# EVALUATION OF LONGTERM EFFECTS OF ELEVATED BLOOD LEAD CONCENTRATIONS IN ASYMPTOMATIC CHILDREN

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One hundred thirty-eight children adjacent to a primary lead smelter with prolonged asymptomatic increased lead absorption were evaluated for evidence of lead toxicity. They were compared to a pair matched control group living 3.2 and 4.4 km from the smelter. Mean blood lead was 50.34 $\mu$g/100 ml for test group and 20.24 $\mu$g/100 ml for controls. The children were evaluated by history, physical and neurological examination, laboratory tests, nerve conduction tests, psychometric evaluation, and teacher rating. Data was analyzed by geographic area, blood lead levels, and multiple risk factors. Statistical evaluation included independent t test, correlated t test, and analysis of variance. Expected significant differences in laboratory tests were identified. No significant differences related to increased lead absorption were identified by physical, neurological, psychometric, and school performance measurements in any of the groups.

The purpose of the El Paso epidemiological study was to study 138 children to obtain objective data concerning the question of possible permanent injury particularly to the nervous system of prolonged abnormal increased lead absorption in the range of 40 to 80 $\mu$g/100 ml.

## SMELTERTOWN BACKGROUND

Smeltertown was a small (0.1 km $\times$ 0.5 km) community isolated by the Rio Grande River and a large smelter. The area contained no drainage system, no municipal sewage system, no grass, and essentially no traffic.

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Annual precipitation is 6 to 8 inches per year, but approximately half of this comes in 1 or 2 storms during the summer. The earthen yards and streets provided a convenient playground for year-round outdoor activity. We identified 206 children living in the area, 193 with known blood lead levels. Sixty-seven per cent of these blood lead levels were in excess to 40 μg/100 ml. In contrast, in the city of El Paso 4 different testing programs tested 836 children and found 14 with blood lead levels in excess of 40 μg/100 ml or an incidence of 1.7%.

The presumed source of lead was from the large smelter by means of contaminated soil and air (1—3). Ninety-six soil samples had a range of 240 to 20,000 parts per million with a mean of 3433 parts per million. Air sampling in 1971 at a site 800 feet from the smelter, not in Smeltertown but an equivalent distance from the smelter, indicated a range of 15—269 mcg per cubic meter with a mean of 92 μg per cubic meter. Home construction was primarily adobe brick, kilfired brick, cinder block, and a minimum of wood frame construction. Paint samples revealed 7% in one survey and 23% in a second survey with lead content levels in excess of 1%. Nineteen water samples revealed no significant lead. It is postulated that the combination of increased soil and air lead content combined with dusty conditions and outdoor living year-round were responsible for the inadvertent inhalation and ingestion of excess quantities of lead (4, 5). This produced prolonged increased lead absorption in excess of 40 μg/100 ml in 67% of the children in the area and all residents were subjected to the conditions responsible for the increased lead absorption.

## STUDY GROUP

The primary requirement for the study group was to have been a resident of Smeltertown. One hundred and thirty-eight children agreed to participate in the study and 101 of these had blood lead levels in excess of 40 μm/100 ml. The age range was 21 months to 18 years with a median age of 9 years. There were 68 males and 70 females.

## CONTROL GROUP

The primary control group was obtained from the city of El Paso. Concentric circles of 3.2 and 4.8 km were drawn from the smelter stack. A survey was conducted on these circles to obtain the names of children willing to cooperate as controls. The names thus obtained were tabulated with the test children and the closest pair match on the basis of age, sex, ethnic background, and income was selected as the control. Many aspects of living in Smeltertown were more rural than they were urban. Therefore, a second control group was obtained from a rural community some 20 km from the smelter. This group was limited to children less than 8 years of age in order to avoid the influence of their 2 different school systems.

Smeltertown offered a unique opportunity for study. It was a sharply defined geographic area of increased lead absorption without any history of symptomatic poisoning or encephalopathy. It also offered the opportunity to study prolonged asymptomatic increased lead absorption on the traditional basis of blood lead levels.

## PROCEDURE

Each child was assigned a randomly drawn study number and when seen by the various examiners, the only means of identification was the child's first name, age, and study number to assure that all testing was on a blind basis. The evaluation of each child included a history questionnaire, selected laboratory studies, general physical examination, neurological examination, nerve conduction tests, psychometric evaluation, and teacher evaluation.

## ANALYSIS

The test group was subdivided into several different subgroups for purposes of statistical comparisons with matched controls on the basis of three sets of criteria-location, the blood lead levels, and exposure risk factors. The groups based on blood lead levels were: 1. Smelter children over 40 μg/100 ml (N = 101), 2. total Smeltertown group (N = 138), 3. Smelter children less than 40 μg/100 ml (N = 37), 4. Smelter children 0—49 μg/100 ml (N = 26), 5. Smelter children 50—59 μg/100 ml (N = 32), and 6. Smelter children greater than 60 μg/100 ml (N = 43).

In view of the prolonged low grade type of increased lead absorption, five other parameters of exposure were utilized to identify the children subjected to the greatest possible risk: 1. blood lead levels greater than 60 μg/100 ml, 2. free erythrocyte protoporphyrin levels greater than 180 μg/100 ml, 3. residence in Smeltertown during the critical development of birth to 3 years of age, 4. a minimum of 2 years residence in Smeltertown, and 5. any x-ray evidence suggesting increased lead absorption. Using these five parameters, a second set of subgroups was established: 1. serious group, those who had four of the five parameters positive, this group contained 44 children; 2. the moderate group, those who had at least three of the five parameters positive, an additional 31 children met this criteria and when combined with the serious group there was a moderate group of 75 children; 3. the low group which included 63 children with less than three positive parameters.

The multiple subgroups were established to allow statistical evaluation of the group on the basis of geographic distribution, blood lead levels, and combined exposure risk factors (Table 1).

Although each Smeltertown child was matched with the most similar control child on the basis of age, sex, ethnic background, and income, the control groups did in reality represent independent samples (6). The

Table 1.

