Blood lead and the symptoms of lead absorption

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ABSTRACT Eighty-one percent of all hourly paid men who had been employed for more than six months in a factory making lead acid batteries and plastics completed a modified Cornell medical index health questionnaire. Blood lead and erythrocyte protoporphyrin (EPP) were also measured. The questions were grouped into symptom categories as follows: all physical, all psychological, "potentially lead induced," pulmonary, cardiovascular, gastrointestinal, skin, nervous system, genitourinary, and fatigue. For each symptom category the pooled percentages of men whose symptom scores were above the common median of the three blood lead groups 10-, 40-, and 60 and over $\mu\text{g}/100\text{ ml}$ (0.48-, 1.93-, and 2.90 and over $\mu\text{mol/l}$) within age/smoking subgroups were calculated. In every symptom category the percentages in the two lower blood lead groups differed little, but the percentages were consistently higher in men with blood concentration of 60 $\mu\text{g}/100\text{ ml}$ (2.90 $\mu\text{mol/l}$) and over. Differences between a combined 10-59 $\mu\text{g}/100\text{ ml}$ (0.48-2.85 $\mu\text{mol/l}$) blood lead group and the 60 and over $\mu\text{g}/100\text{ ml}$ ($\geq 2.90\text{ } \mu\text{mol/l}$) group were statistically significant at the 0.01 level for "potentially lead induced" symptoms and at the 0.05 level for skin and psychological symptoms. Broadly similar results were obtained with four log₁₀ EPP groups 0.6-, 1.5-, 1.7-, and ≥ 2.0 , but differences did not reach statistical significance. There was no obvious explanation as to why symptoms that are not found in classic lead poisoning should be increased almost as much as those that are. It was thought that these results could be biased due to the men's knowledge of the symptoms associated with lead exposure, but the possibility that they may be partly due to lead absorption cannot be excluded.

There is agreement that symptoms of lead absorption may occur when blood lead concentration exceeds 80 $\mu\text{g}/100\text{ ml}$ (3.86 $\mu\text{mol/l}$) but some authors think that symptoms occur at lower levels.^{2,3} This is a matter of prime importance when setting standards.

The relation between symptoms and lead absorption was studied in workers in a factory making lead acid batteries and plastics using a self-administered questionnaire based on the Cornell medical index health questionnaire⁴⁻⁶ with modifications similar to those of Sakurai *et al*.⁷ Lead absorption was estimated by both blood lead and erythrocyte protoporphyrin (EPP).

Methods

The factory has been described previously.⁸ All hourly paid men who had been employed more than six months were requested by letter to take part in the

survey. The number of women employees was thought to be too small for investigation, and men whose occupational lead exposure was under six months were excluded because their blood lead concentrations might not yet be stable. Men were asked to go to the medical department in groups of three to complete the questionnaire and to give a blood sample. Eight questions were added to the Cornell medical index health questionnaire to cover more completely the symptoms of lead poisoning given by Lane *et al*¹ (appendix 1), and two to divide those who were not heavy smokers into non-smokers, ex-smokers, and light smokers. It thus contained 205 questions in all, 35 of which were thought to cover "potentially lead induced symptoms" (appendix 2). To assure confidentiality each man was given a code number to be used in place of his name. Date of birth, date of starting employment, and current department with date of entry were recorded. One of us (MKW) subsequently checked each questionnaire for omissions and obvious inconsistencies.

Received 1 June 1982
Accepted 23 July 1982

Men who had been employed for over six months but had been in their present department under six months were classified as "miscellaneous." The remainder were grouped by departments.

Blood lead concentration and EPP were estimated by the National Occupational Hygiene Laboratory. Blood lead estimations were made by monocolour dithizone and have been described and validated⁹; EPP was estimated by "Zn P model 4000 Haemato-fluorometer," made by Environmental Sciences Associates, Burlington, MA, USA, and marketed in the United Kingdom by MSE/Fisons.

During the survey there was no major lost time working, but there was some industrial unease which together with a high labour turnover in the medical department, produced initially a poor response and two and a half years were taken to complete the survey. The study population (661 men) was defined as men employed on 17 August 1978 (705), excluding those who had been employed for under six months on the day they were due to enter the survey (44). During the survey 53 men (8%) left, 66 men (10%) refused to take part, and six questionnaires were lost, so that the total number of questionnaires obtained was 536 (81%). Of these, nine refused to give samples for blood lead analysis, and 12 samples were not analysed for EPP, three being lost and nine clotted. The analysis of data by blood lead concentrations was, therefore, based on results from 527 men, and that by EPP levels on results from 515 men.

