

Effects of occupational lead exposure

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WANG YL, LU PK, CHEN ZQ, LIANG YX, LU QM, PAN ZQ, SHAO M. Effects of occupational lead exposure. *Scand J Work Environ Health* 11 (1985): suppl 4, 20–25. Fifty-three workers in a battery factory, 52 solderers in a television factory, and 50 embroidery workers (a reference group) were studied. The average air lead levels of the three workplaces were 0.578 mg/m³, 0.002 mg/m³, and 0.001 mg/m³, respectively. Adverse effects in terms of clinical manifestations and biochemical criteria were evident among the battery factory workers. A significant dose-response relationship existed between the toxic effects and the air lead levels. The solderers showed no apparent abnormalities in comparison with the embroidery workers. The early clinical manifestations were dysfunction of the central nervous system, indigestion, arthralgia, and myalgia in the extremities. A positive association was observed between the prevalence of fatigue, mild abdominal pain, and arthralgia and the blood lead (PbB), urinary lead (PbU), and zinc protoporphyrin (ZPP) levels. The symptomatic threshold values of PbB, PbU, and ZPP were 30 µg/dl (1.5 µmol/l), 0.045 mg/l (0.2 µmol/l), and 40 µg/dl (0.7 µmol/l), respectively. The PbB, PbU, free erythrocyte protoporphyrin, and ZPP levels and the blood aminolevulinic dehydratase ratio could be used as indicators of lead exposure, although ZPP is preferred for a preventive monitoring program. The motor and sensory conduction velocities of the median nerve were slower in the exposed groups than in the reference group. No effects on behavioral function were observed among the solderers.

Key terms: biological monitoring, lead poisoning, nerve conduction velocity, screening, toxic effects.

This is a report of an investigation of the effects of occupational lead exposure using criteria with higher specificity and sensitivity in order to provide a basis for early diagnosis and preventive monitoring measures.

There have been many recently published papers and review articles concerning the effects of lead exposure (7, 8, 9, 12, 16, 18, 19, 20). Both the level of lead in workplace air and the prevalence of lead poisoning have been markedly reduced with the improvement of the work environment in factories in the People's Republic of China during the past 33 years (19). As severe lead poisoning has been eliminated in our country, research is now aimed at the subclinical effects of lead exposure.

Subjects and methods

We studied 53 workers (30 female) from the Shanghai Navigation Battery Factory, 52 workers (44 female) from the Shanghai No 1 TV Factory (all of whom were solderers), and 50 workers (43 female) from the Shanghai Embroidery Factory, who served as the reference group. The air lead levels of these workplaces were estimated from personal samples [on five, six, and three workers at the battery factory, television (TV) factory, and embroidery factory, respectively] for three consecutive days. At the same time, each worker was

given a general physical examination with attention to the oral cavity and the nervous system, and a history of symptoms commonly related to lead exposure was inquired about. The following laboratory examinations were performed on a specimen of blood and urine collected from each worker in lead-free tubes: blood lead (PbB) by atomic absorption spectrophotometry (14), urinary lead (PbU) by dithizone colorimetry, urinary delta-aminolevulinic acid (ALA) by the butanal extraction method, blood aminolevulinic dehydratase ratio (ALAD-r) by colorimetry (15), urinary coproporphyrin (CPU) by spectrophotometry, free erythrocyte protoporphyrin (FEP) by fluorometry (13), zinc protoporphyrin (ZPP) by hematofluorometry (1), and hemoglobin by the ferrocyanide hemoglobin method. Also performed on all workers was an electroneurophysiology evaluation consisting of electroencephalography (EEG) and nerve conduction velocity determinations (17) and a behavioral function evaluation consisting of tests of intelligence, memory, vision, and reaction time.

Results

Levels of lead in workplace air

The average airborne lead level in the battery factory was 0.578 mg/m³, a value greatly exceeding the maximal permissible limit of 0.03 mg/m³. In the TV factory it was 0.002 mg/m³, a value much lower than the maximal permissible limit, because of the small amount of lead fume produced in the soldering process due to

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appropriate ventilation. In the embroidery factory it was 0.001 mg/m³ (table 1).

