Lead in human blood and in the environment near a battery factory

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SUMMARY Samples of blood, air, dust, soil, vegetation, and tap water were examined between 1973 and 1975 to determine whether a large battery factory (with a smelter) was contributing to lead in the environment and to lead absorption by the local population. Mean blood lead levels in the children of lead workers were about 6 µg/100 ml higher ($P < 0.001$) than in otherwise comparable children. Capillary blood samples in wives of lead workers were 1.7 µg/100 ml higher ($P < 0.05$) than those of otherwise comparable wives, but venous blood samples from the same subjects showed no significant difference. Lead in dust, soil and vegetation, although variable, decreased in concentration with distance from the factory. This relationship with distance from the factory was not however found in blood lead levels. No consistent effect of distance was found with lead in air, but significantly higher concentrations were recorded at downwind than upwind sites. The blood lead results have been analysed to assess the influence of domestic factors of possible relevance—such as, lead pipes, car ownership, age of house, etc. The presence of a lead worker in the household appears to outweigh these other factors. The findings are consistent with the work of Burrows (1976) who showed that lead workers take lead home. An interlaboratory comparison on lead in blood was carried out. The two laboratories concerned were found to be equally consistent, but there were differences between them and the design of this comparison did not make it possible to say that the results of either were 'absolute' values.

Anxiety about possible harm to health from lead has been evident in recent years. Lead may enter the body from sources such as food and drink, water, or air (Department of the Environment, 1974; Ministry of Agriculture Fisheries and Food, 1972, 1975). An industrial works using lead is an obvious source of emission of lead, which is liable to attract public attention (Godber, 1971; Department of the Environment and the Welsh Office, 1973).

The battery factory studied is situated at Clifton Junction near Manchester and is in an industrial zone with residential areas abutting on the industrial zone but not adjacent to the factory itself. The processes carried out include lead smelting and various other processes which give rise to lead oxide containing dusts which for reasons of industrial hygiene must be removed from workplaces by the ventilation system and are discharged at low level

to the air (some after filtration). Dust may be blown about by the wind, carried on lorries or persons, or on shoes or clothing of workers.

Design of survey

The survey was designed to show whether or not the blood lead levels of people living near the factory or of close relatives of those employed in it were significantly higher than those of a suitable control group. A further objective was to study the distribution of lead from the factory up to a distance of two miles. A similar survey was carried out at the same time for another battery factory at Dagenham in the London borough of Barking, but as this was much smaller in scale than the Clifton Junction study it is not described in this paper.

Six groups of test and control subjects were defined as follows:

1. *Leadworkers families (LF) children*

Children under five years of age of battery factory leadworkers, wherever they lived, whose names were on the register maintained in the medical department of the factory in December 1972;

2. *Births register (BR) children (near)*

A random sample of children under five years who were not the children of a leadworker or battery factory employee and who had lived *within* one mile (1.6 km) of the factory all their lives;

3. *Births register (BR) children (far)*

A random sample of children under five years who were not the children of a leadworker or battery factory employee and who had always lived *more than* one mile (1.6 km) from the factory (but within the local authority areas indicated below);

4, 5, 6. The mothers of subjects in groups 1, 2, and 3 above; these were named LF mothers, BR mothers (near), and BR mothers (far), respectively. NOTE: children selected in groups 1, 2, and 3 are referred to below as 'index' children.

Method

SAMPLING

Survey subjects and controls

LF children were identified by a census of employees which asked for names and dates of birth of all children under five years of age. BR children were sampled from the registers of births in three contiguous former local authority areas—Swinton and Pendlebury MB, Prestwich MB, and Whitefield UD (total population 1971 census 95 327). From these registers for each year of birth children who had died, children whose families were known to health visitors to have changed address during the previous five years, and children whose parents' employment involved the use of lead or its compounds were eliminated. The remaining children were divided into those resident within, and those resident more than one mile (1.6 km) from the works: from each of these sets a random sample was drawn.

Each mother was invited to attend a local clinic for blood sampling with all of her children under five, both by introductory letter and by a personal visit from a public health inspector or health visitor. Transport by taxi was provided for her. Those who failed to attend were visited or telephoned and every effort made to secure attendance; in a few cases the required blood was taken in the home.

Blood specimens

From each family the following samples were

taken: 5 ml of venous blood and 0.2 ml of capillary blood by finger prick from the mother; 0.2 ml of capillary blood by finger or heel prick from the index child, and from each of his siblings under five years of age.

