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Lead Exposure Among Lead-Acid Battery Workers in Jamaica

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To assess lead exposure in the Jamaican lead-acid battery industry, we surveyed three battery manufacturers (including 46 production workers) and 10 battery repair shops (including 23 battery repair workers). Engineering controls and respiratory protection were judged to be inadequate at battery manufacturers and battery repair shops. At manufacturers, 38 of 42 air samples for lead exceeded a work-shift time-weighted average concentration of 0.050 mg/m^3 (range 0.030–5.3 mg/m^3), and nine samples exceeded 0.50 mg/m^3. Only one of seven air samples at repair shops exceeded 0.050 mg/m^3 (range 0.003–0.066 mg/m^3). Repair shop workers, however, had higher blood lead levels than manufacturing workers (65% vs. 28% with blood lead levels above 60 μg/dl, respectively). Manufacturing workers had a higher prevalence of safe hygienic practices and a recent interval of minimal production had occurred at one of the battery manufacturers. Workers with blood lead levels above 60 μg/dl tended to have higher prevalences of most symptoms of lead toxicity than did workers with lower blood lead levels, but this finding was not consistent or statistically significant. The relationship between zinc protoporphyrin concentrations and increasing blood lead concentrations was consistent with that described among workers in developed countries. The high risk of lead toxicity among Jamaican battery workers is consistent with studies of battery workers in other developing countries.

Key words: lead, contamination, developing countries, occupational diseases, battery workers

INTRODUCTION

In developed countries, the lead-acid battery industry is the largest user of lead, and battery workers are at high risk of lead toxicity [Hernberg et al., 1988]. While the risk of occupational lead exposure in the battery industry has been thoroughly studied

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and regulated in most developed countries, less is known about lead exposure among battery workers in developing countries. Lead-acid battery manufacture can be carried out in small-scale operations, using relatively simple technology, and may be an attractive industry for developing economies.

Where studies of battery workers in developing countries have been conducted, excessive lead exposure and high blood lead levels have been found. At a lead-acid battery factory in Sudan, 95% of workers had blood lead (PbB) levels above 40 μg/dl [Awad et al., 1986], the upper limit recommended by the World Health Organization for adult male workers [World Health Organization, 1980]; 23% of the Sudanese workers had PbB above 80 μg/dl. Mean air lead levels ranged from 1.8 to 2.2 mg/m^3, about 40 times the current United States permissible exposure limit (PEL) of 0.050 mg/m^3 [U.S. Department of Labor, 1978]. Blood lead levels above 40 μg/dl were also common among battery workers tested in the Republic of Trinidad and Tobago, where small-scale operations predominated [Ramlal, 1977]. Even at a relatively large factory in Korea, the mean PbB among 234 workers was 54 μg/dl, and mean air lead levels exceeded the U.S. PEL in all production departments [Lee, 1982].

The lead-acid battery industry in Jamaica is characterized by small factories, the largest employing 30 production workers. In addition, small shops that repair and/or rebuild car batteries are common. No occupational health regulations govern permissible air or blood lead levels.

A review of blood lead tests conducted by the Jamaica Government Chemist between January 1986 and March 1987 revealed that lead-acid battery production, repair, and recycling were the most commonly identified sources of elevated blood lead levels in both children and adults. In October 1987, the Ministry of Health, Jamaica, with assistance from the National Institute for Occupational Safety and Health and the Center for Environmental Health and Injury Control of the U.S. Centers for Disease Control, conducted a survey of occupational and environmental lead exposures associated with Jamaica's lead-acid battery industry. In this paper, we report the findings of the occupational exposure survey.

MATERIALS AND METHODS

Three battery manufacturers, identified as the source of blood lead tests submitted to the Government Chemist, were approached and agreed to participate. The companies, all located in Kingston, represent the largest Jamaican battery manufacturer (company A), with 30 production employees, a "medium"-sized company (company B), with 12 production employees, and a small plant (company C), with 5 production workers. As these manufacturers were already conducting some medical screening of their production workers, it is possible that they are more conscious of worker health and might well have lower lead exposures than do other manufacturers. We feel it is unlikely that they have higher lead exposures than are typical for Jamaican battery makers.