Symptoms

The incidence of various nonspecific symptoms referable to the central nervous system, autonomic nervous system, digestive system, and muscles and joints among the battery workers was much higher than those among the other two groups of workers (table 2). There was no significant difference in the prevalence of clinical manifestations between the TV workers and the referents.

Table 1. Time-weighted average levels of lead (mg/m³) in the workplace air by personal sampling.

Factory	Mean	Range
Battery		
Chemicals area	1.014	0.325 — 2.979
Molding	0.141	0.069 — 0.238
Average	0.578	0.069 — 2.979
Restroom	0.032	0.030 — 0.034
Health station	0.011	0.006 — 0.015
Television		
Workplace	0.002	0.001 — 0.002
Health station	0.001	0.000 — 0.001
Embroidery		
Workplace	0.001	0.0003 — 0.001
Health station	0.0001	0.000 — 0.0002

Laboratory examination

The mean and standard deviation of the seven tests performed in these factories are listed in table 3. Five

Table 2. Prevalence of major symptoms by factory.

Symptom	Percentage of workers with symptom		
	Battery factory (N = 53)	Television factory (N = 52)	Embroidery factory (N = 50)
<i>Neuroasthenia syndrome</i>			
Fatigue	88.7**	44.2	30
Tinnitus	34.0*	11.5	16
Insomnia	32.1*	7.7	14
Amnesia	43.4**	1.9	10
<i>Digestive system</i>			
Indigestion	28.3**	1.9	10
Metallic taste	58.5**	0.0	0
Nausea	39.6**	9.6	6
Vomiting	13.2**	0.0	0
Mild abdominal pain	56.6**	5.8	8
Constipation	11.3	42.3**	16
<i>Autonomic nervous system</i>			
Polyhidrosis in the extremities	47.2**	7.7	14
<i>Muscles and joints</i>			
Myalgia in the extremities	34.0**	0.0	2
Arthralgia	54.7**	3.8	18
Numbness in the extremities	50.9**	1.9	6

* p<0.01, ** p<0.001.

Table 3. Comparison of biochemical criteria among the three factories.

Criterion	Battery factory (N = 53)		Television factory (N = 52)		Embroidery factory (N = 50)		F
	Mean	SD	Mean	SD	Mean	SD	
Blood lead level (μg/dl) (1 μg/dl = 0.05 μmol/l)	61.87	33.05	22.06	12.31	18.51	11.95	8.05**
Urinary lead level (mg/l) (1 mg/l = 4.8 μmol/l)	0.08	0.03	0.01	0.02	0.00	0.01	2.41*
Urinary delta-aminolevulinic acid level (mg/l) (1 mg/l = 7.6 μmol/l)	2.35	1.54	1.98	0.95	1.91	1.25	1.79
Blood aminolevulinic dehydratase ratio	2.26	0.64	1.47	0.19	1.44	0.20	70.13***
Urinary coproporphyrin level (μg/l) (1 μg/l = 1.53 nmol/l)	20.04	21.81	20.09	13.22	13.40	14.65	1.80
Free erythrocyte protoporphyrin level (μg/dl) (1 μg/dl = 0.018 μmol/l)	108.26	82.04	31.86	13.01	30.58	9.21	43.37**
Zinc protoporphyrin level (μg/dl) (1 μg/dl = 0.018 μmol/l)	115.50	80.80	44.30	12.50	44.50	9.60	38.10***

* p<0.05, ** p<0.01, *** p<0.001.

Table 4. Correlation coefficient between various laboratory parameters (N = 155).^a

	PbB	PbU	ALAU	ALAD-r	CPU	FEP	ZPP
PbB	—	0.61***	0.12	0.58***	0.04	0.55***	0.55***
PbU		—	0.08	0.59**	0.00	0.51***	0.52***
ALAU			—	0.21**	0.59***	0.26**	0.31***
ALAD-r				—	0.17*	0.71***	0.70***
CPU					—	0.24**	0.27***
FEP						—	0.96***
ZPP							—

^a PbB = blood lead level, PbU = urinary lead level, ALAU = urinary delta-aminolevulinic acid level, ALAD-r = blood aminolevulinic dehydratase ratio, CPU = urinary coproporphyrin level, FEP = free erythrocyte protoporphyrin level, ZPP = zinc protoporphyrin level.