In addition, microaliquots from a proportion of the venous samples were put in capillary containers. A proportion of all of the above were replicated in order to check the reproducibility of the results. All blood specimens were taken with the stringent precautions subsequently published by the Department of Health and Social Security (1976).

The bloods from the test and control groups were examined contemporaneously so that each batch of specimens sent to the laboratories contained a cross-section of specimens from the different groups without means of identification by which the laboratories could tell to which group any individual sample belonged.

For each blood sample a record sheet was prepared giving details of the subject (age, sex, relationship to leadworker, and population sample group), details of his household (social class, geographical location, age and rateable value of house, use of vacuum cleaners and cars, public health inspector's assessment of such hazards as lead pipes, flaking paint, and traffic fumes) and details about the sample itself (capillary, venous, first specimen, replicate, repeat, laboratory used, and result). The record sheets were cross-referenced so that different samples from the same subject could be identified and individual subjects related to their respective families.

If the blood lead level was 'high' (which was taken initially as over 60 $\mu\text{g}/100\text{ ml}$, but later revised to over 50 $\mu\text{g}/100\text{ ml}$) the survey organiser arranged for a repeat blood sample. If this was also high the matter was reported to one of us (WJE or JFT) who discussed the finding with the family doctor and arranged referral to a paediatrician in the case of a child. If it was satisfactory, a report was sent to the family doctor indicating the range within which the result fell and a letter of thanks and reassurance was sent to the mother. In four cases (including both BR and LF children) the first test was over 100 $\mu\text{g}/100\text{ ml}$ but the subsequent test was acceptable (38, 33, 18, and 18 $\mu\text{g}/100\text{ ml}$), and these cases were therefore excluded from the statistical analysis. In 17 other cases where a repeat was taken the first result alone was used for analysis whether or not the second result confirmed the first. This was done to avoid any bias.

Air

Some 265 daily (24 hour average) air samples were obtained from six fixed sites near the Clifton

works during the period April to May 1974. The sampling method was by analysis of the particulate filters on standard UK National Survey of Air Pollution Instruments. These samplers draw about 2 cubic metres of air each day through a Whatman No. 1 filter paper. Background levels of lead in unexposed Whatman No. 1 paper yielded an average value of 0.002 $\mu\text{g}/\text{m}^2$, which corresponds to less than 1% of the values found after exposure. Errors owing to blank values have therefore been ignored.

Dust

A soft new paintbrush was used to brush surface dust on to clean paper from which it was transferred into an already numbered container. Samples were taken from the roadside gutter and from the pavement along the main transport route from the factory gate at the distances shown in Fig. 1; similar samples were taken from other roads carrying a comparable volume of traffic but not used by factory vehicles; samples were also taken from selected reference points near the factory.

Soil

Four cores of soil 15 cm in depth $\times$ 2.5 cm in diameter were taken at each corner of a 1 metre square from undisturbed grassed soil at each of the selected points (as for dust). Cylinders 2.5 cm long from top and bottom of cores constituted the specimens of 'surface' and of 'deep soil' respectively.

Vegetation

The study of vegetation has been described by Ratcliffe (1975).

Tap water

A random sample of 20 households was selected from those households in which blood had been taken and 47 specimens of tap water were obtained from 18 of these homes; the first run-off in early morning from cold and hot taps were sampled separately.

ANALYTICAL PROCEDURES

Blood

Analyses were carried out at two separate laboratories which will be referred to here as Lab A and Lab B. Lab A used anodic stripping voltametry, checking by dithizone and by atomic absorption with flameless atomisation of paper discs on a proportion of the samples. Lab B used the Delves Cup method with atomic absorption spectrophotometry (Delves, 1970). An interlaboratory comparison was carried out by comparing results by Lab B for microaliquots taken from adult venous blood submitted to Lab A.

Environmental specimens

Apart from the specimens of vegetation which were analysed by one of us (JMR), all the environmental specimens were examined at Lab A. For air and water samples the monocolour dithizone method was used. For dust (which was sieved through a 200 mesh sieve) and soil samples polarographic methods were used coupled with confirmation of absence of tin by atomic absorption spectroscopy.