Results

The questions in the questionnaire were grouped into 10 physical and six psychological symptom categories. The number of affirmative replies to the questions tended to be low, and scoring in some of the smaller symptom categories was too low for them to be analysed separately. The analysis was confined, therefore, to 10 main categories. Eight of these represented physical symptoms related to diseases of the following types: pulmonary, cardiovascular, gastrointestinal, skin, nervous system, genitourinary, fatigue, and a category of all physical symptoms that included in addition questions on musculoskeletal symptoms and frequency of illness. The separate categories of inadequacy, depression, anxiety, sensitivity, anger, and tension were combined to give one category of psychological symptoms. The category "potentially lead induced symptoms" consisted of 27 physical and eight psychological questions (appendix 2).

In a preliminary analysis of the data the mean number of "yes" replies in each symptom category were studied in the various departments and in groups classified by blood lead and by EPP con-

centrations. Because the frequency distribution of EPP was found to be extremely skewed with very scattered values at the higher levels it was preferable to form groups using $\log_{10}$ EPP.

Possible confounding factors in the comparison of mean symptom scores were considered to be age, duration of employment in the factory, and smoking habits. There is usually a strong association between age and duration of employment. In an analysis of the mean symptom scores in departments reasonably high, and statistically significant, rank correlations of physical and lead symptoms with age were only slightly reduced when duration of employment was held constant, but slightly lower correlations between mean scores and duration of employment approached zero when age was held constant. In an analysis of individual scores the product-moment correlations between symptoms and age and between symptoms and duration of employment were both near zero.

Duration of employment was not a good measure of exposure since the men would have changed jobs during their employment, including movement into non-lead departments, and there was no information about the duration of time a man might have spent in one job. In view of these deficiencies and the lack of independent correlation between symptoms and duration of employment, it was decided that in comparisons between symptom scores allowance would be made only for differences in age and in smoking habits.

The questions on smoking enabled the men to be classified as non-smokers, ex-smokers, light smokers who smoked no more than 20 cigarettes a day (or the equivalent in pipe tobacco and cigars), and heavy smokers who smoked more than 20 cigarettes a day. Ambiguous replies meant that 12 men could not be classified.

The distributions of symptom scores were found to be skewed, with a high frequency of low scores, so for comparisons between blood lead and EPP groups median scores were calculated and the non-parametric extended median test used in tests of significance. A difference has been described as statistically significant when the probability of it having occurred by chance has been equal to or less than 0.05.

DIFFERENCES BETWEEN DEPARTMENTS IN SYMPTOM SCORES

There were 19 departments, including the non-lead porvic department and the "miscellaneous" group, with mean blood leads varying between $19.9 \mu\text{g}/100 \text{ ml}$ ($0.96 \mu\text{mol/l}$) in transit workers to $61.0 \mu\text{g}/100 \text{ ml}$ ($2.95 \mu\text{mol/l}$) in the furnace men. The number of men in some departments was very small, and it was difficult

to combine departments, since those with similar processes showed differing concentrations of mean blood lead and EPP, and the rank order of departments by mean blood lead differed from that by mean EPP. Therefore, mean symptom scores in the departments were calculated only for the larger symptom categories—potentially lead induced symptoms (35 questions), all physical symptoms (106 questions), and all psychological symptoms (45 questions). Table 1 shows the results, together with mean blood lead and EPP concentrations, mean age, and percentage of heavy smokers in each department. Because of the difficulty in combining departments, and since the main aim of the study was to see if symptom scores were related to concentrations of blood lead and EPP, differences in mean symptom scores between departments were not tested for statistical significance.