Small shops that repair and/or manufacture lead-acid batteries typically employ one or two men and are often located in residential yards. More than 50 such repair shops, commonly known as "backyard" battery repair shops, are known to Jamaican public health officials; of these, more than 30 shops are located in Kingston. Because these repair shops operate intermittently and change locations, we chose a convenience sample of ten shops located in Kingston for which the owners could be

TABLE I. Age and Years of Battery Work Among Battery Workers Surveyed in Jamaica, 1987 by Workplace*

		Manufacturers A	Manufacturers B	Manufacturers C	10 repair shops
No. of production employees surveyed		29	12	5	23
Age (yrs)	Mean	31	31	29	28
	(Range)	(20–50)	(20–51)	(19–51)	(11–47)
Years employed as battery worker	Mean	8	8	5	8
	(Range)	(0–22)	(0–25)	(0–13)	(0–28)

*All workers were black males.

contacted and agreed to participate in time for the survey. As the owners of these shops agreed to participate, it is possible that conditions at these shops may be, on average, better than at repair shops as a whole. A survey of members of households exposed to these shops is reported elsewhere [Matte et al., 1989].

At each workplace, observations were made of work practices, engineering controls, and respirator use. At the three battery manufacturers, personal breathing-zone air samples were collected from at least one employee in each production area. Three area samples were also collected at company C. Because of the intermittent nature of repair shop operations, air samples (personal or area) were collected at a shop only if batteries were being repaired on the day the shop was surveyed. Air samples were collected on mixed cellulose-ester filters using a flow rate of 2 liters per minute and were collected for a period as near as possible to an entire work-shift. Air samples were analyzed for lead using a published method [National Institute for Occupational Safety and Health, 1984].

Using a standard questionnaire, we interviewed all production employees at battery manufacturers and all repair employees at battery repair shops about demographic information, work practices, smoking, and symptoms of possible lead toxicity. A venous blood sample was drawn from each employee and tested for zinc protoporphyrin (ZPP), using a portable hematoflourometer (Aviv Biomedical), and for lead, using a published method [Searle et al., 1973].

Air lead, blood lead, and ZPP values were log-transformed for most analyses. Differences in geometric means were assessed using t-tests; least-squares regression was used to assess the relationship between blood lead, air lead, and work practices and between ZPP and blood lead. Differences in symptom prevalences were assessed using prevalence ratios and test-based 95% confidence limits.

RESULTS

All workers, except one at company A, agreed to participate. Employees at the three battery manufacturers and the repair shops as a group were similar in terms of age and years employed as battery workers (Table I).

Process Description and Environmental Assessment

At companies A and B, grids (the metallic lead lattices which are pasted with lead oxide to make battery plates) were manufactured using automatic casting machines equipped with thermostatically controlled lead pots. The grids were pasted with lead oxide by machine (company A) or manually (company B). After drying, pairs of plates were broken apart, and excess metal and oxide was manually filed off. Company C purchased prepasted plates. At all companies, finished plates were then manually gas-welded into groups (cells). Cell connectors and battery terminals, cast from lead using a manual small-parts caster, were manually gas-welded to cells to assemble whole batteries. During our survey, we learned that company A had resumed full production only 4 weeks before our survey, after a period of minimal production lasting about 3 months.

At company A, local exhaust ventilation was provided for casting operations and mixing of lead oxide paste; the latter was not functional during our survey. No local exhaust ventilation was provided at companies B or C. Respirators were used by some employees at all three companies, but none were equipped with high-efficiency particulate air (HEPA) filters, which are recommended for exposure to lead dust or fume [National Institute for Occupational Safety and Health, 1987]. None of the companies had formal programs for fitting or maintaining respirators. Only company A provided a lunchroom, changing area, and enclosed showers, although some workers at the other companies did change and shower outdoors. All three companies were performing twice-yearly blood lead testing of workers. None had formal policies for medical removal of workers with high blood lead levels, but the usual practice has been to remove workers with blood lead levels above 70 μg/dl.