STATISTICAL METHODS

Blood

We found no significant difference between the mean blood lead levels of the index children (whether LF or BR) and their siblings, and moreover there was no correlation between lead levels and size of family so it was decided for the final presentation to merge these groups within each year of birth since this would increase the number of subjects without introducing a bias. The results presented are arithmetic means and standard deviations; log transformation of all the original data before analysis did not alter any of our conclusions. The 'within laboratories' and 'between laboratories' variances were examined, and the linear regression of one laboratory's results on the other's was calculated, using adult venous blood and the corresponding microaliquots.

Environmental specimens

All the values for soil and dust from ledges quoted in this paper are the means of four specimens taken from the same place at the same time. At each point selected for dust sampling on transport routes means of two specimens from the gutter and two from the pavement are given.

Associations between blood levels and environmental factors

Simple bivariate regression analyses were made taking blood lead as 'dependent' variable and considering in turn the following factors: age, length of residence, age of house, rateable value of house, distance and direction from the works, length of time during which there had been a lead-worker in the family. Children and adults were considered separately in most cases, but in the correlation with age they were also taken together, using the capillary samples from the adults.

Results

POPULATION SAMPLE CHARACTERISTICS AND RESPONSE RATES

Table 1 sets out relevant information. The number of 'index children included in results' was less than

Table 1 Population samples and response rates

Population	LF (Leadworkers' families)	BR (Births register)	
		Near (< 1 mile)	Far (> 1 mile)
Leadworkers on register in December 1972	1387	N/A	N/A
Responders to census	905	N/A	N/A
Response rate (%)	65	N/A	N/A
Samples of index children drawn	158	165	195
Index children who attended	152	88	129
Response rate (%)	96	53	66
Included in results (children)			
Index children	147	71	122
Siblings	45	32	48
Total	192	103	170
Included in results (mothers)			
Social class I	0		10
II	0		25
III	0		100
IV	146		47
V	0		2
Not specified	1		9

Table 2 Children's capillary blood—blood lead levels of leadworkers' families compared with children selected from births register ($\mu\text{g lead}/100\text{ ml blood}$ —Lab B)

Age (years)	LF children			BR children			Difference of means	Significance level
	No.	Mean	SD	No.	Mean	SD		
< 1	10	25.1	11.0	18	21.8	11.8	3.3	NS
1-2	20	33.5	11.1	38	28.9	7.6	4.6	NS
2-3	73	33.4	9.1	107	28.0	8.1	5.4	$P < 0.001$
3-4	63	34.8	7.5	70	24.7	6.3	10.1	$P < 0.001$
4-5	26	31.0	6.0	40	28.6	7.3	2.4	NS
All	192	33.1	8.6	273	27.0	7.8	6.1	$P < 0.001$

the 'index children who attended' for technical reasons such as an unsatisfactory sample which was not repeated, or because (in the case of 12 BR children) a previously unknown occupational association with lead did not come to light until the clinic attendance. The mis-match in social class was unavoidable because of the sampling methods used. No significant difference was, however, found between the mean blood lead level of BR children in each social class and that of all BR children, or between the corresponding means for BR adults.

BLOOD LEAD

Table 2 shows the findings for children's blood. At each year of age the blood lead in LF children is higher than that in BR children. For the total group this difference is statistically significant and it is also significant for the 2 and 3-year-old groups. It appears that three years is the most critical age, for the LF children have maximum blood lead levels then and at that age the difference between them and the BR children is greatest. If children of all ages in social class IV are taken alone, the means are 33.0 for LF children and 26.8 for BR children; the difference of 6.2 $\mu\text{g}/100\text{ ml}$ is significant ($P > 0.01$). The mean blood level for the 103 BR children living within one mile of the factory was

27.3 $\mu\text{g}/100\text{ ml}$ whereas the mean for the 170 children living over one mile away was 26.7 $\mu\text{g}/100\text{ ml}$, a difference which was not statistically significant ($P > 0.05$).

The results for the 28 children under 12 months of age were examined. There was no child under three months old. No child between three and five months of age had a blood lead level over 30 $\mu\text{g}/100\text{ ml}$; three children between five and 12 months (1 LF and 2 BR) had blood lead levels between 40 and 60 $\mu\text{g}/100\text{ ml}$.

