paint, colors, glaze, pesticide, or glass	1,018 (82.2%)	162 (13.1%)	58 (4.7%)	1,238	7.0 [0.1–91.2]	NS
Other work in a lead–handling workplace	400 (86.4%)	60 (13.0%)	3 (0.6%)	463	6.7 [0.1–53.0]	NS
Crushing, welding, cutting, riveting, heating or rolling substances lined with lead or coated with lead–containing paints	44 (88.0%)	4 (8.0%)	2 (4.0%)	50	6.0 [1.0–53.4]	NS
Manufacturing electrical wires	84 (89.4%)	5 (5.3%)	5 (5.3%)	94	6.0 [1.2–70.0]	NS
Other work using lead	504 (87.0%)	58 (10.0%)	17 (2.9%)	579	5.7 [1.4–61.7]	***
Painting or baking	80 (97.6%)	2 (2.4%)	0 (0.0%)	82	5.4 [1.4–21.1]	***
Work in a lead–using facilities	44 (95.7%)	2 (4.3%)	0 (0.0%)	46	4.8 [1.0–39.3]	**
Soldering	2,315 (97.5%)	57 (2.4%)	2 (0.1%)	2,374	3.4 [0.1–47.2]	***
Unknown	4 (–)	4 (–)	4 (–)	12	–	–
Total	6,143 (80.6%)	1,181 (15.5%)	299 (3.9%)	7,623	7.1 [0.1–100.0]	–

*** $p<0.001$, ** $p<0.01$, * $p<0.05$, NS $p>0.05$ using Welch's t-test compared with overall PbB_{GM}.

level, the gender difference of PbB in the present study was approximately 2.5-fold, which was higher than the 1.35-fold difference observed in French citizens and the 1.31-fold difference observed in Swedish elderly urban residents. Accordingly, it is natural to think that a major factor responsible to the gender gap of PbB in the present study was the difference between the distribution of men and women by job categories.

This study demonstrated that age and employment duration are positively correlated with PbB, which is consistent with previous studies[19]. It is widely acknowledged that a positive correlation exists between the level of lead exposure and PbB[22]. However, the protocol for WEM currently carried out in Japan include worksites but not individual exposure measurements[6]. Therefore, we could not directly correlate the measured exposure levels to individual PbB. We observed that the PbB_{GM} increased as the WEC class increased. Furthermore, in comparison with WEC class I, the adjusted OR for PbB higher than 20 μg/dl in WEC class III was 5.53 while the OR for WEC class II was 3.29. This result shows that the airborne lead levels at worksites are associated with the PbB of workers. If the WEM system is perfect, all workers working at WEC class I must belong to PbB distribution I. But in our case, among WEC class I workers 2.9% was PbB distribution III and 12.4% was PbB distribution II, which shows that the WEM system alone is not perfect to protect workers from exposure to lead. Although the WEM system needs a back up system, such as biological monitoring using PbB, our results tell that the WEM system offers a certain level of reliable information about how effectively the environmental exposure is controlled at LHWS. Our study indicated that the PbB_{GM} decreased as the size of the factory (indicated by the number of employees) increased. This could be explained by the relationship between WEC class and factory size. According to a Labour Environment Investigation, rates of abnormal findings at health examinations among workers in WEC class II or III LHWSs were higher among small-scale enterprises compared with that of large-scale factories[11]. We previously reported that the working environment in small-scale enterprises tended to be poorer than that of large-scale factories[23]. However, the OR of PbB higher than 20 μg/dl, for the numbers of

Table 6. Odds ratios for PbB higher than 20 μg/dl by gender, age, employment duration, factory size, WEC class, and job categories

Variables		Adjusted OR	(95% CI)	Probability
(Intercept)		0.07	(0.05–0.10)	***
Gender	Men	4.48	(3.42–5.88)	***
	Women	Reference		–
Age (per 10–yr)		1.16	(1.08–1.26)	***
Employment duration (per 10–yr)		1.22	(1.11–1.35)	***
Factory scale (per 100–persons)		0.84	(0.81–0.87)	***
WEC class	I	Reference		–
	II	2.75	(2.24–3.37)	***
	III	7.01	(5.34–9.20)	***
Job categories				
Smelting or refining lead		91.55	(47.13–177.83)	***
Crushing, welding, or cutting in lead–using facilities		12.73	(2.79–58.04)	**
Glazing or baking		12.30	(7.87–19.21)	***
Manufacturing, repairing, or disassembling lead–acid batteries		10.34	(7.29–14.65)	***
Lead lining		5.27	(2.51–11.04)	***
Manufacturing products from lead or lead alloys		4.75	(3.30–6.84)	***
Manufacturing electrical wires		3.95	(1.78–8.75)	***
Hardening, tempering, or sand–bathing using molten lead		2.82	(1.84–4.32)	***
Crushing, welding, cutting, riveting, heating or rolling substances lined with lead or coated with lead–containing paints		2.30	(0.84–6.34)	NS
Smelting or refining copper or zinc		2.04	(1.00–4.18)	NS
Manufacturing products from rubber, plastics, lead–containing paint, colors, glaze, pesticide, or glass		2.00	(1.42–2.80)	***
Manufacturing lead compounds		1.94	(1.31–2.87)	***
Other work using lead		1.63	(1.08–2.46)	*
Other work in a lead–handling workplace		1.44	(0.95–2.18)	NS
Soldering		Reference		–
Work in a lead–using facilities		0.94	(0.21–4.21)	NS
Workplace cleaning		0.74	(0.22–2.54)	NS
Painting or baking		0.48	(0.11–2.03)	NS