DIFFERENCES IN SYMPTOM SCORES BETWEEN LEVELS OF BLOOD LEAD AND BETWEEN LEVELS OF EPP

Blood lead values ranged from 10 to 86 $\mu\text{g}/100\text{ ml}$ (0.48 to 4.15 $\mu\text{mol/l}$) and EPP from 4 to 286 $\mu\text{g}/100\text{ ml}$ (0.07 to 5.09 $\mu\text{mol/l}$). A preliminary analysis was carried out using eight blood level groups and 10 log EPP groups, cross classified by age and smoking habits. The data were examined to see if there was any linear trend in mean symptom scores associated with blood lead or EPP concentrations. None of the symptom categories showed a linear trend, although the highest blood lead and EPP group tended to have

the highest mean symptom score. The stratification by age and smoking habits had produced very small subgroups, and in view of the lack of trend it was decided to combine some of the blood lead and EPP groups. The criterion used in combining was based on recent proposals by the Occupational Safety and Health Association,¹⁰ who have recommended lowering the blood lead concentration at which a worker should be removed from his job to 60 μg (0.29 μmol)/100 g and the concentrations at which he could return to his original job to 40 μg (0.19 μmol)/100 g. Three blood lead groups were formed: men with blood lead under 40 $\mu\text{g}/100\text{ ml}$ (1.93 $\mu\text{mol/l}$), those 40 μg and over but under 60 μg (2.90 $\mu\text{mol/l}$), and 60 μg and over. At first three log EPP groups were formed by predicting the log EPP for blood lead concentrations of 40 μg and 60 μg using the regression equation calculated from the data: $\log \text{EPP} = 1.044 + 0.0115 \times \text{blood lead } (\mu\text{g}/100\text{ ml})$. This gave log EPP groups of 0.60 up to 1.5, 1.5 up to 1.7, and 1.7 and over. This division, however, put 19% of the men in the highest log EPP group compared with 6% in the highest blood lead group. Since an acceptable level for zinc protoporphyrin (ZPP) has been given as 100 $\mu\text{g}/100\text{ ml}$ (1.78 $\mu\text{mol/l}$) a division was made to give a fourth log EPP group of two and over. In terms of EPP these limits are equal to four up to 32 $\mu\text{g}/100\text{ ml}$, 32 up to 51, 51 up to 100, and 100 and over.

Symptom scores by age and smoking habits

Tables 2 and 3 show the distribution by smoking

Table 1 Mean symptom scores in departments, with mean age, percentage of heavy smokers, mean blood lead, and geometric mean of EPP

Departments	No of men	Age	Heavy smokers (%)	Lead symptoms	All physical symptoms	All psychological symptoms	Blood lead		EPP	
							$\mu\text{g}/100\text{ ml}$	$\mu\text{mol/l}$	$\mu\text{g}/100\text{ ml}$	$\mu\text{mol/l}$
Assembly A, pack burning	7	43.0	43	2.7	6.6	3.0	41.1	1.99	33.0	0.59
Assembly A, other processes	23	36.0	9	2.4	6.1	1.6	32.6	1.57	24.6	0.44
Assembly B, pack burning	18	40.9	22	2.2	6.7	1.9	45.1	2.18	41.0	0.73
Assembly B, other processes	67	43.5	19	3.8	9.2	2.5	38.3	1.85	25.7	0.46
Assembly B, reed stacking	8	39.9	13	2.1	5.6	1.5	42.9	2.07	44.6	0.79
Casting	47	41.9	36	3.4	8.7	3.2	39.5	1.91	30.1	0.54
Formation	19	40.1	26	3.2	7.9	2.7	45.2	2.18	43.5	0.77
Furnace	14	42.3	42	3.1	8.5	2.6	61.0	2.95	114.8	2.04
Machine shop, fitters	58	40.9	15	2.5	7.0	2.2	37.9	1.83	26.0	0.46
Machine shop, electricians	24	43.4	13	1.7	4.7	2.6	28.2	1.36	23.7	0.42
Machine shop, building maintenance	8	49.2	13	3.4	8.1	1.5	32.5	1.57	35.1	0.62
Machine shop, toolmakers	21	39.0	19	2.5	4.9	2.8	28.4	1.37	18.6	0.33
Pasting	41	40.6	20	2.5	5.7	3.6	47.1	2.27	49.2	0.88
Plate cutting	17	41.7	6	2.6	7.0	3.0	53.4	2.58	69.4	1.24
Porvic	77	34.4	43	3.3	7.7	3.0	23.2	1.12	19.2	0.34
Transit	22	41.2	27	2.5	6.5	3.4	19.9	0.96	21.3	0.38
Warehouse and packing	13	48.8	31	3.0	7.2	2.7	36.2	1.75	22.2	0.40
Yard	6	50.0	33	3.5	9.2	2.0	37.2	1.80	31.8	0.57
Miscellaneous	25	46.8	24	3.0	8.4	1.6	32.9	1.59	24.9	0.44
All departments	515	41.0	25	2.9	7.3	2.6	36.2	1.75	29.0	0.52