*Group classification for statistical analysis*

| Group | N | Smeltertown children blood lead values* | | | Control children blood lead values* | | |
|---|---|---|---|---|---|---|---|
| | | Mean | S. D. | Range | Mean | S. D. | Range |
| 1. All groups-total | 138 | 50.34 | 16.23 | 14—93 | 20.24 | 6.97 | 7—43 |
| 2. Over 40 μg/100 ml | 101 | 58.01 | 10.88 | 40—93 | 20.83 | 7.19 | 8—37 |
| 3. Under 40 μg/100 ml | 37 | 29.37 | 7.74 | 14—39 | 18.67 | 6.06 | 7—37 |
| 4. 40—49 μg/100 ml | 26 | 44.92 | 2.57 | 40—49 | 19.16 | 7.51 | 10—43 |
| 5. 50—59 μg/100 ml | 32 | 55.03 | 2.62 | 50—59 | 19.34 | 7.59 | 8—37 |
| 6. Over 60 μg/100 ml | 43 | 68.16 | 7.46 | 60—93 | 22.90 | 6.08 | 13—40 |
| 7. Serious | 44 | 66.63 | 8.74 | 50—93 | 23.29 | 6.58 | 8—40 |
| 8. Moderate | 75 | 61.33 | 10.32 | 41—93 | 21.53 | 6.80 | 8—40 |
| 9. Low | 63 | 37.25 | 11.64 | 14—59 | | | |
| 10. Moderate male | 39 | 60.89 | 10.23 | 41—85 | | | |
| female | 36 | 61.80 | 10.39 | 45—93 | | | |
| 11. Less than 8 year vs. rural | 42 | 56.40 | 15.39 | 15—93 | 16.48 | 4.75 | 10—23 |
| 12. City control vs. rural | 42 | | | | 23.07 | 7.75 | 10—43 |

* Values given in micrograms per 100 cubic centimeters whole blood.

significant independent t values to the level of 0.1 probability were identified and used to help select the 62 most important items for further statistical analysis. These 62 selected items were then analyzed using the correlated t test for matched pairs and a two way analysis of variance for age, residence, and blood lead level (7).

## RESULTS

### *History*

The history form was completed by one of the project workers from information supplied by the parents on a trip to their homes. This portion of the study could not be on a blind basis since specific information was requested concerning residence in Smeltertown or any other possible lead exposure. The initial questions in this form were primarily related to control matching data which is tabulated in Table 2. The close similarity between the test children and their controls is graphically demonstrated in the Table. There was considerable data available on the Smeltertown children not participating in the study from previous medical supervision. That information is also tabulated in Table 2 and the close similarity to the test children is apparent.

Table 2

*Tabular comparison of items relative to control matching*

| Items | Smeltertown No. | Study | City No. | Control | Rural No. | Control | Smeltertown* No. | Nonstudy |
|---|---|---|---|---|---|---|---|---|
| Father's age (years) | 110 | 39.02 | 123 | 40.17 | 40 | 37.47 | 23 | 37.95 |
| Race % Mexican/American | 132 | 94% | 135 | 96% | | 95% | | |
| Job rating* | 105 | 1.53 | 90 | 1.43 | 37 | 1.70 | 30 | 1.36 |
| Education (years) | 97 | 7.54 | 86 | 7.83 | 37 | 8.45 | 2 | 5.00 |
| Years lived in Smeltertown | 112 | 22.15 | 7 | 7.57 | 2 | 9.5 | 21 | 18.09 |
| Mother's age (years) | 135 | 35.31 | 135 | 36.80 | 42 | 32.02 | 23 | 38.86 |
| Race % Mexican/American | 138 | 97% | 137 | 99% | | 93% | | |
| Job rating* | 129 | 1.06 | 120 | 1.10 | 41 | 1.07 | | |
| Education (years) | 125 | 7.27 | 120 | 6.77 | 41 | 7.65 | 4 | 9.00 |
| Years lived in Smeltertown | 135 | 23.16 | 8 | 8.04 | | 0 | 21 | 20.09 |
| Income** | 137 | 2.27 | 137 | 1.92 | 42 | 2.42 | 21 | 1.52 |
| Number of children per family | 138 | 4.99 | 137 | 5.05 | 42 | 4.80 | 37 | 4.64 |
| Child's average age differential (days) | 138 | — | 137 | +0.69 | 42 | -6.4 | | |
| Race % Mexican/American | 138 | 96% | 137 | 97% | 42 | 96% | | |
| Years lived in Smeltertown | 138 | 7.13 | 0 | — | 0 | — | 27 | 7.25 |
| Birth history conditions (3—10) | 134 | 3.84 | 129 | 3.93 | 41 | 3.63 | 19 | 3.36 |
| Complicated delivery (1—4) | 135 | 1.10 | 132 | 1.11 | 42 | 1.09 | 17 | 1.23 |
| Birth weight (pounds) | 124 | 7.25 | 131 | 7.37 | 42 | 6.92 | 9 | 7.20 |
| Pica (1—5) | 138 | 2.15 | 126 | 1.35 | 42 | 1.64 | 14 | 2.71 |
| Body complaints (14—56) | 138 | 15.27 | 135 | 14.51 | 42 | 15.83 | 20 | 14.85 |
| Past health (2—8) | 138 | 2.46 | 135 | 2.47 | 42 | 2.42 | 23 | 2.26 |
| Blood lead mean | 138 | 50.34 | 137 | 20.24 | 41 | 16.48 | 55 | 43.49 |

* Scale — Common labor = 1, Skilled labor = 2, Service occupation = 3, Professional = 4

** Scale — Annual income in dollars:
< 3,000 = 1
3,000— 5,000 = 2
5,000— 7,000 = 3
7,000—10,000 = 4
> 10,000 = 5

+From available information in records.

The average age of the smelter test children was 0.69 days younger than the city control children and 6.4 days older than the rural control children. The age differential varied slightly with the different subgroups with the lead test children being younger by 2.29 days in the group less than 40, older by 8.3 days in the group 40—49, older by 8.25 days in the group 50—59, and younger by 10.76 in the group over 60

$\mu g$/100 ml. Both history and neonatal course were similar in all groups. Pica was significantly greater in the lead test children. Pica was considered of minor significance in the study, however, because of the previous indoctrination of the lead test families concerning pica and the age distribution of the lead test children.