At repair shops, gas welding is used to assemble cells from plates and to attach connectors and terminals to the rebuilt cells. Parts may be scavenged from used batteries or cast from molten lead, which is smelted onsite at nine of the ten shops. Nine of ten repair shops operate in sheds with natural ventilation only; one operates outdoors. Respirators were available for use at only two shops; in neither case were they equipped with HEPA filters. Showers were available to workers at six shops, but three of these were located in a residence at the premises.

At battery manufacturers, 38 of 42 air lead samples exceeded the U.S. PEL of 0.050 mg/m^3, time-weighted average (range 0.030–5.3 mg/m^3); only one of seven samples collected at battery repair shops exceeded the U.S. PEL (range 0.003–0.066 mg/m^3) (Fig. 1). Geometric mean lead levels were highest at the largest workplace, company A, and lowest at the repair shops. Five samples at company A and four at company B exceeded 0.50 mg/m^3, ten times the U.S. PEL. Only at companies A and B were processes sufficiently separated to allow assessment of air lead levels by process. At company A, the highest geometric mean air lead level was found in the assembly area and the lowest in the parts casting area, while at company B, plate filing and assembly were the highest and lowest exposure areas, respectively (Fig. 2).

Blood Lead Levels

Twenty-eight percent of workers at battery manufacturers and 65% of workers at repair shops had blood lead levels above 60 μg/dl (Fig. 3). For comparison, U.S. OSHA regulations require an employee with a blood lead level of 60 μg/dl or greater, or three blood lead levels averaging 50 μg/dl or greater, to be removed from lead exposure [US Department of Labor, 1978]. Excluding company A, where levels tended to be lower, blood lead levels at battery manufacturers and repair shops were distributed similarly. Eight of the production workers at battery manufacturers were considered supervisory, but their duties required them to spend varying periods in

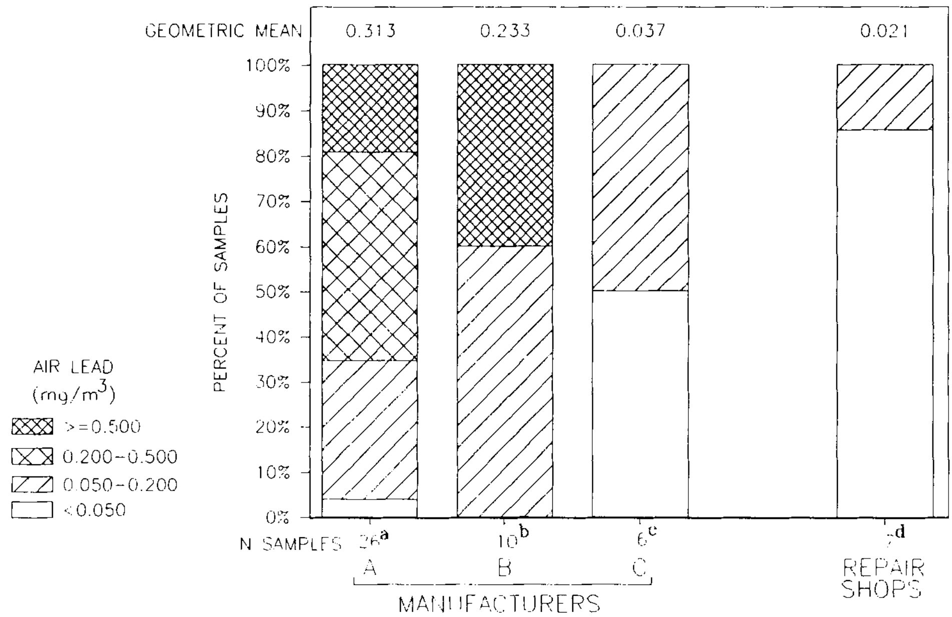

Fig. 1. Distribution of air lead levels at battery manufacturers and repair shops surveyed in Jamaica, 1987. **a:** All personal samples; 7 workers had 2 personal samples on consecutive days. **b:** All personal samples. **c:** 3 personal samples, 3 area samples. **d:** 3 personal samples, 4 area samples.

production areas. Six of these workers had blood lead levels 30 μg/dl or above (range 28–86 μg/dl).

