Budget Allocation

From figures available in other countries, it can be postulated that a free comprehensive health service for everyone would require expenditure of at least U.S. \$100–300 per person per year. This figure excludes the cost of training doctors, nurses, and others. It also excludes capital expenditure, which may require \$100m.–200m. for a modern teaching hospital of 500 beds and \$2m.–20m. for district hospitals of 50–100 beds. It is possible therefore to contemplate exenditure, far in excess of present estimates and appropriations, which would still leave about 80% of the population without an effective health service.

The only alternative is to build fewer large hospitals, but more health centres and small district hospitals providing free or partly-free service for the population subdivided into units of 5000–20,000 people. These units, staffed by "nuclear" health teams of doctor, nurse-practitioner, sanitarian, and medical auxiliary, can be linked to district hospitals providing 1 bed per 2000–5000 of population. District hospitals should be linked for special services, training, and additional resource to existing teaching centres. A plan of this kind would offer considerable economy in expenditure, would provide a much wider and more realistic base for training and health education, and, above all, would reach a much higher proportion of the population. The nuclear health teams can be increased as recruitment and training proceed. The district units would provide bases for epidemiologically planned surveillance and in-progress evaluation of activity.

Conclusion

To anyone who has witnessed in a developing country the work of field units and small district hospitals, it is clear beyond doubt that national adoption of a first-things-first community-based plan must bring visible benefit to the community because it identifies common disorders which can be controlled—notably malnutrition, intestinal, respiratory, urinary, and skin infections, simple surgical, ocular, orthopædic, and obstetric defects, anæmia, and debilitating diseases. Control of such conditions, by improving well-being, family health, earning power, and morale, opens doors for family-planning, health education, and self-help through family, extended-family, and locality networks, thereby concentrating more of the resource of medicine in the front-line of human suffering where it belongs.

This approach is a necessary intermediate between the successful but austere "barefoot" doctor plan of China and the extravagant hospital-doctor plans of most other countries. It is already clear that some stringency is required to reconcile health needs with geography, available manpower, and economy even in highly developed countries. In developing countries, it is difficult to see any alternative, if standards of life and health are to be raised; but it is easy to see how suffering and possibly disaster might occur in the short term if first things continue to take second place in policy.

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NEUROPSYCHOLOGICAL DYSFUNCTION IN CHILDREN WITH CHRONIC LOW-LEVEL LEAD ABSORPTION *

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Summary To investigate the relation between low-level lead absorption and neuropsychological function, blind evaluations were undertaken in forty-six symptom-free children aged 3–15 years with blood-lead concentrations of 40–68 μg. per 100 ml. (mean 48 μg. per 100 ml.) and in seventy-eight ethnically and socioeconomically similar controls with levels <40 μg. per 100 ml. (mean 27 μg. per 100 ml.). All children lived within 6·6 km. of a large, lead-emitting smelter, and in many cases residence there had been lifelong. Mean age in the lead group was 8·3 years and in the controls 9·3. Testing with Wechsler intelligence scales for schoolchildren and preschool children (W.I.S.C. and W.P.P.S.I.) showed age-adjusted performance I.Q. to be significantly decreased in the group with higher lead levels (mean scores, W.I.S.C. plus W.P.P.S.I., 95 *v.* 103). Children in all ages in the lead group also had significant slowing in a finger-wrist tapping test. Full-scale I.Q., verbal I.Q., behaviour, and hyperactivity ratings did not differ.

Introduction

IN the debate on childhood lead absorption a major unresolved issue is whether blood-lead levels of 40–80 μg. per 100 ml. adversely affect the nervous system.[1,2] Previous work has suggested that absorption sufficient to produce such levels might result in behaviour abnormalities [3] (among them hyperactivity [4]), in fine motor deficits,[3,5] or in subclinical peripheral neuropathy.[6] Those findings have, however, been frustratingly inconsistent.[7–10]

In an effort to clarify this situation we investigated a group of children who had lived near a large, lead-emitting ore smelter in El Paso, Texas. Previous investigations [11,12] had shown a high prevalence of blood-levels in the range 40–80 μg. per 100 ml. in this population, especially among young children, and had indicated that the principal means of lead uptake was the chronic ingestion and inhalation of particulate lead emitted by the smelter.[11]

To evaluate neuropsychological function in these children, we selected two groups from among those who had participated in earlier blood-lead surveys; blood-lead levels in one group were ≥40 μg. per 100 ml. and in the other were <40 μg. per 100 ml. In blind fashion we conducted general medical and neurological examinations as well as specific tests of

* A brief account of this work appeared in the Center for Disease Control's *Morbidity and Mortality Weekly Report*, 1974, no. 23.

fine motor, perceptual-motor, behavioural, and cognitive function. Subtle but statistically significant differences were found between the groups in performance I.Q. and in fine motor function, but not in verbal I.Q. or in tests of behaviour.