* p<0.05, ** p<0.01, *** p<0.001.

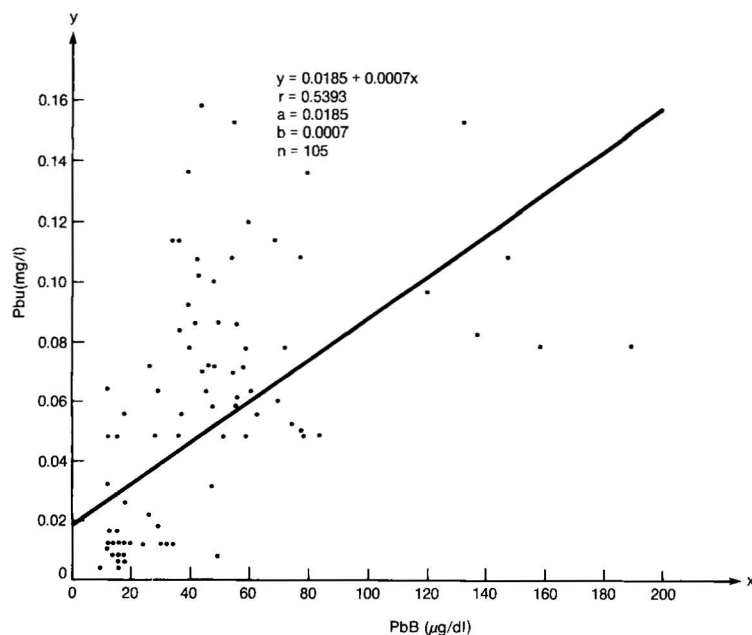


Figure 1. Correlation regression for the urinary (PbU) and blood (PbB) levels of lead in the workers of the battery and television factories combined. (1 mg Pb/l urine = 4.8 μ mol Pb/l urine, 1 μ g Pb/dl blood = 0.05 μ mol Pb/l blood)