The mean lead level in capillary blood examined by one laboratory from the 147 LF mothers was 23.6 $\mu\text{g}/100\text{ ml}$ whereas that from 193 BR mothers was 21.9 $\mu\text{g}/100\text{ ml}$, a difference which although small was statistically significant ($P < 0.05$). There was however no statistical significance in the venous blood of these two groups examined by the other laboratory. Neither laboratory found a significant difference between the BR (near) and BR (far) groups of mothers.

The blood lead level for the BR children was analysed by distance and direction of their homes from the factory (Table 3). No significant difference was found between the mean blood lead of children living in different sectors or at any distance and the mean of the whole group—except that it was significantly higher ($P < 0.05$) for the 53 children

Table 3 Children's capillary blood—blood lead levels of BR children living at various distances and in various directions from the factory ($\mu\text{g lead}/100\text{ ml blood}$ —Lab B)

Distance (miles)	Direction									Significant difference from mean
	N	NE	E	SE	S	SW	W	NW	All	
< $\frac{1}{8}$	0	0	0	0	1 34.0	1 27.5	2 27.5	0	4 29.1	NS
$\frac{1}{8}$ — $\frac{1}{4}$	0	0	0	0	13 33.4	14 24.6	13 27.9	0	40 28.6	NS
$\frac{1}{4}$ —1	0	0	18 27.1	0	1 20.0	18 27.3	22 25.2	0	59 26.3	NS
1—2	6 25.3	12 26.3	28 29.0	3 27.7	22 23.7	37 24.9	11 28.0	0	119 26.1	NS
2—3	4 24.0	25 26.2	7 36.1	0	0	12 30.2	0	0	48 28.5	NS
> 3	0	3 21.7	0	0	0	0	0	0	3 21.7	NS
All	10 24.8	40 25.9	53 29.3	3 27.7	37 27.3	82 26.2	48 26.7	0	273 26.9	—
Significant difference from mean	NS	NS	P < 0.05	NS	NS	NS	NS	—	—	—

Number of children.

Mean blood level (in italics if 10 or more subjects in group).

Table 4 Correlation of various factors with group means

Factor	Difference in mean blood lead ($\mu\text{g}/100\text{ ml}$) Lab B	Significance level	Comments on blood lead levels
Leadworker in family	6.1	P < 0.001	See Table 2, 192 LF children higher than 273 BR children. (Note: Significant difference also with adults' capillary blood)
Lead pipes in house	4.2	P < 0.005	40 BR children in houses with lead pipes higher than 85 BR children in houses on which Environmental Health Officer reported 'No lead hazard'. (Note: No significant difference with adults or with LF children)
Age of subject	3.8	P < 0.01	133 BR girls higher than 193 BR mothers. (Note: Significant difference also between LF girls and mothers; confirmed for all groups by regression analysis, see text)
Car ownership	3.2	P < 0.005	182 BR children with car higher than 90 BR children without. (Note: No significant difference with LF children or adults or with BR adults)
Sex	2.4	P < 0.02	140 BR boys higher than 133 BR girls. (Note: No significant difference with LF children)
Capillary or venous blood	1.6	P < 0.001	Capillary higher. 222 women

living in the eastern sector. Similarly constructed tables for the BR adults, for the LF children and for the LF adults showed no significant differences of mean—with the only exception that 30 BR adults living in the north-eastern sector had blood lead levels significantly lower ($P < 0.02$) than the mean for their group.

Regression analysis also gave anomalous results with the four groups of subjects, no correlation with direction from the factory being stronger than $r = 0.25$. Thus the evidence on direction from the factory is conflicting: no consistent effect was demonstrated. No consistent effect on blood lead was found for: rateable value of house, length of residence, or length of time a leadworker had been resident. Table 4 sets out, for a number of factors which did seem to have a significant influence, the difference between the mean blood lead of the groups specified. The difference of 3.8 μg shown for 'age of subject' is a straightforward difference of

means between that for 133 BR girls and that for 193 BR mothers. Linear regression gave a best-fit relationship:

$$\text{Capillary blood lead} = 27.3 - 0.178 \times \left\{ \begin{array}{l} \text{age in} \\ \text{years} \end{array} \right\} \quad \begin{array}{l} r = 0.31 \\ P < 0.01 \end{array}$$

For the leadworkers families, the effect of age was more pronounced:

$$\text{Capillary blood lead level} = 34.0 - 0.439 (\text{age}) + 0.0033 (\text{age})^2 \quad \begin{array}{l} r = 0.49 \\ P < 0.01 \end{array}$$