In analyzing the relationship between work practices and blood lead, we excluded supervisory employees at battery manufacturers (most of whom did not consider themselves "exposed" to lead). Compared to repair shops, battery manufacturers had a lower proportion of workers who were current smokers and higher proportions of workers who reported that they "always" followed certain hygienic practices (Table II). At battery manufacturers, the geometric mean PbB was significantly increased among current smokers, compared to nonsmokers, and among those who reported not always washing their hands before meals, compared to those who always washed. For each hygienic practice, however, the geometric mean PbB was still above 40 μg/dl among those workers who reported always following that practice. Among repair shop workers, associations between work practices and blood lead were weaker and, in some instances, opposite than expected.

Air lead levels from personal samples were available for 32 battery manufacturer workers. For these workers, there was no crude correlation between $\log_{10}$(PbB) and $\log_{10}$(air lead) ($r=0.002$, $p=0.99$). To determine if an underlying relationship between air and blood lead was obscured by other factors, a multivariate model of $\log_{10}$(PbB) was derived from the following variables: $\log_{10}$(air lead), behavioral variables from Table II, and a variable for workplace (company A vs. others, because of the recent resumption of full production at company A). After backwards elimination of the least significant variables, until only those significant at the $p < 0.10$ level remained, the following model was derived:

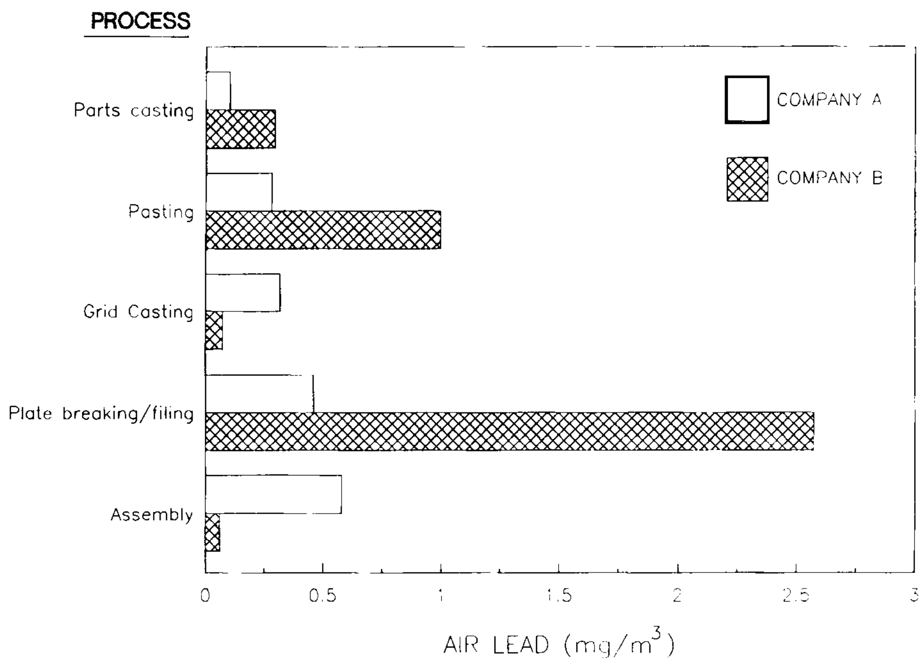

Fig. 2. Geometric mean air lead levels by process area at two battery manufacturers in Jamaica.