Methods

Survey Population

All children included in this study were aged 3 years 9 months to 15 years 11 months and had lived within 6·6 km. of the El Paso smelter for at least 12 of the 24 months preceding the study. All except three had taken part in a survey of blood-lead levels in August, 1972 [11]; the three exceptions were sibs of survey participants. Excluded were any children with a history of symptoms compatible with acute lead poisoning or acute lead encephalopathy and children who had at any time received edetic acid (E.D.T.A.) chelation therapy. Included were four children who had received oral penicillamine therapy, but whose blood-lead levels had not fallen below 40 μg. per 100 ml. on repeated determinations.

Participating children were divided into two groups: in the lead-absorption group were all those who in August, 1972, had had a blood-lead of 40–80 μg. per 100 ml., and the three sibs not tested in 1972 but whose blood-lead levels in 1973 exceeded 40 μg. per 100 ml. The control group comprised children whose blood-lead levels had been <40 μg. per 100 ml. in August, 1972. Controls were selected so that as a group they matched children in the lead-absorption group for age, sex, language spoken at home (English or Spanish), length of residence within 6·6 km. of the smelter, census tract of residence in August, 1972, and socioeconomic status [13] (table I).

Evaluations

After parental permission had been granted, children in the two groups were evaluated individually by examiners who did not know the children's blood-lead levels or group assignments. The examinations were done in a 2-week period in June, 1973.

Children first underwent complete medical and neurological evaluations. No cases of acute symptomatic lead poisoning were found, but five children—two in the lead-absorption group and three controls—were found to have pre-existing, presumably unrelated neurological disease and were not studied further. The diagnoses were Hand-Schueller-Christian disease with hypothalamic involvement (lead-absorption group), neonatal intestinal obstruction with subsequent slow learning (lead-absorption group), status epilepticus at age 4 months (control group), and borderline mental retardation presumed to be due to perinatal asphyxia (two cases in the control group). No gross impairment was found on neurological examination of any of the other children in either group.

TABLE I—COMPARISON OF GROUP FEATURES (1973)

Characteristics	Lead-absorption group	Control group
No.	46	78
Blood-lead (μg./100 ml.):		
Mean (and range), 1972	48·3 (40–68)	26·9 (1–39)
Mean (and range), 1973	40·5 (22–58)	26·5 (15–39)
Age (yr.) (mean/±S.D.)	8·3±3·4	9·3±3·6
Age distribution: <5	10 (*22%*)	12 (*15%*)
5–8	17 (*37%*)	25 (*32%*)
9–11	10 (*22%*)	18 (*23%*)
12–15	9 (*20%*)	23 (*29%*)
M/F	30/16 (*65%/35%*)	45/33 (*50%/42%*)
No. speaking some or all Spanish at home	45 (*98%*)	74 (*95%*)
Socioeconomic index [13] *(mean ±S.D.)*	66·9±13·7	66·4±15·0
Duration of residence in study area (yr.) (mean±S.D.)	6·6±3·4	6·7±3·6
Site of residence, 1972:		
0–1·6 km. from smelter	22 (*48%*)	35 (*45%*)
1·7–4·0 km. from smelter	16 (*35%*)	29 (*37%*)
4·1–6·6 km. from smelter	8 (*17%*)	14 (*18%*)

TABLE II—AGE DISTRIBUTION OF CHILDREN GIVEN THE W.P.P.S.I.

Age	Lead-absorption group	Control group
3 yr. 9 mo. to 3 yr. 11 mo.	5	2
4 yr.	5	10
5 yr.	2	2
6 yr.	0	1
Total	12	15
Mean (±S.D.)	*4·3 (±0·6) yr.*	*4·7 (±0·7) yr.*

The parents of those remaining were asked whether their children had practised pica or experienced recurrent abdominal pain, clumsiness, irritability, or convulsions; answers were recorded as "yes" or "no" on a precoded form. Parents of children up to age 10 years were asked to rate their child's level of activity according to a standard scale [14]; typical activity in each of six situations was scaled from 0 (no activity) to 4 (severely hyperactive), and an average level of activity was computed. All children's behaviour and activity during the examination were also rated by the physician.

Neurological Assessment

All children 5 years old and above were given a battery of neurological tests intended to evaluate motor function:

(1) *Standing on each foot* (recorded as the greatest number of seconds up to 15 in the best of three trials);

(2) *Tandem walking* (recorded as the most correct steps up to 9 in the best of three attempts);

(3) *Alternate tapping* with a stylus on two metal plates 30 cm. apart, a measure of proximal arm muscle function and of coordination (recorded for each hand as the number of taps in one 10-second trial after a 5-second warm-up period);

(4) *Tapping with a stylus* on a single metal plate while hand and wrist were held above the table (finger-wrist tapping), a measure of wrist flexor and extensor muscle function (recorded for each hand as the number of taps in one 10-second trial after a 5-second warm-up period);

(5) *Visual reaction-time* (recorded for each hand in milliseconds as the average of three trials); and

(6) *Auditory reaction-time* (recorded for each hand in milliseconds as the average of three trials).

Electronic testing equipment similar to that developed by Baloh et al.[7] was used in tests (3)–(6).