*** p<0.001, ** p<0.01, * p<0.05, NS p>0.05 using Welch's t–test compared with overall PbB_{GM}.

employees (per 100) was significantly lower than 1, even when adjusted by WEC class. This suggests that there were different exposure risks between worksites in factories of different sizes, even if the WEC class was similar. These differences may be due to the improper installation of local air exhaust or incorrect use of respiratory protective devices in small-scale factories. This also may be partly explained by a sampling bias due to the assertion that most small-scale factories identified by Labour Inspection Offices have some industrial hygiene-related problems, while large-scale factories have fewer such problems. Therefore, this overestimation may result in the conclusion that occupational health administration in small-scale lead-handling factories is unsatisfactory and requires improvement.

Considering the PbB and the ORs of PbB higher than 20 μg/dl according to job categories, jobs such as lead smelting or refining and manufacturing, repairing, or disassembling lead-acid batteries showed a relatively high-risk of lead exposure, while jobs such as soldering had a relatively low-risk of lead exposure. Hernberg reported that several lead handling occupations, such as lead refining, welding or cutting of lead construction materials, manufacturing lead-acid storage batteries, manufacturing paint containing lead, mixing lead with polyvinyl chloride, mixing lead with glass, and scraping and sanding paint containing lead have a relatively high-risk of lead exposure[24]. Although a straightforward comparison with our results can not be made because the industry or job classification standards were not the same, the lead exposure risks in some industries or job categories, such as lead refining, and manufacturing lead storage batteries, were high in both studies. However, manufacturing lead paint, which was reported to be a high-risk industry by Hernberg, had a low OR in the present study.

One group of job categories that showed high ORs was jobs handling molten lead, such as smelting or refining lead, manufacturing, repairing, or disassembling lead-acid batteries, and lead lining. When melting lead or during the welding process in the manufacturing of lead-acid storage batteries, lead fumes are generated. Moreover, during the paste mixing and kneading procedure in the manufacturing of lead storage batteries, fine lead oxide powder is released into the workers' environment. These conditions suggest that the key factors in lead exposure are based on the inhalation of lead fumes or fine dust containing lead[25]. This is consistent with reports that have shown that blood lead concentrations among workers engaged in these occupations are high[26–28]. Other jobs with high ORs were glazing or baking with lead-containing glaze. Lead exposure in these jobs could result from the inhalation of lead vapor generated in the baking process, or the ingestion of lead by workers who hold glaze brushes in their mouths. Kumagai *et al.* indicated these factors as causes of exposure among workers engaged in the manufacturing of cloisonne[29].

The above results showed that the risk of lead exposure is closely related to the scale of the enterprise, the WEC class, and the type of jobs that require the handling of lead or lead-containing materials. According to a Labor Environment Investigation, 29% of workers had not recognized that lead-handling jobs are hazardous[11]. However, this rate tended to increase with a decrease in the enterprise scale and was highest among small-scale enterprises. In order to effectively promote lead poisoning prevention, our study indicates not only the importance of improving work environments and work management, but also the necessity of educational programs for workers.

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Appendix: Summary of the method for determining the work environment control class in Japan

In Japan, work environment control class is determined using samples obtained by an A-sampling and B-sampling method[6, 14, 30]. A-sampling is an air sampling method: The air is sampled at each cross-sectional point of an implied grid that extends over a unit workplace. B-sampling is a fixed-point air sampling method: The air is sampled at a specific point in the unit workplace where the exposure of a worker is expected to be the highest.

The work environment control class is determined as follows.

	$E_{A1} < E$	$E_{A2} \le E \le E_{A1}$	$E_{A2} > E$
Only A-sampling	I	II	III
$C_B < E$	I	II	III
$E \le C_B \le 1.5E$	II	II	III
$C_B > 1.5E$	III	III	III

In cases in which measurements were collected in one workday, 1st and 2nd evaluation values are calculated using the following formulae.

$$\log E_{A1} = \log M_1 + 1.645\sqrt{\log^2\sigma_1 + 0.084}$$

$$\log E_{A2} = \log M_1 + 1.151\,(\log^2\sigma_1 + 0.084)$$

In cases in which measurements were collected over successive workdays, 1st and 2nd evaluations are calculated using the following formulae.

$$\log E_{A1} = \frac{1}{2}(\log M_1 + \log M_2) + 1.645\sqrt{\frac{1}{2}(\log^2\sigma_1 + \log^2\sigma_2) + \frac{1}{2}(\log M_1 - \log M_2)^2}$$

$$\log E_{A2} = \frac{1}{2}(\log M_1 + \log M_2) + 1.151\left\{\frac{1}{2}(\log^2\sigma_1 + \log^2\sigma_2) + \frac{1}{2}(\log M_1 - \log M_2)^2\right\}$$

E Administrative control level for each material (ex. Lead: 0.1 mg/m^3)
E_{A1} 1st evaluation value
E_{A2} 2nd evaluation value
C_B Measured value of a sample obtained by B-sampling
M_1 Geometrical mean of measured values of samples obtained by A-sampling in 1st day
M_2 Geometric mean of measured values for samples obtained by A-sampling on the 2nd day
σ_1 Geometric standard deviation for measured values of samples obtained by A-sampling on the 1st day
σ_2 Geometric standard deviation for measured values of samples obtained by A-sampling on the 2nd day