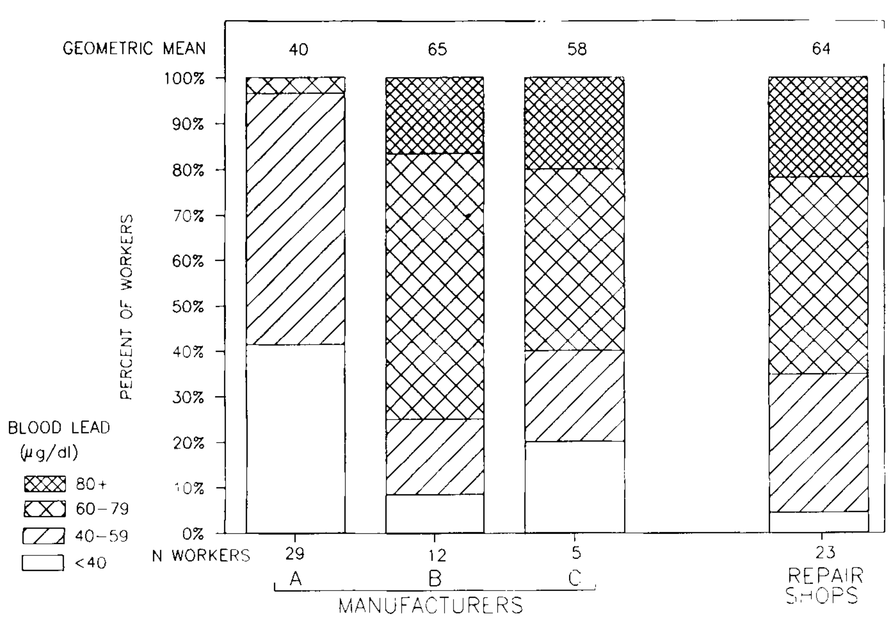

Fig. 3. Distribution of blood lead levels among battery workers surveyed in Jamaica.

TABLE II. Geometric Mean Blood Lead Levels by Smoking and Work Practices Among Battery Workers Surveyed in Jamaica, 1987*

		Manufacturers[a]		Repair shops	
Behavior present?→		Yes	No	Yes	No
Behavior					
Current smoker	GM	57	46[b]	66	62
	(N)	(15)	(23)	(13)	(10)
Always washes hands	GM	48	71[b]	63	64
before eating	(N)	(34)	(4)	(12)	(11)
Always showers	GM	48	59	66	63
before leaving work	(N)	(29)	(9)	(6)	(17)
Always changes clothes	GM	[c]	[c]	62	66
before leaving work	(N)			(10)	(13)
Always wears respirator	GM	45	54	67	62
while working	(N)	(14)	(24)	(9)	(14)

[a]Excludes supervisory employees.
[b]$p < 0.05$, t-test for difference in geometric means.
[c]All workers always changed clothes.
*GM = geometric mean blood lead in μg/dl; (N) = No. of workers.

$$\log_{10}(\text{PbB}) = 1.59 - 0.19*\text{company A} + 0.07*\text{smoking} + 0.05*\log_{10}(\text{air lead}).$$

This model explained 63% of the variance in $\log_{10}$(PbB). The small number of air samples collected and the intermittent nature of repair shop operations precluded any analysis of the blood lead-air lead relationship for repair shop workers.

Lead Toxicity

To assess relationships between blood lead and symptoms of possible lead toxicity, the prevalence of selected symptoms among workers whose PbB was 60 μg/dl and above was compared to the prevalence among workers with lower blood lead levels (Table III). The prevalences of gastrointestinal symptoms, trouble concentrating, and muscle weakness were higher among workers in the high-blood-lead group, but the differences were not statistically significant.

Among all workers, PbB explained 65% of the variance in $\log_{10}$(ZPP) ($p<0.0005$, Fig. 4). We assessed whether the shorter duration of recent lead exposure in company A workers affected the slope of this relationship. The coefficient of the interaction term, company A * PbB, was significantly less than zero ($p<0.05$), indicating a slower rate of increase in ZPP with increasing PbB among company A workers than among other workers. This interaction, however, only explained an additional 2% of the variance in $\log_{10}$(ZPP).