Table 2 *Distribution of smoking habits and mean age in blood lead groups*

Smoking habits	Blood lead $\mu\text{g}/100\text{ ml}$ ($\mu\text{mol/l}$)									Total		
	10- (0.48-)			40- (1.93-)			≥ 60 (2.90)			No	%	Mean age
	No	%	Mean age	No	%	Mean age	No	%	Mean age			
Non-smokers	64	19.8	36.1	22	12.7	39.8	5	16.7	44.8	91	17.3	37.9
Ex-smokers	75	23.1	40.9	46	26.6	46.8	12	40.0	47.7	133	25.2	45.1
Light smokers	96	29.6	42.4	55	31.8	42.9	4	13.3	41.1	155	29.4	42.8
Heavy smokers	83	25.6	40.7	45	26.0	38.8	8	26.7	40.2	136	25.8	40.7
Unknown	6	1.8	38.4	5	2.8	42.7	1	3.3	48.0	12	2.3	41.0
Total	324	100.0	40.3	173	100.0	42.4	30	100.0	44.4	527	100.0	41.9

Table 3 *Distribution of smoking habits and mean age in log EPP groups*

Smoking habits	$\log_{10}$ EPP												Total		
	0.60-			1.50-			1.70-			≥ 2.00			No	%	Mean age
	No	%	Mean age	No	%	Mean age	No	%	Mean age	No	%	Mean age			
Non-smokers	61	19.8	35.8	17	15.3	41.4	8	10.8	38.2	4	18.2	43.2	90	17.5	37.4
Ex-smokers	76	24.7	40.7	28	25.2	47.2	24	32.4	47.0	4	18.2	49.3	132	25.6	43.5
Light smokers	83	26.9	41.0	37	33.3	44.5	25	33.8	46.4	8	36.4	34.7	153	29.7	42.4
Heavy smokers	82	26.6	39.1	27	24.3	42.0	13	17.6	43.3	6	27.3	43.2	128	24.8	40.4
Unknown	6	1.9	37.2	2	1.8	33.8	4	5.4	50.2	0	—	—	12	2.3	41.0
Total	308	100.0	39.3	111	100.0	43.9	74	100.0	45.4	22	100.0	41.3	515	100.0	41.3

Table 4 *Mean symptom scores by age (figure in parentheses is the total number of questions in the symptom group)*

Age	No of men	All physical (106)	All psychological (45)	Potential lead induced (35)	Pulmonary (9)	Cardio-vascular (12)	Gastro-intestinal (17)	Skin (8)	Nervous system (16)	Genito-urinary (10)	Fatigue (6)
15-24	45	6.1	2.7	2.5	0.4	0.6	0.8	0.6	1.5	0.3	0.3
25-54	398	7.1	2.8	2.9	0.6	0.6	1.3	0.7	1.4	0.5	0.4
55-64	84	9.6	2.1	3.5	0.9	1.3	1.6	0.7	1.6	0.8	0.9
All ages	527	7.4	2.7	3.0	0.6	0.7	1.3	0.7	1.5	0.5	0.5

Table 5 *Mean symptom scores by smoking habits*

Smoking habits	No of men	All physical	All psychological	Potential lead induced	Pulmonary	Cardio-vascular	Gastro-intestinal	Skin	Nervous system	Genito-urinary	Fatigue
Non-smokers	91	6.1	3.4	2.7	0.5	0.6	1.0	0.7	1.1	0.3	0.5
Ex-smokers	133	6.9	2.0	2.4	0.5	0.8	1.4	0.6	1.3	0.6	0.2
Light smokers	155	6.9	2.1	2.8	0.5	0.6	1.3	0.7	1.3	0.5	0.5
Heavy smokers	136	9.3	3.5	3.8	1.0	0.9	1.5	0.8	2.0	0.7	0.5
Unknown	12	9.2	2.4	3.2	0.5	1.3	0.9	0.8	2.5	0.5	0.3
Total	527	7.4	2.7	3.0	0.6	0.7	1.3	0.7	1.5	0.5	0.4