With the exception of the LF children, the other groups did show a significant weak correlation between blood lead and the age of the house they lived in. Quite clearly, this factor is linked with other environmental factors, such as lead pipes or type of paint, and does not operate independently. For the BR children linear regression gave a best fit relationship:

$$\text{Capillary blood lead level} = 25.8 + 0.0622 \times \left\{ \begin{array}{l} \text{age of} \\ \text{house} \\ \text{in years} \end{array} \right\} \quad \begin{array}{l} r = 0.18 \\ P < 0.01 \end{array}$$

LEAD IN AIR

Because sampling was limited to a period of two months, it was not possible to study concentrations under all kinds of weather conditions. The wind speed and direction however were monitored and these records have been used to estimate the number of hours for which each sampling site was within 15° of the downwind direction from the factory on each day. This number of hours is referred to here as the 'downwind time', and is naturally only a notional figure, owing to the arbitrary nature of its definition. Lead concentrations on days with different downwind times are given in Table 5.

Table 5 Mean lead-in-air concentrations

Downwind time (hours)	No. of samples	Mean concentration ($\mu\text{g}/\text{m}^3$)	SD
0	178	0.45	0.27
≥ 0	265	0.53	0.36
≥ 1	87	0.69	0.45
≥ 6	21	0.66	0.36

From this it can be seen that the general background is about 0.45 $\mu\text{g}/\text{m}^3$ (based on zero downwind time). Although there is considerable variability, as indicated by the standard deviation results, it can also be said that the downwind sites are on average higher in lead by some 0.2 $\mu\text{g}/\text{m}^3$. The effect of increasing downwind time from one to six hours is however not clear, presumably because of the small number of samples and the high variability.

The results for the six different sites are summarised in Table 6. The slight effect of downwind

Table 6 Mean lead-in-air concentrations for individual sites

From factory		Average downwind time per day (hours)	No. of days sampler operated	Mean concentration ($\mu\text{g}/\text{m}^3$)	SD
Distance (metres)	Direction				
800	NE	0.71	59	0.60	0.29
800	East	0.63	38	0.48	0.30
800	SSW	2.63	61	0.65	0.43
2400	NE	0.82	52	0.46	0.26
2400	East	0.86	59	0.40	0.27
2400	SSW	3.43	24	0.81	0.58

position relative to the factory is again indicated by these results, but no consistent effect of distance can be discerned. Results over 1.0 $\mu\text{g}/\text{m}^3$ have been examined individually in an attempt to identify specific causes of high concentrations. Out of 20 such results 70% were associated with downwind times of at least one hour, but the converse relationship did not hold, since of some 17 samples with over eight hours' downwind only two gave results of over 1.0 $\mu\text{g}/\text{m}^3$. It was thought that the weather

may have been a contributory factor in this variation and so a preliminary examination of the current weather was made. This seemed to indicate that high concentrations were more likely to occur on calm days, but owing to the small number of samples this could not be established with confidence.

OTHER ENVIRONMENTAL SAMPLING RESULTS

The results for dust on transport routes, dust from ledges, and surface soil are shown diagrammatically in Figs 1 to 3, while data for indigenous mosses and moss bags and for grasses have been presented in a previous paper (Ratcliffe, 1975). Results for deep soil were lower than for surface soil by a factor of 5 within one-third of a mile, and by progressively smaller factors at greater distances. The mean lead level found in 47 specimens of tap water taken at 18 homes in the survey area was 0.048 parts per million (ppm). Although the mean for all hot tap specimens (0.049 ppm) was similar to that for all cold tap specimens (0.047 ppm), in individual houses a high level of lead was often found in one tap or the other but less often in both. Although the number of samples is too small to be statistically significant, it was noted that in four BR families living in houses where tap water lead was high their mean blood lead levels were higher than the general mean for BR subjects—the adults by 2 $\mu\text{g}/100\text{ ml}$ and the children by 6 $\mu\text{g}/100\text{ ml}$.

Fig. 1 Mean values of lead in specimens of dust on transport routes from factory and on other roads carrying comparable traffic (1 unit = 10^5 ppm by weight)

Fig. 2 Mean values of lead in specimens of dust from ledges (1 unit = 10 ppm by weight).

Fig. 3 Mean values of lead in specimens of surface soil (1 unit = 10 ppm by weight).