The parents were questioned about the occurrence of 14 nonspecific symptoms: weakness, irritability, weight loss, vomiting, anemia, headache, abdominal pain, poor apetite, insomnia, dizziness, poor coordination, confusion, paralysis, or convulsions. Their answers were rated on a 1—4 scale for severity giving a number range of 14 for no complaints to 56 for severe complaints in all categories. The complaint rate was low with an average figure of 15.27 for the test group, 14.71 for the city controls, and 15.83 for the rural controls. The differences in the subgroups favored the city controls over the lead test children and were stastistically significant. However, the complaint rate for the rural controls was higher than the lead test children. The complaint rate did not increase with the blood lead levels. The group over 60 $\mu g$/100 ml. had a rate of 14.93 compared to 15.73 for the 40—49 $\mu g$/100 ml. Previous questioning of the parents of lead test children may have increased the number of positive responses. Specific evaluation of each child with positive responses failed to reveal anything clinically significant. Past serious illnesses with possible residual effects rated on the scale of 2—8 resulted in a value of 2.46 for the lead test children and 2.47 for the city control, and 2.42 for the rural controls.

The Weery Weese Peters Scale concerning hyperactivity (8) completed the history questionnaire. The raw scores slightly favored the lead exposed children, but the independent t test and the correlated paired t test did not indicate significant difference. Two way analysis of variance indicated a significant difference in hyperactivity with age but not with residence or to lead levels (Table 3).

*Laboratory tests* (Table 4)

The mean blood lead value was used to separate the children into subgroups for analysis. The lead test children had been under observation for 18 month. They had moved from the area from 6—15 months prior to the study. For these children, the average of the two highest available blood lead values obtained during the total period of observation was used as the mean blood lead value. For the city controls, their mean lead values represented the average of the two blood leads obtained during the study. Only one blood lead value was obtained from the rural children.

All blood lead specimens sent to the laboratory were identified by number only. Every fifth child had a duplicate sample drawn which was sent to a different laboratory. There was a difference of 1.58 $\mu g$/100 ml in the mean lead values between the primary laboratory and the control laboratory.

Table 3.

*Analysis of variance. Two way evaluation of blood lead level Smeltertown, residence, and age*

(Selected examples referred to in text)

Lead level: Low group = 0—39 $\mu$g/100 ml; High group = 40 $\mu$g/100 ml
Age Level: Low group = 0—5.99 yrs.; High group = 6.00+ years
Residence level: Low group = Non-Smelter; High group = Smeltertown

| Variable tested | Source of variance | Mean squares | DF | F Ratio | Sign. Level | Low Group | | High Group | |
|---|---|---|---|---|---|---|---|---|---|
| | | | | | | Mean | N | Mean | N |
| Hyperactivity by history | Lead level | 187.23 | 1 | 1.03 | — | 17.11 | 212 | 16.52 | 102 |
| | Age | 542.64 | 1 | 2.98 | — | 19.83 | 99 | 15.59 | 215 |
| | Interaction | 648.42 | 1 | 3.56 | .10 | | | | |
| | Within cells | 182.22 | 310 | | | | | | |
| | Residence level | 591.56 | 1 | 3.24 | .10 | 18.14 | 176 | 15.36 | 138 |
| | Age | 859.47 | 1 | 4.71 | .05 | 19.83 | 99 | 15.58 | 215 |
| | Interaction | 160.97 | 1 | 0.88 | — | | | | |
| | Within cells | 182.43 | 310 | | | | | | |
| Hemoglobin | Lead level | 1.85 | 1 | 0.02 | — | 13.61 | 146 | 13.54 | 67 |
| | Age | 414.25 | 1 | 3.66 | .001 | 12.82 | 63 | 13.91 | 150 |
| | Interaction | 3.24 | 1 | 0.03 | — | | | | |
| | Within cells | 11.32 | 209 | | | | | | |
| | Residence level | 8.23 | 1 | 0.08 | — | 13.70 | 132 | 13.68 | 111 |
| | Age | 312.28 | 1 | 3.19 | .01 | 12.85 | 36 | 13.87 | 207 |
| | Interaction | .54 | 1 | 0.006 | — | | | | |
| | Within cells | 9.81 | 239 | | | | | | |

| Variable tested | Source of variance | Mean squares | DF | F Ratio | Sign. level | Low group Mean | Low group N | High group Mean | High group N |
|---|---|---|---|---|---|---|---|---|---|
| Bone density | Lead level | 887.03 | 1 | 2.16 | — | 52.12 | 202 | 57.05 | 98 |
| | Age | 1506.81 | 1 | 12.41 | .01 | 47.33 | 91 | 56.52 | 209 |
| | Interaction | 142.42 | 1 | 0.35 | — | | | | |
| | Within cells | 411.35 | 296 | | | | | | |
| | Residence level | 967.30 | 1 | 2.37 | — | 50.99 | 169 | 57.27 | 131 |
| | Age | 5077.41 | 1 | 12.46 | .01 | 47.33 | 91 | 56.52 | 209 |
| | Interaction | 588.22 | 1 | 1.44 | — | | | | |
| | Within cells | 407.59 | 296 | | | | | | |
| Finger to thumb opposition | Lead level | 46.60 | 1 | 1.05 | — | 27.14 | 170 | 29.48 | 87 |
| | Age | 1380.54 | 1 | 31.21 | .001 | 33.92 | 40 | 26.82 | 217 |
| | Interaction | 62.83 | 1 | 1.42 | | | | | |
| | Within cells | 44.23 | 253 | | | | | | |
| | Residence level | 2.50 | 1 | 0.055 | — | 28.28 | 141 | 27.50 | 116 |
| | Age | 1560.98 | 1 | 34.29 | .001 | 33.92 | 40 | 26.82 | 217 |
| | Interaction | 0.24 | 1 | .0053 | — | | | | |
| | Within cells | 45.52 | 253 | | | | | | |
| WISC-WAIS full scale IQ | Lead level | 547.69 | 1 | 2.23 | — | 88.55 | 151 | 86.91 | 77 |
| | Age | 12621.02 | 1 | 51.41 | .01 | 58.57 | 14 | 89.92 | 214 |
| | Interaction | 793.41 | 1 | 3.23 | .01 | | | | |
| | Within cells | 245.47 | 224 | | | | | | |
| | Residence level | 52.14 | 1 | 0.21 | — | 87.61 | 122 | 88.44 | 106 |
| | Age | 12461.60 | 1 | 50.09 | .01 | 58.57 | 14 | 89.92 | 214 |
| | Interaction | 35.28 | 1 | 0.14 | | | | | |
| | Within cells | 248.80 | 224 | | | | | | |