Table 6 *Mean and median symptom scores in blood lead groups*

Blood lead		No of men	All physical		All psychological		Potential lead induced		Pulmonary	
($\mu\text{g}/100\text{ ml}$)	($\mu\text{mol/l}$)		Mean	Median	Mean	Median	Mean	Median	Mean	Median
10-	0.48-	324	7.5	4.9	2.7	0.8	3.0	1.5	0.6	0.3
40-	1.93-	173	6.8	5.4	2.4	0.9	2.7	1.4	0.5	0.2
60-	2.90-	30	9.9	8.5	4.1	1.8	4.3	2.9	0.9	0.5
Total		527	7.4	5.2	2.7	0.9	3.0	1.5	0.6	0.3

habits and mean age in the blood lead and log EPP groups. There was little difference in the percentage of heavy smokers in the blood lead groups but some variation in the other smoking categories. Excluding the highest log EPP group, where numbers were small, the percentages of both non-smokers and heavy smokers decreased as log EPP increased.

Age tends to increase as concentrations of blood lead and EPP increase except in the highest log EPP group. In general ex-smokers were the oldest and non-smokers the youngest.

Table 4 shows the mean symptom scores for three age groups. Compared with the total number of questions in the symptom categories the mean scores were low, and differences between age groups small, but physical symptoms did tend to increase with age, while psychological symptoms differed little but showed a slight decrease in men aged 55-64.

Table 5 shows mean symptom scores classified by smoking habits. There were no large differences between the means but, excluding men whose smoking habits were unknown, the heavy smokers had the highest mean score in every symptom category. There was little difference among the other three groups except for psychological symptoms, where the mean score of non-smokers was only a fraction lower than that of heavy smokers.

Symptom scores by levels of blood lead

Table 6 shows the mean and median symptom scores in the blood lead groups. Differences among groups are small, especially in the low scoring symptom categories, but apart from the genitourinary symptoms, men in the blood lead group of 60 $\mu\text{g}/100\text{ ml}$ (2.90 $\mu\text{mol/l}$) and over consistently had the highest mean and median scores.

Because of the skewed distributions of the symptom scores significance tests were carried out using the non-parametric extended median test. This, in effect, tests the significance of the differences between the percentages of men in each blood lead group who score above the common median of the three groups combined. To standardise for the effects of age and smoking habits the data were stratified into age and smoking groups, ex- and light smokers having to be combined to avoid too small numbers in subgroups. Comparisons made within each age/smoking subgroup were found to be consistent enough for the results to be pooled to give a composite test of the differences between the blood lead groups. The results in table 7 show for each blood lead group the total percentage of men who scored above the common medians in the individual age/smoking subgroups. In all of the symptom categories the percentages in the two lower blood

Table 7 Pooled percentages of men who scored above the common median in age/smoking subgroups, by blood lead concentrations

Symptom category	Blood lead			Overall comparison		10-59 μg v $\geq 60 \mu\text{g}$	
	$\mu\text{g}/100\text{ ml}$ 10- $\mu\text{mol/l}$ 0.48-	40- 1.93-	≥ 60 ≥ 2.90	χ^2 (2 df)	Significance level	χ^2 (1 df)	Significance level
All physical	44.0	44.0	62.0	3.60	NS	3.60	NS
All psychological	39.6	36.9	58.6	4.91	NS	4.64	$p < 0.05$
Potentially lead induced	45.9	41.1	69.0	7.78	$p < 0.05$	6.74	$p < 0.01$
Pulmonary	34.0	29.8	48.3	3.93	NS	3.06	NS
Cardiovascular	37.7	32.7	44.8	2.10	NS	0.92	NS
Gastrointestinal	38.0	36.3	41.4	0.32	NS	0.18	NS
Skin	35.2	37.5	58.6	6.23	$p < 0.05$	5.99	$p < 0.05$
Nervous system	37.7	36.3	55.2	3.82	NS	3.72	NS
Fatigue	27.0	20.8	37.9	4.66	NS	2.44	NS

NS = Not statistically significant.