Discussion

ENVIRONMENTAL LEAD IN THE VICINITY OF A LEAD WORKS

Apart from air samples and some anomalous results—such as the lead in dust in the northern sector (Fig. 2)—generally the environmental sampling showed higher concentrations of lead near the factory with a sharp fall-off as distance increased. This is well illustrated, for example, by the pattern of lead concentration in dust on the transport routes (Fig. 1); after 400 yards (0.4 km) it had declined to a level of about one-tenth of that found in specimens taken at the factory gates; it should be noted, however, that this level of lead in the road dust was about eight times as great as that found in samples of dust taken from comparable roads not carrying lead works traffic. It was also found that mean lead levels for soil, grass, and moss were very much higher within one-third of a mile (0.5 km) than beyond (Fig. 3). Surveys in the vicinity of lead works in other parts of the country (Department of the Environment, 1974) have shown a similar pattern of high values for lead in dust and soil close to the works. Our studies revealed slightly increased mean concentration of lead in air in the downwind position relative to the factory, but no consistent effect of distance.

Unlike the position at Tower Hamlets and Rotherhithe (Department of the Environment, 1974) where many children lived close to the works, and where higher blood lead levels were found in them than in those who lived further away, only a few of our subjects lived within one-third of a mile (0.5 km) of the factory (Table 3), and we found no consistent difference in mean blood lead levels between those who lived near and those who lived further away which could confidently be attributed to the effect of the factory. At the other extreme, the survey area did not extend beyond the local authority boundaries (which were roughly three miles—4.8 km—from the works). It cannot be claimed that the 'control' population sample living within those boundaries and more than one mile (1.6 km) from the works is drawn from an environment (if such could be found) free from sources of lead; their area of residence forms part of a large conurbation—with all the varied sources of lead that an urban environment can produce. This population sample is however probably representative of many urban populations today.

FACTORS AFFECTING THE INTERPRETATION OF RESULTS

A survey of the type described can yield results

which may be interpreted qualitatively, but it is necessary to express some reservations about precise numerical values and comparisons with other surveys. Cochrane (1954) has stressed the importance of response rates in population sampling work. Notwithstanding the efforts made, our response rate was only 53% in the BR (near) group, although it was rather better in the others.

Lead in dust values are particularly erratic and differences of the order of tenfold can be found between specimens taken at the same spot. For this reason dust and soil values quoted in this paper are the means of four specimens (or two in the case of the transport routes, Fig. 1) taken from the sample place at the same time.

In the interlaboratory comparison of blood lead analysis it was found that the two laboratories were equally consistent within themselves, both having 'within samples' variance of about 2.8 µg/100 ml. Although one laboratory was giving results some 6.9 µg/100 ml higher than the other, there was some evidence that the interlaboratory difference declined in magnitude as the survey proceeded. Further investigation indicated that some 2.7 µg/100 ml of the total interlaboratory difference of 6.9 µg/100 ml could be accounted for by the use of different containers for the venous samples and the corresponding microaliquots. We conclude that interlaboratory difference is a factor which must be considered when comparing blood lead levels ascertained in different surveys.

Either capillary or venous blood may be used in a survey: we found that the mean lead level in capillary blood was 1.6 µg/100 ml higher than that in venous blood. This observation rests on the analysis by the same laboratory of specimens of capillary blood and microaliquots of venous blood taken on the same occasion from 222 women.

SIGNIFICANCE OF BLOOD LEAD LEVELS

The outstanding finding in this survey was that the children of the leadworkers had higher mean blood lead levels than comparable children of people who were not leadworkers: this confirms the findings of the surveys at Welwyn Garden City and Darley Dale (Department of the Environment, 1974) which were based on relatively small numbers of subjects. In our study 17% of LF children had blood lead levels in excess of 40 µg/100 ml compared with 5% of BR children. The difference between means—6.1 µg/100 ml averaged over the whole range of our under-fives—was particularly striking at ages two and three. This confirms the impression that it is because of behaviour such as crawling and sucking that children of this age are more liable than others to absorb lead that may be present in their environ-

ment. We also found a significant difference between the means of LF and BR mothers when capillary blood data were used. Since, however, this difference was relatively small, and not confirmed by the data for mothers' venous blood, we attach far less weight to it than we do to the children's result.