| Variable tested | Source of variance | Mean squares | DF | F Ratio | Sign. level | Low group Mean | Low group N | High group Mean | High group N |
|---|---|---|---|---|---|---|---|---|---|
| McCarthy general cognitive | Lead level | 132.30 | 1 | 0.45 | — | 82.25 | 61 | 80.74 | 23 |
| | Age | 475.85 | 1 | 1.61 | — | 83.07 | 58 | 79.08 | 26 |
| | Interaction | 215.47 | 1 | 0.73 | — | | | | |
| | Within cells | 295.80 | 80 | | | | | | |
| | Residence level | 15.96 | 1 | 0.055 | — | 81.18 | 56 | 83.14 | 28 |
| | Age | 582.46 | 1 | 1.99 | — | 83.07 | 58 | 79.08 | 26 |
| | Interaction | 518.61 | 1 | 1.78 | | | | | |
| | Within cells | 291.90 | 80 | | | | | | |
| Oseretsky motor level | Lead level | 1.24 | 1 | .00 | — | 101.04 | 150 | 97.09 | 82 |
| | Age | 2486.50 | 1 | 26.97 | .001 | 62.00 | 17 | 102.62 | 215 |
| | Interaction | 8.47 | 1 | .009 | — | | | | |
| | Within cells | 921.83 | 228 | | | | | | |
| | Residence level | 367.62 | 1 | 0.41 | — | 95.26 | 121 | 104.41 | 111 |
| | Age | 26216.73 | 1 | 29.27 | .001 | 62.00 | 17 | 102.62 | 215 |
| | Interaction | 523.46 | 1 | 0.58 | — | | | | |
| | Within cells | 895.57 | 228 | | | | | | |
| Califoria test of personality total adjustment | Lead level | 50.23 | 1 | 0.08 | — | 79.88 | 152 | 71.80 | 80 |
| | Age | 10090.39 | 1 | 16.82 | .01 | 50.80 | 15 | 78.96 | 217 |
| | Interaction | 424.67 | 1 | 0.71 | — | | | | |
| | Within cells | 600.28 | 228 | | | | | | |
| | Residence level | 26.63 | 1 | 0.044 | — | 78.11 | 123 | 75.94 | 109 |
| | Age | 10996.72 | 1 | 18.01 | .01 | 50.80 | 15 | 78.91 | 217 |
| | Interaction | 12.00 | 1 | 0.020 | — | | | | |
| | Within cells | 610.69 | 228 | | | | | | |
| Frostig perceptual quotient | Lead level | 1.29 | 1 | .008 | — | 100.14 | 72 | 102.09 | 44 |
| | Age | 1408.25 | 1 | 9.14 | .01 | 108.52 | 21 | 99.19 | 95 |
| | Interaction | 3.62 | 1 | .024 | — | | | | |
| | Within cells | 153.98 | 112 | | | | | | |
| | Residence level | 10.65 | 1 | 0.069 | — | 101.10 | 67 | 100.57 | 49 |
| | Age | 1535.02 | 1 | 9.99 | .01 | 108.52 | 21 | 99.19 | 95 |
| | Interaction | 9.05 | 1 | 0.059 | | | | | |
| | Within cells | 153.62 | 112 | | | | | | |

Table 4.

*Laboratory items with significant independent t test values*
(significance level = 0.05)

| Test | Scale | Pb[a] > 40 µg/100 ml: Smelter Mean | Control Mean | Sign. P | Smelter groups | < 40 µg/100 ml | 40—49 µg/100 ml | 50—59 µg/100 ml | > 60 µg/100 ml | Serious group | Moderate group | < 8 years | Rural vs. control |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Blood lead level # 1 | | 42.20 | 21.81 | C** | C** | C** | C** | C** | C** | C** | C** | R** | R** |
| Blood lead level ave. of 2 highest | | 58.01 | 20.83 | C** | C** | C** | C** | C** | C** | C** | C** | R** | R** |
| Free erythrocyte protoporphyrin | | 217. | 82. | C** | C** | C** | C** | C** | C** | C** | C** | R** | R** |
| Hemoglobin % of normal | g | 98.1 | 100.2 | C | C | | C | | | | | R** | R |
| Hematocrit % of normal | g | 93.48 | 94.23 | | | | C | | | | | | |
| SMA values — Sodium | mg% | 138.2 | 138.9 | | T* | T* | | | | | | T | |
| Potassium | mg% | 4.09 | 4.19 | T | T* | | | | T | | T* | | T |
| Triglycerides | mg% | 96.7 | 93.9 | | | | | T | | | | | T |
| Inor. phosphor. | mg% | 4.86 | 5.06 | | | | | | T | T | T | | |
| Albumin | mg% | 3.84 | 3.94 | T | T | | T | | | | | T | |
| Total protein | mg% | 7.36 | 7.55 | T* | T* | | | | T | T* | T* | T | |
| Uric acid | mg% | 4.98 | 4.72 | | | | | | T* | T** | T | T* | |
| Glucose | mg% | 100.6 | 105.1 | L | L | | L | | | | | | |
| Bone weight % | | 57.98 | 54.76 | | | | | | | C | | | |
| Bone size % | | 54.14 | 54.89 | | | C | | | | | | | |
| Bone density % | | 57.04 | 49.82 | C | C | | | | C | C* | C* | | |

a Pb = Lead values in µg/100 ml
b Difference favors: L = Smeltertown, C = City control, R = Rural control,
T = Advantage indefinte
c * Significant to 0.01 level
d ** Significant to 0.001 level

A scatter diagram of the blood lead levels against age demonstrated the persistent elevated blood lead levels through 14 years of age. This is consistent with a continuing chronic exposure to a relatively low source dose of lead. The usual pica at 18 to 30 months of age seen in children with pica for paint was not observed.

Free erythrocyte protoporphyrin (FEP) values plotted against age produced a similar scatter diagram with an even distribution of elevated values throughout childhood. The differences clearly distinguish the test group from the control group ($P < .001$).

No significant differences in red blood cell morphology or stippling were noted on routine blood smears between any of the groups.