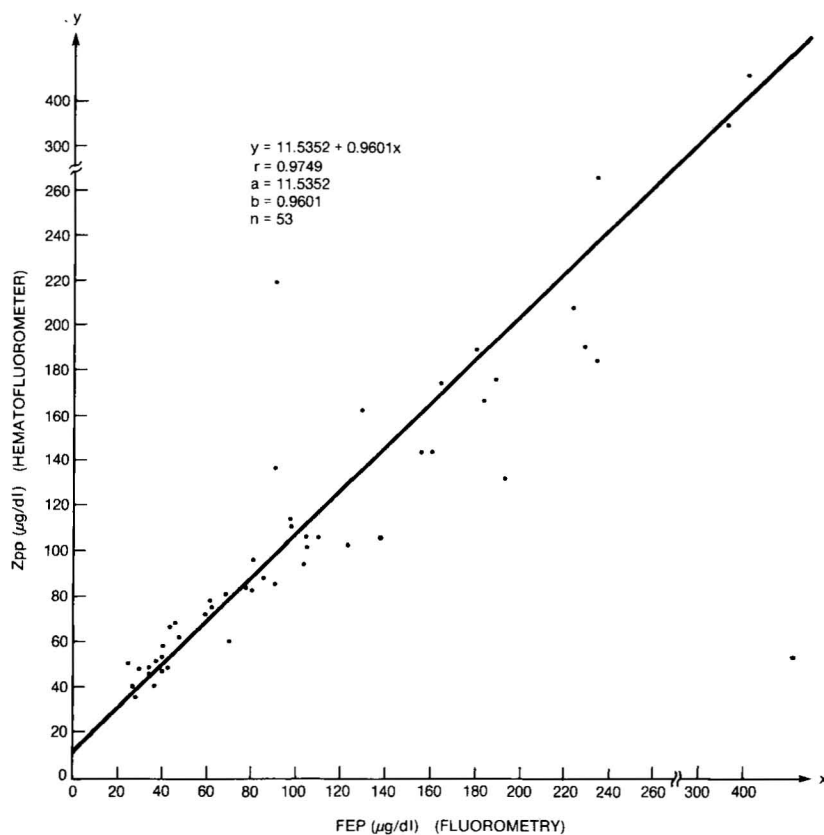


Figure 2. Correlation regression of the zinc protoporphyrin (Zpp) and free erythrocyte protoporphyrin (FEP) levels of the workers from the battery factory. (1 μ g/dl = 0.018 μ mol/l)

tests (all except ALAU and CPU) were highly significant by variance analysis. Values for the battery factory workers were significantly higher than those of the other two factories. No significant differences

between the TV workers and the referents were observed.

The correlations among the aforesaid criteria are listed in table 4. In the 21 pairs of correlations

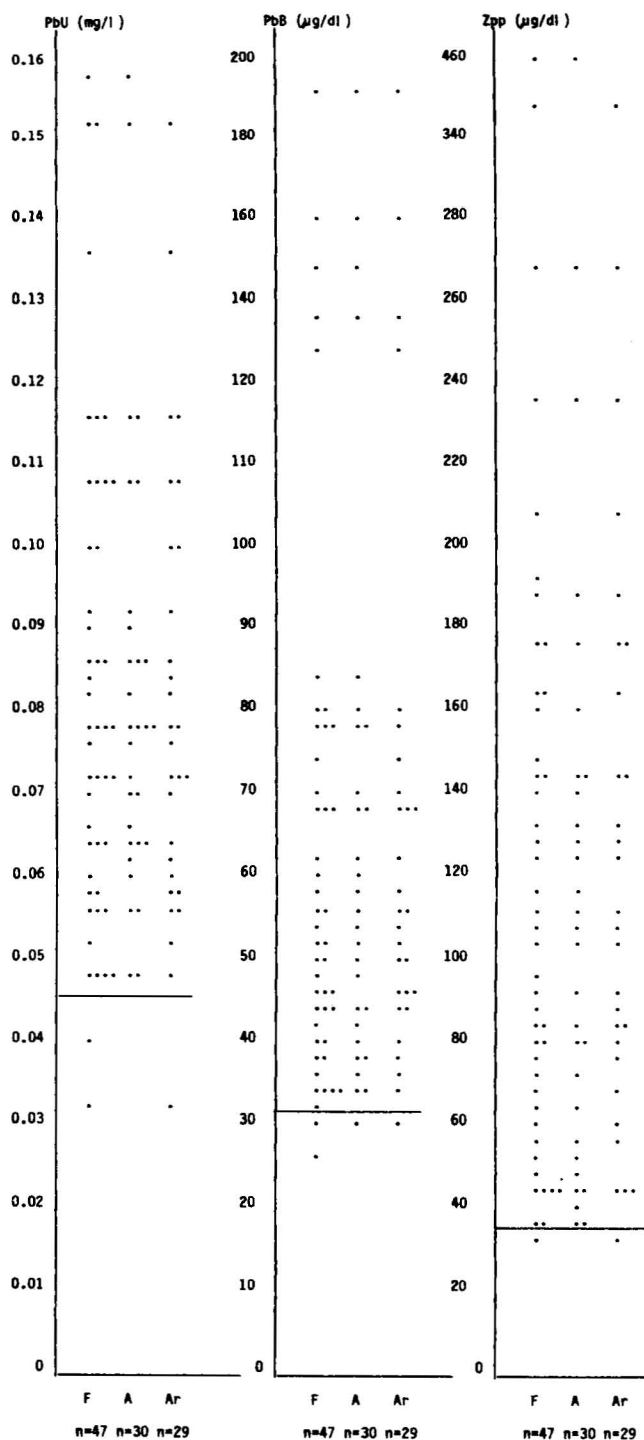


Figure 3. Relationship between the symptoms [fatigue (F), abdominal pain (A), and arthralgia (Ar)] and biochemical indicators [urinary lead level (PbU) blood lead level (PbB), and zinc protoporphyrin (Zpp)] for the workers in the battery factory. (1 mg Pb/l urine = 4.826 μ mol Pb/l urine, 1 μ g Pb/dl blood = 0.05 μ mol Pb/l blood, 1 μ g Zpp/dl blood = 0.018 μ mol/l blood)