DISCUSSION AND SUMMARY

Our survey revealed a high prevalence of elevated blood lead levels among workers at battery manufacturers and battery repair shops in Jamaica. Blood lead levels at battery manufacturers in Jamaica were higher than those found among workers at a large U.S. battery manufacturer, where only 6% of blood leads exceeded 60 μg/dl [Gartside et al., 1982], but were similar to that found at a Korean manu-

TABLE III. Symptoms by Blood Lead Level Among Battery Workers Surveyed in Jamaica, 1987*

Symptoms	Percent with symptom: PbB < 60 (N=41)	Percent with symptom: PbB ≥ 60 (N=28)	Prevalence ratio[a]	95% C.I.
Severe headaches	20	19	0.9	(0.3–2.6)
Trouble concentrating	15	25	1.7	(0.6–4.5)
Trouble remembering	22	25	1.1	(0.5–2.7)
Trouble sleeping	18	4	0.2	(0.0–1.2)
Muscle weakness	24	39	1.6	(0.8–3.3)
Joint pain	27	25	0.9	(0.4–2.1)
Decreased libido or potency	20	18	0.9	(0.3–2.5)
Decreased appetite	12	21	1.8	(0.6–5.2)
Nausea	7	14	2.0	(0.5 –7.9)
Abdominal pain	12	18	1.5	(0.5–4.6)

*C.I. = confidence interval; PbB = blood lead in μg/dl.
[a]Prevalence of symptom in workers with PbB ≥ 60 μg/dl ÷ prevalence of symptom in workers with PbB < 60 μg/dl.

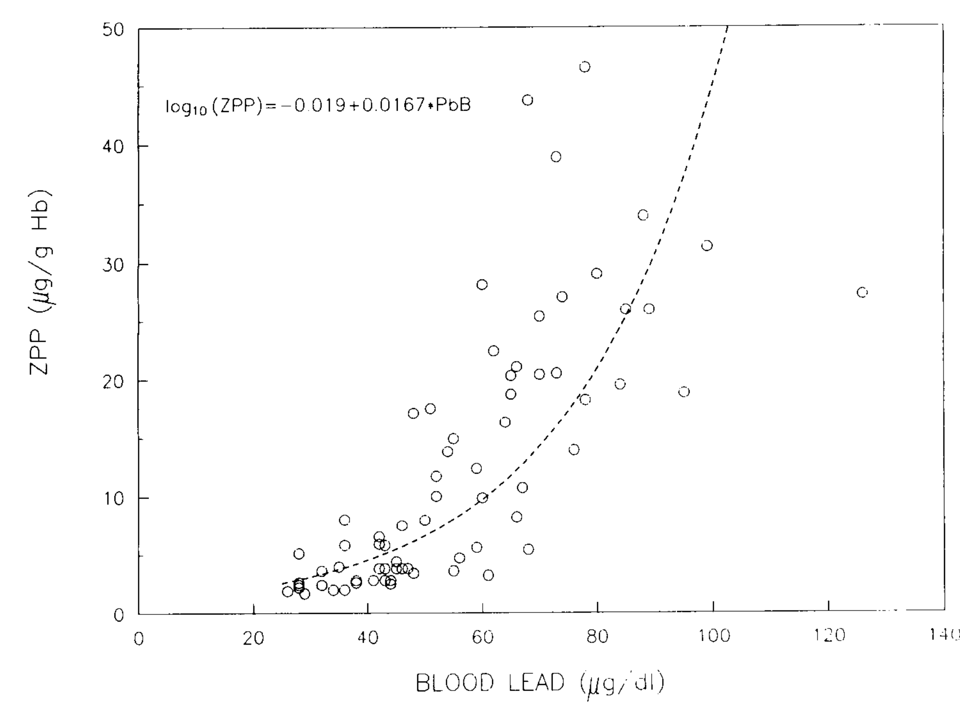

Fig. 4. Relationship between blood lead and zinc protoporphyrin (ZPP) among battery workers in Jamaica. Hb = hemoglobin; PbB = blood lead.

facturer, where 38% of worker blood lead levels exceeded 60 μg/dl [Lee, 1982]. Because of the recent shutdown at company A, however, our data probably underestimate usual blood lead levels at the battery manufacturers we surveyed. It should be noted that our analysis focused on blood lead levels exceeding U.S. regulatory standards, while subclinical lead toxicity occurs at much lower blood lead levels [Landrigan et al., 1985].

The risk of blood lead levels above 40 μg/dl in Jamaican battery repair shop workers (96%) is substantially higher than among self-employed battery workers studied in Nigeria (63%) [Asgowa, 1979]. The Nigerian workers were referred to as "battery chargers," but the nature of their work was not described further. We believe that "backyard" battery repair shops, or similar operations, probably exist in other developing countries, but we are unaware of other studies of battery repair workers.