Hemoglobin values ranged from 10.3 grams to 16.2 grams in the lead test children and from 10.5 to 16.8 grams in the control children. In 8 of 9 groups mean hemoglobin value was slightly lower in the lead test children than in their controls. The mean values dropped slightly with increasing levels from 13.89 grams in those less than 40 $\mu$g/100 ml, 13.84 grams in the 40—49 $\mu$g/100 ml, 13.66 grams in the 50—59 $\mu$g/100 ml, 13.05 grams in the group over 60 $\mu$g/100 ml. In the serious group the mean value was 13.16 grams compared to 13.31 grams in the moderate group. The differences were statistically significant in the group over 40 $\mu$g/100 ml the total smelter group, and the group 40—49 $\mu$g/100 ml. The results seem to indicate that increased blood lead may have some effect on blood production as indicated by the slightly lower values, but none of the hemoglobin values were low enough to be considered significant anemia.

The differences in some of the specific SMA-15 values were statistically significant. Sodium, potassium, calcium, phosphorus, alkaline phosphatase, albumin, and total protein were slightly lower in the lead test group than in their controls. The uric acid values were higher in the lead test children than in the controls. Although there were several statistically significant differences noted, all of the SMA values were within the normal range for the test performed.

X-rays evaluation of the children was limited to a film of the right hand and wrist. The X-rays were taken using a standard technique (9) with a slight underexposure of film and incorporates a standard graduated thickness aluminum wedge adjacent to the hand. The films were read initially by a certified radiologist and no significant differences were noted between any of the groups. The X-rays were then forwarded to Wright State University Research Institute where the photo densities of the film were compared by computer with previous established standards for bone weight, bone size, and bone density. Classical lead poisoning should result in increased bone weight, normal bone size, and increased bone density. This technique did show some significant differences in bone density which was not picked up with gross interpretation of the films. The analysis of variance indicated the significant difference in bone density related to age but no significant difference related to residence or to lead level (Table 3). The absence of lead lines and progression up the diaphysis of the bone are consistent with the prolonged low grade type lead exposure.

### *Physical and neurological examination*

The general physical examination further demonstrated the similarity between the lead test children and their controls. In the total group, the lead test children were half centimeter shorter and six-tenths of a kilogram lighter than their controls. Differences in all groups were minimal and none was statistically significant.

The systolic blood pressure was significantly lower in the lead test child, although, the diastolic pressure was not. Significantly lower values in the lead test children were probably related to their previous experience with repeated physical examination. Vision and hearing were the same except for some minor rural advantage in hearing over both the lead test children and city control children. The general physical examination, cranial nerve tests, evaluation of muscle tone, muscle strength, and deep tendon reflexes indicate that these tests were extremely insensitive with most of the children with identical results. The Prechtl test, Romberg test, hopping on one foot, and tandem walking failed to reveal any significant differences.

A hyperactivity estimate made by the examining physician based on the child's performance during the physical examination also failed to reveal any evidence of hyperactivity.

Two tests of motor function-finger-to-thumb opposition, and rapid alteration of supination and pronation of the forearms seemed particularly appropriate for the study. The original article (10) demonstrated that performance related significantly to learning proficiency and the test had been standardized for age and for developing proficiency. The finger-to-thumb opposition test was rated on a one to four basis in five categories. Able or unable, clumping of fingers, contralateral overflow movements, timing, and sequence. The children were rated for right and left side, stress and nonstress. Rapid alternating hand movements under both stress and nonstress conditions were rated in terms of ability, uncontrolled slapping movements, hand elevation, and symmetry of movement. It was hoped that the addition of the multiple subgroup scores would give a sufficient number range to assist in detecting significant subtle differences. A graph of the results (Fig. 1) demonstrated the expected improvement with age which was more apparent in the finger-to-thumb opposition tests than it was in the alternating hand movements. When compared to the control groups by age, however, there were no significant differences between the lead test children and their controls. The analysis of variance confirmed that the differences related to age ($P < .001$) but indicated no differences related to residence or to blood lead levels (Table 3).

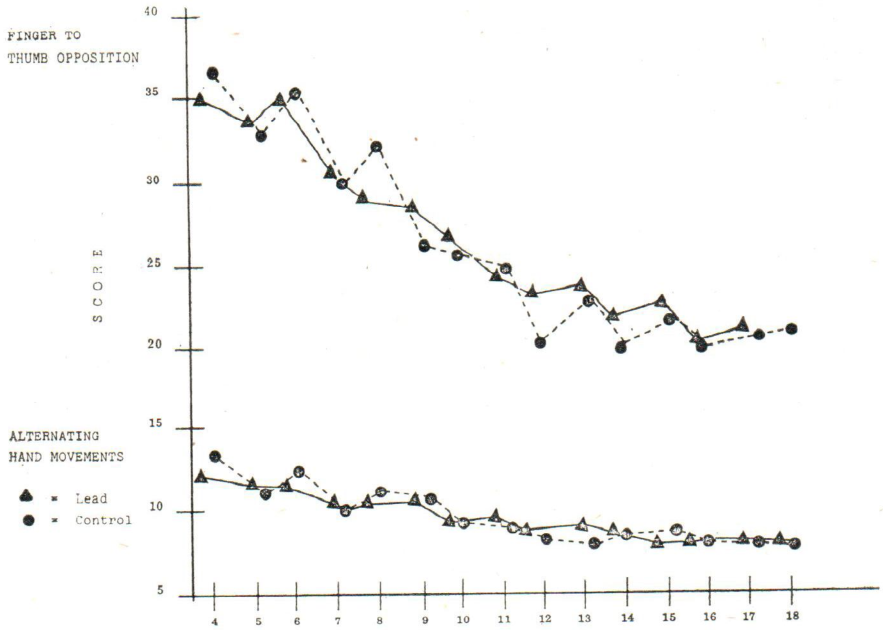


Fig. 1. *Graphic presentation of total scores in finger to thumb opposition and rapid alternating hand movements for lead and control children by age*

*Nerve conduction tests*

Nerve conduction tests were performed on 208 children, 109 lead test children and 89 city control children. The conduction time of the ulnar nerve and the distal latency period were tested. Four or five different stimuli were given to each child and oscillographic images were recorded by a polaroid camera. These results were then averaged to get a mean conduction time for each child. In the total group the median latency was 3.98 milliseconds for the lead test children against 4.08 milliseconds for the control children. The ulnar nerve conduction time was 45.2 milliseconds for the lead test children compared to 44.4 milliseconds for the control children. All groups failed to show any significant difference between the test children and their controls.