analyzed, 17 were highly significant (all except PbB/ALAU, PbB/CPU, PbU/ALAU and PbU/CPU). The regression analyses of PbB/PbU for the battery and TV workers and FEP/ZPP for the battery workers are presented in figures 1 and 2. The correlations showed a linear regression pattern.

Concerning the relationship between clinical manifestations and biochemical criteria, there was a positive correlation between clinical manifestations in the battery workers and their levels of PbB, PbU, and ZPP (table 5).

The relationship between symptoms (fatigue, ab-

Table 5. Correlation of symptoms and laboratory parameters among the battery workers.^a

Symptoms	Blood lead level	Urinary lead level	Zinc protoporphyrin	
			Men	Women
Fatigue	***	***	*	***
Tinnitus	NS	*	NS	*
Insomnia	***	***	NS	***
Loss of memory	***	***	*	***
Indigestion	*	***	NS	***
Nausea	*	***	*	***
Vomiting	NS	***	NS	**
Mild abdominal pain	***	***	NS	***
Constipation	NS	*	NS	NS
Polyhidrosis in the extremities	*	***	NS	***
Arthralgia	**	***	NS	***
Numbness in the extremities	***	***	*	***

^a NS = not significant, * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$.

dominal pain, and arthralgia) and levels of PbB, PbU, and ZPP are shown in figure 3. The results showed a close relationship between the clinical manifestations and biochemical criteria. A symptomatic threshold limit could thus be estimated. The threshold lines plotted just above the fifth percentile of prevalence demonstrated that the symptomatic threshold limit was 0.045 mg/l (0.2 $\mu\text{mol/l}$) for PbU, 30 $\mu\text{g/dl}$ (1.5 $\mu\text{mol/l}$) for PbB, and 40 $\mu\text{g/dl}$ (0.7 $\mu\text{mol/l}$) for ZPP.

Electrophysiology data

Only 10 cases with abnormal EEG recordings were found (four battery workers, five TV workers, and one embroidery worker). There was no significant association between abnormal EEG recordings and factory. The results of the motor and sensory conduction velocity testing are shown in table 6. The conduction velocity of the median nerve in the reference group was faster than in the lead-exposed groups, but the conduction velocity of the ulnar nerve revealed no difference among the three groups.

Behavioral function evaluation

The results of the behavioral function tests are not reported for the battery workers because their co-

operation was poor during the tests. The TV workers scored lower than the embroidery workers on the finger tapping test ($p < 0.05$), but the embroidery workers scored lower than the TV workers on the similarity test. There was no significant difference between these two groups on the other tests. No evidence of behavioral dysfunction was found among the TV workers.

Discussion

Our data showed evidence of a dose-response relationship. Clinical manifestations were significantly more frequent among the battery workers than among workers in the other two factories. As the air lead level in the TV factory was below the maximum permissible limit, it was not surprising that no toxic effects of lead were found among its workers. The biochemical parameters of lead exposure were also much higher among the battery workers than among workers in the other two factories.