Cardiovascular		Gastrointestinal		Skin		Nervous system		Genitourinary		Fatigue	
Mean	Median	Mean	Median	Mean	Median	Mean	Median	Mean	Median	Mean	Median
0.8	0.3	1.3	0.7	0.7	0.3	1.5	0.9	0.6	0.3	0.4	0.2
0.6	0.2	1.3	0.7	0.7	0.3	1.4	1.0	0.5	0.2	0.4	0.1
0.2	0.4	1.4	1.1	1.2	0.9	2.0	1.7	0.5	0.3	0.6	0.3
0.7	0.3	1.3	0.7	0.7	0.3	1.5	1.0	0.5	0.3	0.4	0.2

Table 8 Mean and median symptom scores in log₁₀ EPP groups

EPP			No of men	All physical		All psychological		Potential lead induced		Pulmonary	
Log EPP	($\mu\text{g}/100\text{ ml}$)	($\mu\text{mol/l}$)		Mean	Median	Mean	Median	Mean	Median	Mean	Median
0.6-	4-	0.07-	308	7.3	4.8	2.6	0.9	2.9	1.5	0.6	0.2
1.5-	32-	0.57-	111	7.4	5.0	2.7	0.6	3.1	1.4	0.5	0.2
1.7-	51-	0.91-	74	7.6	6.7	2.2	0.6	2.8	1.3	0.5	0.3
≥ 2.0	≥ 100	≥ 1.78	22	7.1	6.5	4.4	1.7	3.2	2.2	0.7	0.5
Total			515	7.3	5.2	2.6	0.9	2.9	1.5	0.6	0.3

lead groups differ little, the main difference being the higher percentage in men with blood lead concentrations of 60 $\mu\text{g}/100\text{ ml}$ (2.90 $\mu\text{mol/l}$) or over. In overall comparisons among the three groups, however, only skin and lead symptom categories showed statistically significant differences, both at the 0.05 level.

Partitioning the χ^2 into two components, one comparing the two lower blood lead groups with each other and the other comparing the combined lower blood lead groups with the $\geq 60\text{ } \mu\text{g}/100\text{ ml}$ (2.90 $\mu\text{mol/l}$) group, showed that the contribution of the difference between the two lower level groups was negligible.

Differences between the combined 10–59 $\mu\text{g}/100\text{ ml}$ (0.48 – 2.85 $\mu\text{mol/l}$) blood lead group and the $\geq 60\text{ } \mu\text{g}/100\text{ ml}$ (2.90 $\mu\text{mol/l}$) group were statistically significant at the 0.01 level for potentially lead induced symptoms and at the 0.05 level for skin and psychological symptoms.

Symptom scores by levels of log EPP

Table 8 shows the mean and median symptom scores in log EPP groups. Apart from psychological symptoms, where the highest EPP group has the highest mean score, the means in the EPP groups are similar and show little consistent pattern. The median scores show a greater tendency to be highest in the ≥ 2.0 log EPP group, but again differences between the groups are small.

Table 9 shows the results of the median tests. Apart

from gastrointestinal symptoms, which show a reverse trend, the ≥ 2.0 log EPP group has the highest percentage of men scoring above the common median, although differences are slight in the cardiovascular category. Comparison of the percentages, however, gave no statistically significant differences. Since χ^2 on one degree of freedom has to be at least 3.84 for significance at the 0.05 level, only the skin and fatigue symptom categories could have shown a statistically significant component in separate comparisons between combinations of the log EPP groups, but both failed to do so.

Discussion

In 1968 Lane and his 17 colleagues thought, from personal experience, that symptoms could not be attributed to lead when the blood lead was below 80 $\mu\text{g}/100\text{ ml}$ (3.86 $\mu\text{mol/l}$).¹ Sakurai *et al*⁷ in 1974 studied symptoms in 125 rubber hose and car tyre workers with slight to moderate lead exposure and a smaller control group. They concluded that symptoms are not likely when blood lead concentration is under 50 $\mu\text{g}/100\text{ ml}$ (2.42 $\mu\text{mol/l}$). More recently Lilis *et al*² studied 158 smelter workers with high exposure, and selected the subgroup of 48 whose blood lead concentrations had never been over 80 $\mu\text{g}/100\text{ ml}$ (3.86 $\mu\text{mol/l}$) and who had never been chelated. Associations were found between central nervous system symptoms (tiredness, fatigue, nervousness, sleeplessness or somnolence, and anxiety) and ZPP, and between muscle and joint pain