*Psychometric evaluation*

The psychometric evaluation battery was designed to cover 43 of the 53 basic learning abilities listed by *Vallet* (11). Testing was complicated by the wide age range of the children and by the fact that most standardized psychological test instruments had been normed in cultures other than the Mexican culture. The director of the department guidance in special education of the El Paso Public Schools selected his best psychometrists for this purpose. They all had spanish surnames, were bilingual in English and Spanish, and were experienced in the administration of these tests to the Mexican/American children. The general intelligence was tested with the Wechsler Adult Intelligence Scales for Children (WISC) (12) for ages 6 to 15 years, and the Wechsler Adult Intelligence Scale for Children (WAIS) (13) for ages 16 to 18 years. For the children less than 6 years of age we chose the McCarthy Scales (14) which had been normed including Spanish surnamed children.

The children under 6 years of age were also given the Berry Developmental Test of Visual Motor Integration (15). The children older than 6 received the Peabody Test (16), the Wide Range Achievement Test (WRAT) (17), the Wepman Test of Auditory Discrimination (18), the Oseretsky Test of Motor Development (19), the Bender Gestalt with Koppitz Scoring of Visual Motor Age (20), the Draw-A-Person Test (21), the California Test of Personality (22), and the Frostig Developmental Test of Visual Perception (23). The psychometric evaluations were done in two different half days. The psychometric test results are tabulated in Table 5. Only those tests with significant differences are listed.

In the total group, the verbal I. Q. for the lead test children was 86.86 compared to 86.94 for the controls. The performance I. Q. was 95.19 for the lead test children compared to 93.06 for the controls. The total I. Q. was 90.05 for the lead test children compared to 88.9 for the children. In Table 5 the mean values for the lead test children over 40 $\mu$g/100 ml are listed for reference. There were no significant I. Q. differences between the lead test children and the control children in any of the subgroups.

The McCarthy Scale for Children was composed of 6 different sections. The general cognitive score is a combination of the verbal, perception, and quantitative score and is the nearest equivalent in this test to an I. Q. score. There were no significant differences between the groups with the McCarthy Scales. No significant differences for either WISC or the McCarthy Scales were detected by the correlated t or the analysis of variance (Table 3).

The Peabody Test, the Wide Range Achievement Test, the Wepman Test of Auditory Discrimination, the Bender Test with Koppitz Scoring and the Draw-A-Person Test failed to show any significant differences between the lead children and their controls. The Oseretsky Test of Motor Development showed a single isolated significant statistical independent t and correlated t difference in motor retardation rating favoring the lead test children over the controls in the moderate group. The analysis of variance in the Frostig eye-motor function test, perceptual quotient, indicated a significant difference (P = 0.01) related to age but not to lead level or to residence.

*Psychometric items with significant independent t values*
(significance level = 0.05)

| Test | > 40 µg/100 ml Smelter Mean | Control Mean | Sign. P | Smelter groups | < 40 µg/100 | 40—49 µg/100 | 50—59 µg/100 | > 60 µg/100 | Serious group | Moderate group | < 8 years | Rural vs Control |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| WISC | | | | | | | | | | | | |
| Performance | 95.06 | 94.46 | | | L | | | | | | | |
| Information | 6.82 | 7.14 | | | | | | C | | | | |
| Vocabulary | 7.15 | 7.42 | | | | | C | | | | | |
| Picture composition | 9.37 | 9.47 | | | L | | | | | | | |
| Object assembly | 9.53 | 9.00 | | | | L | | | | | | |
| Coding | 9.85 | 9.60 | | | | | | | | | | R |
| Oseretsky motor retardation | 20.72 | 22.75 | | | | | | | | L | | |
| California Test of Personality | | | | | | | | | | | | |
| Self reliance % | 31.48 | 37.90 | | C | C | | | | | | | |
| Belonging | 7.01 | 6.96 | | | C | | | | | | | |
| Social standard % | 33.23 | 42.86 | C | C | | | | C* | | | | |
| Social skills % | 33.51 | 39.77 | | | | | | C | C | | R | |
| Antisocial tendency | 6.03 | 6.55 | | C | | | | | | | | |
| Antisocial tendency % | 25.76 | 31.63 | | C | | | | | | | | |
| School relations | 5.52 | 6.09 | | C | C | | | C | | | | |
| School relations % | 24.53 | 31.89 | C | C* | C | | | C | C | | | |
| Total social adjustment | 39.06 | 40.89 | | | C | | | | | | | |
| Total social adjustment % | 22.44 | 27.13 | | C | | | | | | | | |
| Total adjustment | 20.78 | 26.17 | C | C* | | | | | | | | |
| Frostig | | | | | | | | | | | | |
| Form constancy, standard score | 8.85 | 8.35 | | | | | | | | | L | |
| Teacher evaluation | | | | | | | | | | | | |
| School performance rating | 129.1 | 120.8 | | | | C | | | | | | |
| Grasp material | 1.13 | 1.35 | | | C | | | | | | | |
| Total problem factors | 2.01 | 2.14 | | | | | | | | L | | |
| Addition school information | 1.66 | 1.54 | | | | | | | | | | R |
| Language factor estimate | 1.57 | 1.22 | C* | C* | | | | C | C | C | | |

a Difference favors: L = Smeltertown, C = City control, R = Rural control
b * Significance equals 0.01

The California Test of Personality, when evaluated on the basis of grouping by blood lead values had several significant t differences all of which favored the control children. The differences noted were scattered and apparently not related to the lead levels. These differences were frequent in the total group, nonexistent in the moderate group, and in the less than 40 μg/100 ml group. These differences are probably related to the smeltertown children's historical geographic isolation, closing of their school, adverse news media exposure, and forced displacements from their homesteads.

*Teacher evaluation* (24)

The teacher evaluation form was used to evaluate the children in a normal classroom situation. It could not be done on a blind basis. The children were related on attendence, overall grades, class rating in terms of average, advanced, or below average, activity in terms of hyperactivity, relationship to other children, weak and strong points, any specific factors interfering with performance, and any additional observations. The only significant difference noted was in the days absent in the group of children over 40 μg/100 ml. The average number of days for this group was 5.51 for the lead test children and 4.07 for the controls. The performance rating, a product of the grade point average and the class rating, had one significant difference in the 40-49 μg/100 ml group which slightly favored the control children.