High air lead levels prevailed at the battery manufacturers, where engineering controls were generally lacking or nonfunctional. A comparison of air lead levels measured in the various departments at companies A and B and those reported in other published surveys [Lee, 1982; Williams et al., 1969] show that high- and low-exposure processes in battery manufacture may vary between workplaces. Furthermore, workers in one department of a small workplace may be exposed to high lead levels generated from nearby processes. Respirators used at these workplaces were not adequate for the air lead levels that prevailed, and none of the manufacturers had programs to ensure proper respirator use and maintenance. Therefore, even if a higher proportion of workers wore respirators regularly, it is probable that blood lead levels would remain unacceptably high.

Inhaled airborne lead is the most important route of lead exposure in occupational settings [Hernberg et al., 1988], and control of airborne lead should reduce lead absorption by other routes as well. Although our small, cross-sectional study was not designed to assess the relationship between airborne and blood lead, we did detect a positive association when adjusting for other factors. That we did not find a stronger relationship is not surprising, since we could not account for the effect of size of airborne lead particulate [Froines et al., 1986], job tenure, or lead ingestion from contamination of the hands and face [Chavalitnitikul et al., 1984]. Even in a much larger battery factory survey, only 9% of the variance in blood lead was explained by air lead levels alone [Gartside et al., 1982].

At battery repair shops, measured air lead levels were comparatively low. It is possible that levels are at times quite high, as during smelting operations. Given the intermittent nature of the processes at these shops, however, we believe the small number of samples collected during actual battery repair may overestimate the time-weighted average air lead levels. Despite apparently lower air lead exposure, the repair shop workers had similar blood lead levels to company B and C workers. This finding may have several explanations, including, nearly all repair shop workers perform gas welding, which generates highly respirable lead fume; repair shop worker households were found to be highly contaminated during a related survey [Matte et al., 1989]; and repair shop workers appeared to have poorer hygiene than manufacturing workers.

Symptoms are a relatively crude measure of lead toxicity, and our study included a relatively small number of workers. Still, our data are consistent with some symptoms of lead toxicity occurring in workers with blood lead levels above 60 μg/dl [Hernberg et al., 1988]. Zinc protoporphyrin elevation is a more sensitive index of lead toxicity, and the relationship between ZPP and blood lead among Jamaican workers was similar to that described for lead-exposed males in developed countries by Wildt et al. [1987] who reported a regression equation for Swedish lead workers of:

$$\log[\mathrm{ZPP}(\mu g/dl)] = 1.21 + 0.0148*\mathrm{PbB}.$$

The AVIV hematoflourometer measures ZPP in micrograms per gram of hemoglobin; because we did not measure hemoglobin, a constant, equal to the log of the average hemoglobin concentration, should be added to the y-intercept from our data for comparison with Swedish workers. Assuming the subjects in our study, who were all black males, had an average hemoglobin value of 14.5 g/dl [National Center for Health Statistics, 1983], the adjusted regression equation for the Jamaican workers was

$$\log[\mathrm{ZPP}(\mu g/dl)] = 1.14 + 0.0167*\mathrm{PbB}.$$

During and after our survey, we made recommendations to the battery manufacturers and battery repair shop operators for improving engineering controls, work practices, respiratory protection, worker education, and medical surveillance. Although we did not sample workplaces at random, for reasons stated earlier, we do not believe that other Jamaican battery manufacturers and repair shops have lower lead exposures than those found in our survey. We believe that traditional occupational health measures, adapted to accommodate local needs and resource limitations, can substantially reduce occupational lead exposure in Jamaica. There are several impediments, however, to improving worker health and safety in Jamaica and other developing countries. These impediments include a lack of standards regulating exposures, scarcity of trained inspectors, and little, if any, safety and health training of employers and workers [Michaels et al., 1988]. High unemployment (about 25% in Jamaica [Ministry of Health, Jamaica, 1985]) may contribute to the popularity of cottage industries, like battery repair shops, where prevention of work-related health problems is particularly difficult.

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