Table 9 Pooled percentages of men who scored above the common median in age/smoking subgroups, by log₁₀ EPP levels

Symptom category	Log ₁₀ EPP				Overall comparison	
	0.6-	1.5-	1.7-	≥ 2.0	χ^2 (3 df)	Significance level
	(%)	(%)	(%)	(%)		
All physical	46.4	41.3	54.3	54.5	3.44	NS
All psychological	44.4	45.0	42.9	59.1	1.95	NS
Potentially lead induced	46.4	45.0	44.3	59.1	1.16	NS
Pulmonary	32.8	33.0	30.0	50.0	3.16	NS
Cardiovascular	34.8	38.5	38.6	40.9	0.90	NS
Gastrointestinal	45.0	44.0	42.9	40.9	0.23	NS
Skin	38.4	32.1	32.9	54.5	4.79	NS
Nervous system	36.4	37.6	37.1	50.0	1.62	NS
Fatigue	26.5	24.8	17.1	36.4	4.14	NS

NS = Not statistically significant.

Symptoms	Cardiovascular		Gastrointestinal		Skin		Nervous system		Genitourinary		Fatigue	
	Mean	Median	Mean	Median	Mean	Median	Mean	Median	Mean	Median	Mean	Median
Lowest	0.3	0.3	1.3	0.7	0.7	0.3	1.4	1.0	0.5	0.2	0.4	0.2
Low	0.3	0.3	1.4	0.7	0.6	0.3	1.5	1.0	0.5	0.3	0.5	0.2
Medium	0.3	0.3	1.5	0.9	0.6	0.3	1.5	1.1	0.6	0.3	0.3	0.1
High	0.3	0.3	0.7	0.4	1.0	0.7	1.7	1.4	0.4	0.1	0.6	0.3
Highest	0.3	0.3	1.3	0.7	0.7	0.3	1.4	1.0	0.5	0.3	0.4	0.2

or soreness or both, and ZPP. It was concluded that blood lead concentration should not exceed 60 $\mu\text{g}/100\text{ ml}$ (2.90 $\mu\text{mol/l}$). But the subgroup of those with the lowest blood lead among highly exposed smelter workers might behave differently from workers with moderate and stable exposure in the same blood lead range, as in the present study, particularly since this selected group tended to be young with a short duration of employment. For it is also the general experience of the Employment Medical Advisory Service in the United Kingdom that symptoms do not occur with blood lead concentrations under 80 $\mu\text{g}/100\text{ ml}$ (3.86 $\mu\text{mol/l}$),¹¹ and only comparatively recently have permitted concentrations been reduced to this figure from 120 $\mu\text{g}/100\text{ ml}$ (5.79 $\mu\text{mol/l}$) in 1972¹² and 100 $\mu\text{g}/100\text{ ml}$ (4.83 $\mu\text{mol/l}$) in 1977.¹³ Lilis *et al* also found that adverse effects correlated more strongly with ZPP than with blood lead and said that blood lead was an inappropriate biological guide.² This is contrary to the present findings where symptom scores showed a stronger association with high blood lead concentrations than with high EPP concentrations (tables 6–9).

Dahlgren in the United States in 1978³ reported severe lead colic in workers having blood lead concentrations as low as 40 $\mu\text{g}/100\text{ ml}$ (1.93 $\mu\text{mol/l}$), measured within two weeks of cessation of lead exposure. Beritic¹⁴ in Yugoslavia in 1971 reported similar findings. Again it is difficult to reconcile these findings with experience in the United Kingdom. Irwig *et al*,¹⁵ in a well argued study of black male lead workers in South Africa, found increasing abdominal ache, constipation, and tremor with increasing blood lead concentrations. The prevalence of abdominal ache in the blood lead quartiles <68 $\mu\text{g}/100\text{ ml}$ (3.28 $\mu\text{mol/l}$), 68–85 $\mu\text{g}/100\text{ ml}$ (3.28–4.11 $\mu\text{mol/l}$), 86–106 $\mu\text{g}/100\text{ ml}$ (4.15–5.12 $\mu\text{mol/l}$), and $\geq 107\text{ }\mu\text{g}/100\text{ ml}$ (5.17 $\mu\text{mol/l}$) was 12%, 23%, 24%, and 37%. Urinary lead, urinary δ -aminolaevulinic acid, and packed cell volume were also measured, but the authors found that "blood lead was the best, and almost exclusive, predictor of morbidity." They gave no opinion, however, of the concentration of blood lead at which symptoms begin to appear.