The hyperactivity rating on a scale of 1-20 gave a mean value of 5.61 for the Smeltertown children compared to 5.98 for the controls. The differences, although, slightly in favor of the lead test children were not statistically significant. There were several significant differences in the language factor estimate showing the lead children to have a greater language problem than the controls. This factor was based on estimates by judgement of the teacher's reports and may represent some bias on the part of the estimator or possibly some increased language factor related to their historical isolation.

## DISCUSSION

The tragic effects of lead encephalopathy had been well documented (25-30). The possibility of the subtle neurological damage due to increased lead absorption in the asymptomatic range has been postulated (31, 32). The level at which lead may produce permanent deleterious effects without encephalopathy is yet to be proven. Several recent publications which attempted to answer this question have resulted in conflicting conclusions (31-38). The research that has been done must be carefully evaluated before the conclusions that have been drawn are accepted as conclusive.

Studies related to geographic distribution have the advantage of eliminating the possibility of symptomatic lead intoxication while testing a population group all of which had been exposed to conditions that were apparently responsible for increased lead absorption. The inclusion of individuals with normal levels may obscure minor deficits which could possibly be present in those with definite increased absorption.

The use of the arbitary level of 40 $\mu$g/100 ml as normal or abnormal also has serious deficiencies. The immediate blood lead value for both test and control children indicates only the child's present blood lead level and does not eliminate the possibility of having had a much higher level even to the point of encephalopathy in previous years. It does not indicate prolonged exposure, only the immediate level.

The free erythrocyte protoporphyrin (FEP) can be used as an additional measure of adverse metabolic effect, soft tissue lead, and increased lead absorption even in the absence of significant blood lead elevations (39, 40).

Smeltertown offered an unusual opportunity to combine the advantages while minimizing the disadvantages of all types of screening. The conditions of exposure were nearly universal for everybody in the area. There was no history of encephalopathy or symptomatic disease. The prolonged slow gradual decline of the blood lead values and significant elevation of FEP values even after removal from the area was confirmation of the hypothesis that this area did represent prolonged low grade chronic increased lead absorption. It was a coincidence that the majority of the children's blood lead levels happened to fall within the range of 40-80 $\mu$g/100 ml, but it did represent an opportunity to evaluate the children on the basis of blood lead levels as well as their geographic origin. The degree of blood lead level overlap between test and control children in geographic groups and separation in the blood level groups is tabulated in Table 6.

Psychometric tests designed for specific age spans have an inherent weakness of being least accurate at the lower end of the scale. This weakness was further compounded in Smeltertown by the ethnic background. To compensate for this weakness, a battery of psychological tests were used to cover most area of motor development and as a counter check against each other. The careful pair matching of each child by age with the control was and essential prerequisite to the accuracy of the test results.

The variables of anemia and nutrition were fortunately absent in Smeltertown. The two way analysis of variance, matching lead level against age, and residence against age confirmed that age was the most important variable to control.

Blood lead levels alone, although a simple guide to remember, are not adequate to identify the true lead risk to the child. FEP values used in conjuction with the blood lead values give an additional reference of toxicity. The El Paso Smeltertown experience demonstrates the need for a more adequate formula to evaluate the degree of risk associated with increased lead absorption. The significance of blood lead and FEP values are relative to the source of lead, quantity consumed, degree of anemia, and state of nutrition. Consideration of these factors in Smel-

Table 6

*Distribution of children in groups by blood lead level*

| Bl Pb Level µg/100 ml* | Total group N = 138 | | < 8 yrs. N = 42 | | | < 40 µg/100 ml N = 37 | | 40—49 µg/100 ml N = 26 | | 50—59 µg/100 ml N = 32 | | > 60 µg/100 ml N = 43 | | Serious N = 44 | | Moderate-serious N = 31 | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Pb. | Con. | Pb. | Rural | City | Pb. | Con. | Pb. | Con. | Pb. | Con. | Pb. | Con. | Pb. | Con. | Pb. | Con. |
| 8—9 | | 2 | 0 | 1 | 0 | 0 | 1 | | | | 1 | | | | 1 | | |
| 10—19 | 6 | 69 | 2 | 31 | 14 | 6 | 23 | | 15 | | 14 | | 17 | | 15 | | 20 |
| 20—29 | 10 | 49 | 0 | 10 | 20 | 10 | 11 | | 7 | | 13 | | 18 | | 19 | | 8 |
| 30—39 | 21 | 16 | 5 | | 6 | 21 | 2 | | 3 | | 4 | | 7 | | 8 | | 3 |
| 40—49 | 26 | 2 | 4 | | 2 | | | 26 | 1 | | | | 1 | | 1 | 10 | |
| 50—59 | 32 | | 12 | | | | | | | 32 | | | | 7 | | 15 | |
| 60—69 | 33 | | 15 | | | | | | | | | 33 | | 27 | | 6 | |
| 70—79 | 5 | | 2 | | | | | | | | | 5 | | 5 | | | |
| 80—89 | 4 | | 1 | | | | | | | | | 4 | | 4 | | | |
| >90 | 1 | | 1 | | | | | | | | | 1 | | 1 | | | |
| | | | | | | | | | | | | | | | | Serious+ N = 75 | |
| Means | 50.34 | 20.24 | 56.40 | 16.48 | 23.07 | 29.37 | 18.67 | 44.92 | 19.16 | 55.03 | 19.34 | 68.16 | 22.90 | 66.63 | 23.29 | 61.33 | 21.53 |

* Values given in micrograms per 100 cubic centimeters whole blood.

tertown children reduced the risk suggested by the blood lead and FEP values. Similar consideration of an anemic poorly nourished todler with the same blood lead and FEP values compounded by pica for paint would indicate a critical situation.

## CONCLUSION

One hundred thirty-eight geographically isolated children with chronic exposure to conditions resulting in increased lead absorption in excess of 40 $\mu$g/100 ml in 67% of residents were studied for objective evidence of permanent deleterious effects due to lead.