The blood lead level reflects the body burden of lead absorption. It has been proposed recently that the blood lead level of adults should not exceed 40 $\mu\text{g/dl}$ (1.9 $\mu\text{mol/l}$), and for women of reproductive age it should be set at 30 $\mu\text{g/dl}$ (1.5 $\mu\text{mol/l}$) (5, 10). Our results showed that both the clinical manifestations and biochemical test results of the TV workers [PbB 22.1 (SD 12.3) $\mu\text{g/dl}$ or 1.1 (SD 0.6) $\mu\text{mol/l}$] were not different from those of the reference group. However, among the battery workers [PbB 61.9 (SD 33.1) $\mu\text{g/dl}$ or 3.0 (SD 1.6) $\mu\text{mol/l}$] both the clinical manifestations and biochemical test results were significantly high. As shown in figure 3, the prevalence of fatigue, mild abdominal pain, and arthralgia increased when the PbB value exceeded 30 $\mu\text{g/dl}$ (1.5 $\mu\text{mol/l}$). It is reasonable to set the symptomatic threshold at 30 $\mu\text{g/dl}$ (1.5 $\mu\text{mol/l}$).

Our data demonstrated a close association between PbB and PbU (figure 1). Since the prevalence of clinical manifestations apparently increased when the PbU level exceeded 0.045 mg/l (0.2 $\mu\text{mol/l}$), we recommend this as the symptomatic threshold. There is great diversity among the normal ranges of PbU issued by different countries (4). The normal ranges issued in

Table 6. Motor and sensory conduction velocities of the three groups of workers.

Factory	Number of subjects	Motor conduction velocity (right) (m/s)				Sensory conduction velocity of the median nerve (right) (m/s)	
		Median nerve		Ulnar nerve			
		Mean	SD	Mean	SD	Mean	SD
Battery	53	58.78	7.48	59.70	6.04	60.92	8.61
Television	52	59.12	6.52	59.45	7.18	61.23	8.56
Embroidery	50	61.44	6.01	60.89	8.52	63.48	4.13
Analysis of variance		F = 5.32, p<0.05		F = 0.69, p>0.05		F = 4.28, p<0.05	

most districts of China are below 0.05 mg/l (0.24 $\mu\text{mol/l}$) (3).

An increased excretion of ALAU and CPU indicates lead interference with porphyrin metabolism. ALAU and CPU will increase only after the PbB exceeds 30–40 $\mu\text{g/dl}$ (1.5–1.9 $\mu\text{mol/l}$) (20). We failed to show differences in these two parameters among the three groups studied. We conclude that they are not good criteria for screening for lead exposure and that they have limited practical usefulness.

It is well established that ALAD activity is susceptible to inhibition by lead. The ratio of active to inactive ALAD (ALAD-r) used in the present study was positively correlated with the blood lead level (15). The ALAD-r of the battery workers was the highest of the three groups. The ALAD-r of the TV workers was slightly higher than that of the embroidery workers ($p > 0.05$). There were positive correlations between ALAD-r and each of the following: PbB, PbU, FEP, and ZPP with correlation coefficients of 0.58, 0.59, 0.71, and 0.70, respectively. Thus ALAD-r appears useful in assessing lead-related biological effects.

Elevations of FEP and ZPP are due to the inhibition of lead on heme synthetase in immature erythrocytes of the bone marrow. The FEP level represents the accumulation of erythrocyte protoporphyrin (6, 11). The normal ranges of FEP and ZPP reported are up to 60 $\mu\text{g/dl}$ (1.1 $\mu\text{mol/l}$) and 50 $\mu\text{g/dl}$ (0.8 $\mu\text{mol/l}$), respectively (10). The mean value of these two indices for the battery workers was three times the upper limit of normal. Since there were almost no subjective symptoms present at ZPP levels less than 40 $\mu\text{g/dl}$ (0.7 $\mu\text{mol/l}$) (figure 3), it seems reasonable to take this level as the symptomatic threshold. Among the parameters listed in table 4, ZPP showed the best correlation with other criteria, slightly better than that of FEP. It is suitable to use ZPP as a screening criterion for preventive monitoring purposes.

The determination of the conduction velocity of a peripheral nerve has been suggested as a sensitive index for the detection of early lead poisoning (2). Our data showed that the motor and sensory conduction velocities of the median nerve in the lead-exposed groups were slower than those of the reference group, but that the motor conduction velocity of the ulnar nerve was the same in all three groups.

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