A weakness of our present results lies in the small numbers of men in the highest blood lead and log EPP

groups. Although this makes the results of these groups less reliable, there seems no reason why it should cause a bias in a consistently unfavourable direction. A more likely explanation is that the highly exposed lead workers confess to more symptoms either because lead is causing the symptoms or because of bias in answering "yes" due to their knowledge of lead symptoms—that is, they might expect to have more symptoms. Every man, on starting employment, is told which departments have the highest lead exposure and what the symptoms of lead poisoning are. If lead were causing symptoms directly it would be expected that only those symptom categories known to be affected in lead poisoning and especially the "potentially lead induced symptoms" would be involved and the skin, for example, would not be. When all systems are involved as in the present case, even though the greatest excess is in "potentially lead induced symptoms," it suggests that the results may be due to bias rather than to lead absorption. This does not explain, however, the consistently higher symptom scores in heavy smokers, since the proportion of heavy smokers is similar in the blood lead groups and the numbers of men in the highest level blood lead and EPP groups is small. The possibility that lead absorption is causing some of the excess in the more highly exposed workers cannot be excluded. But whether the rather small increase, if it exists, could be considered materially significant is beyond the scope of this paper.

We are very grateful to all the men who took part in the survey, to members of the medical department who helped and especially Sister Margaret Smith, to the directors of Chloride Automotive Batteries Ltd for permission to undertake it, and to the Chloride Group for financial assistance.

We are also very grateful to Mr K R Sullivan, computer programmer, for help in the analysis of the data.

Appendix 1

Symptoms of lead poisoning given by Lane *et al*¹

Tiredness	Anaemia	Paraesthesiae
Lassitude	Pallor	Neuropathy

Constipation	Diarrhoea	Encephalopathy
Slight abdominal discomfort or pain	Nausea	
Anorexia	Colic	
Altered sleep	Reduction of muscle power	
Irritability	Muscle tenderness	

Appendix 2

Questions forming the symptom category "potentially lead induced symptoms." The original Cornell medical index number is shown. Additional questions are indicated by *.

- 45 Is your appetite always poor?
- 48 Do you often suffer from an upset stomach?
- 49 Do you usually feel bloated after eating?
- * Do you often feel sick?
- 51 Do you often vomit?
(orig: "Are you often sick to your stomach?")
- 52 Do you suffer from indigestion?
- 53 Do severe pains in the stomach often double you up?
- 54 Do you suffer from constant stomach trouble?
- 57 Do you suffer from diarrhoea or frequent loose bowel movements? ("Diarrhoea" added to original)
- 60 Do you constantly suffer from bad constipation?
- * Do you suffer from hard bowel movements?
- 66 Do you usually have severe pains in the arms and legs?
- * Do your muscles feel tender or sore?
- * Are you more pale than you used to be?
- 79 Do you suffer badly from frequent severe headaches?
- 80 Does pressure or pain in the head often make life miserable?
- 86 Do you have constant numbness or tingling in any part of your body?
- * Do you often get pins and needles?
- 87 Was any part of your body ever paralysed?
- * Have your hands or feet ever felt heavy or weak?
- 108 Do you often get spells of complete exhaustion or fatigue?
- 109 Does working tire you out completely?
- 110 Do you usually get up tired and exhausted in the morning?
- 111 Does every little effort wear you out?
- 112 Are you constantly too tired and exhausted even to eat?

- 127 Were you ever treated for severe anaemia (thin blood)?
- * Have you been anaemic (had thin blood)?
- 139 Do you usually have great difficulty in falling asleep or staying asleep?
- * Have you noticed a change for the worse in your sleeping habits?
- 180 Are you easily upset or irritated?
- 182 Do little annoyances get on your nerves and make you angry?
- 183 Does it make you angry to have anyone tell you what to do?
- 184 Do people often annoy and irritate you?
- 188 Are you constantly keyed up and jittery?
- 192 Are you often awakened out of your sleep by frightening dreams?

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