1. No evidence of gross or subtle injury was detected by an extensive battery of tests in the geographic groups, the groups separated by lead levels, or in selected groups considered to be of greatest risk.
2. Age was the most critical variable in comparing the lead test groups with the control groups.
3. No impairment of fine motor or perceptual skills was detected on physical, neurological, or psychometric examination.
4. Hyperactivity was not apparent from history questionnaire, physician estimate, psychological evaluation, or teacher evaluation.
5. Anemia and nutrition considered significant to the clinical toxicity of increased lead absorption, were not significant variables in the study.
6. Any source of abnormal lead absorption in children must be monitored and controlled to maintain a reasonable margin of safety. Significant increased lead absorption in the blood lead range of 40-80 $\mu$g/100 ml was apparently not harmful to these children. The margin of safety, however, was greatly diminished. If the situation were compounded with other sources of increased lead absorption, symptomatic lead poisoning would be more likely to occur.
7. Identification of the source of the lead, degree of exposure, anemia, and nutrition should be used in conjuction with lead levels and FEP levels to decide which children are most at risk.

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*Sažetak*

PROCJENA DUGOTRAJNIH UČINAKA POVIŠENIH KONCENTRACIJA OLOVA U DJECE BEZ SIMPTOMA

U El Pasu, u olovnotopioničkom naselju u Teksasu provedena su kliničko-epidemiološka ispitivanja u 138 djece koja nisu imala kliničkih znakova prekomjerne apsorpcije olova, a imala su povećane koncentracije olova u krvi. U kontrolnoj skupini bila su djeca odabrana na principu parova, koja su živjela 3 do 4 km i otprilike 20 km od topionice. Ova su djeca odabrana na temelju identične dobi, spola, rasne pripadnosti i materijalnog položaja.

Srednja vrijednost koncentracije olova u krvi bila je 50,34 $\mu$g/100 ml u skupini ispitanika i 20,24 $\mu$g/100 ml u kontrolnoj skupini. Ispitivanja su provedena na slijepo tako da su ispitivači znali samo šifru svakog djeteta, ali ne i kojoj skupini pripada.

Ispitivanja su uključila anamnestičke podatke prikupljene posebnim upitnikom od roditelja a sadržavala su pitanja o 14 nespecifičnih simptoma. Zatim su rađeni odabrani laboratorijski testovi, opći klinički pregled, neurološke pretrage, testovi nervne provodljivosti, psihometrijske procjene i procjena djetetova učitelja.

Dobiveni podaci analizirani su na temelju područja gdje su djeca živjela, na temelju razine krvnog olova odnosno multiplih rizičnih faktora. Statistička je obrada obavljena pomoću nezavisnog t-testa i t-testa korelacije kao i analizom varijance.

S obzirom na mjesto stanovanja nisu utvrđene ni očite a ni suptilne promjene u eksponirane djece. Nije bilo ispada fine motorike niti su fizikalnim, neurološkim ili psihometrijskim ispitivanjima utvrđena ikakva oštećenja percepcije.

Na temelju anamnestičkih podataka odnosno prema procjeni učitelja djeca nisu pokazala uočljivu hiperaktivnost.

Značajno povećanje koncentracije olova u krvi od 40 do 80 $\mu$g/100 ml očito nije bilo škodljivo za ispitivanu djecu. Međutim, ovako visoki nivo olova predstavlja za ispitivanu djecu značajno suženje granica sigurnosti jer bi pri dodatnoj ekspoziciji olovu postojala povećana vjerojatnost pojave simptoma olovnog otrovanja.

## DISCUSSION FOLLOWING THE PAPER

HERNBERG: Drs Seppäläinen, Tola, Kock and myself made neurophysiological examinations on 26 storage battery workers, whose PbB-s had never exceeded 70 μg/100 ml, as ascertained by regular monitoring of PbB during the entire exposure period. The results show a significant reduction of the motor conduction velocity of the slower fibers of the ulnar nerve, as compared to a control group. However, when compared to earlier measurements from a more heavily exposed group, the present results were less abnormal. Thus there was a dose-response relationship on a group basis. In 10 cases out of 26 pathological neurophysiological findings were present, borderline findings in 4, and in 12 the results were normal, as referred to those of a control material of about 100 persons without any toxic exposure. The most prominent findings were diminution of motor units upon maximal contraction, and denervation potencial. The results indicate that exposure to lead which does not results in PbB-s in excess of 70 μg/100 ml may cause subtle nervous damage.

Dr Mc Neil, in your study you measured the MCV's only, not the conduction velocity of the slower fibers. In our experience, this reduces sensitivity. Furthermore, I think your values for the MCV are unexpectedly low even in your control group — values about 10 m/s higher than the measured ones would rather be expected. For these reasons I think that the possibility of subtle nervous damage has not been completely ruled out in your study.

Mc NEIL: MCV values were consistent with normal values in El Paso. Even if lower than expected any differences in MCV due to Pb should have been apparent.

We considered testing for the »slow fibers« as you suggest but did not have the timing mechanism necessary, so elected to use our standard procedure.

My knowledge of your work is very limited although you do seem to have an interesting area for further investigation.

Do these changes hold true for children as well as for adults?
How reproducible are your findings?
Are the changes reversible?
How significant are the »slow fiber« conduction changes?

COLE: I have reviewed your study on nerve conduction rates in lead workers. Regarding this I would like to ask two questions 1) Can you define a threshold of effect for the decrease in nerve conduction velocity on the slow fibers of the ulnar nerve? 2) Would the fact that 2—3 years elapsed between the time of nerve evaluation of controls and workers affect the results due, perhaps, to variability of the testing method?

HERNBERG: 1) Our present data do not allow us to make such statements. The only thing we think we have shown is that subtle nervous damage may occur at PbB's below 70 μg/100 ml. Defining a treshold for the action requires studies on a population large enough to allow stratification in categories of subjects who have never exceeded 60, 50, 40 etc. μg/ Pb/100 ml blood. We plan to start such studies later this year.

2) We have used the same equipment and the same methods for many years now. I do not think that this time lag affects the results. For example, one recent study (1974) of a group of styrene-exposed workers showed even slightly higher values for both the exposed and the control groups as compared to the control groups in the lead studies.

ZIELHUIS: Do you agree that NO-effect level for minimal brain damage in children will probably be > 50—60 μg Pb/100 ml?

Mc NEIL: Yes, I agree that the level will be > 50—60 μg Pb/100 ml. If other variables are controlled as they were in smeltertown I think the no-effect level for brain damage will be > 80 μg Pb/100 ml. The blood Pb alone is not adequate to establish the level for M. B. D.