The absence of significant association for non-leadworkers between their blood lead levels whether their residence was near or far from the factory, or was in any particular direction from the factory, is consistent with the hypothesis that it is the leadworker himself who brings the lead home. It seems reasonable to suspect that the lead is carried home in the form of dust on his person or on his clothing. This hypothesis has been elegantly validated by Burrows (1976), who, in a survey in which Lab A was used, demonstrated that of all the means by which a leadworker may bring lead home, his shoes are by far the most important.

The data were analysed to assess the effect of a number of factors each of which was looked at as if it were acting alone (Table 4). The magnitudes of the effects indicated in this table should be regarded as upper limits, as in many cases the effects were not equal in all population subgroups. In whatever way this exercise may be interpreted, there was no doubt that the presence of a leadworker in the home was the biggest single factor, and the one which operated most consistently, in bringing about a significant raising of the blood lead level of the children in the household.

This survey was planned and conducted without any preconceptions about the range of blood lead levels or what limits were 'normal', 'acceptable', or 'dangerous'. Moncrieff *et al.* (1964) took 36 µg/100 ml as 'the upper limit of normal', and since then numerous studies (for example, Betts *et al.*, 1973) have suggested upper limits of normal ranging from 35 to 40 µg/100 ml. Our work exemplifies the difficulty of laying down and applying rigid numerical standards in this field: although 95% of our BR children had blood lead levels below 40 µg/100 ml, this proportion would have been higher, and the mean lead levels in each group lower than the means shown in Tables 2 and 3, if we had taken venous blood from the children and used Lab A instead of Lab B. During the survey three children who were found after a second blood test to have a high level (64/60, 60/59, and 61/54) were referred to a paediatrician. All were discharged from out-patients after investigations and a number of attendances, and a check with both general practitioner and paediatrician 9-12 months later indicated no known departure from normal health.

DAGENHAM SURVEY

The survey undertaken at a battery factory at Dagenham, while basically similar in concept to that at Clifton Junction, was on fewer samples of both human blood and environmental samples and therefore the results showed generally lower levels of statistical significance than did this larger survey. Despite this, the main results of the Clifton Junction survey were confirmed by the Dagenham work.

Conclusions

Lead is a poison and the aim must be 'minimal exposure to lead at work, as little contamination of the environment as possible, and no involvement of the surrounding populace and workers' families' (Department of the Environment, 1974). We have found no consistent evidence—in spite of demonstrable dissemination of lead to the environment—that the factories studied are producing measurable lead absorption in people living in their vicinity. We have however shown that of the sources studied the presence of a leadworker in the home is the factor which operates most strongly and most consistently in raising the blood lead level of the family. Our data suggest however that the influence of other factors—such as lead pipes in the home and car ownership—merits further evaluation.

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References

- Betts, P. R., Astley, R., and Raine, D. N. (1973). Lead intoxication in children in Birmingham. *British Medical Journal*, 1, 402-406.

- Burrows, G. E. (1976). Lead: From the factory to the home. MD thesis. University of Liverpool.
- Cochrane, A. L. (1954). The detection of pulmonary tuberculosis in a community. *British Medical Bulletin*, **10**, 91-95.
- Delves, H. T. (1970). A micro-sampling method for the rapid determination of lead in blood by atomic absorption spectrophotometry. *Analyst*, **95**, 431-438.
- Department of the Environment (1974). *Lead in the Environment and its Significance to Man*. HMSO: London.
- Department of the Environment and the Welsh Office (1973). *Lead and the Environment*. Joint circulars 6/73 and 53/73. HMSO: London.
- Department of Health and Social Security (1976). *Supra-regional Assay Service*, pp. 84-85. DHSS: London.
- Godber, Sir George (1971). *Environmental Hazards from Lead*. CMO letter 20/71 to Medical Officers of Health. DHSS: London.
- Ministry of Agriculture, Fisheries, and Food (1972). *Second Report on the Monitoring of Foodstuffs for Heavy Metals*. HMSO: London.
- Ministry of Agriculture, Fisheries, and Food (1975). *Survey of Lead in Food: First Supplementary Report*. HMSO: London.
- Moncrieff, A. A., Koumides, O. P., Clayton, Barbara E., Patrick, A. D., Renwick, A. G. C., and Roberts, G. E. (1964). Lead poisoning in children. *Archives of Disease in Childhood*, **39**, 1-13.
- Ratcliffe, J. M. (1975). An evaluation of the use of biological indicators in an atmospheric lead survey. *Atmospheric Environment*, **9**, 623-629.