Psychological Assessment

Psychological evaluations were done by one of six psychometrists. The Wechsler intelligence scale for children (W.I.S.C.) [15] was used for thirty-four children, 5 years 1 month old and above, in the lead-absorption group, and for thirty-six children above 5 years in the control group. The Wechsler preschool and primary scale of intelligence (W.P.P.S.I) [16] was used for twelve preschool children, 3 years 9 months to 5 years 7 months, in the lead group, and for fifteen preschool children, 3 years 9 months to 6 years 6 months, in the control group (table II).

All psychometrists were bilingual, and tests were administered in English or Spanish, as appropriate for each child; fifteen (33%) of children in the lead-absorption group and nineteen (24%) of children in the control group were tested in Spanish ($P>0·5$ by chi-square). The following subtests were used in the W.I.S.C.: information, arithmetic, comprehension, and digit span in the verbal scale, and picture completion, block design, object assembly, and coding in the performance scale. Subtests in the W.P.P.S.I. were information, arithmetic, comprehension, and sentence completion in the verbal scale, and picture completion, block design, animal house, and geometric design in the performance scale. The vocabulary subtest was omitted from the verbal scale of both W.I.S.C. and W.P.P.S.I. because of the poor standardisation which results on translation of this subtest into Spanish. All Wechsler scores were age standardised. As a further measure of perceptual-motor function, all children were administered the Bender motor gestalt test,[17] which measures accuracy in copying simple geometric designs; accuracy was scored using an age-standardised scale.[18] The behaviour of each child in the psychological testing situation was evaluated by the psychometrist using a standardised 5-point rating-scale.[19]

Blood-lead

A venous blood-sample for lead analysis was obtained from every child in 1973 at the time of the neuropsychological testing. Analysis was performed in duplicate by modified Delves' cup atomic-absorption spectrophotometry,[20] and results are expressed as the mean of the two determinations.

TABLE III—MEDICAL HISTORY DATA

History of	Lead-absorption group	Control group
Pica	7 (*15%*)	4 (*5%*)
Abdominal colic	12 (*26%*)	11 (*14%*)
Clumsiness	5 (*11%*)	6 (*8%*)
Irritability	18 (*39%*)	21 (*27%*)
Convulsions	3 (*7%*)	3 (*4%*)
Hyperactivity score [14] (mean ±S.D.)	*0·88±0·79*	*0·69±0·70*

All results non-significant by *t* test.

Results

Mean age in the lead absorption group was 8·3 (±3·4) years and in the control group 9·3 (±3·6) years (table I). This difference was not statistically significant (P>0·10). 65% of the lead group and 58% of the controls were male. The groups matched closely in ethnic background, primary language, socioeconomic index,[13] and duration of residence near the smelter.

Blood-lead Data

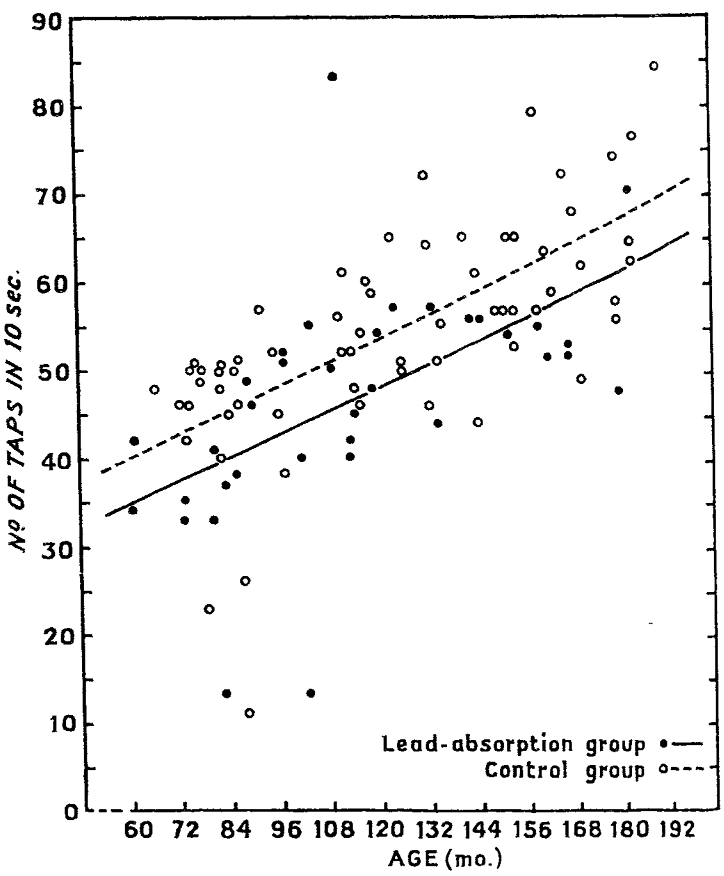
Blood-lead data which had been below 40 µg. per 100 ml. in 1972 tended to remain stable (table I); of eighty blood-lead levels below 40 µg. per 100 ml. in 1972, all except two remained below that mark in 1973. The two children whose blood-lead rose above 40 µg. per 100 ml. were excluded from further analysis, and the remaining seventy-eight were considered to comprise the control group.

Blood-lead levels which had been ≥40 µg. per 100 ml. in 1972 tended to be lower in 1973, probably because many children had moved from the immediate vicinity of the smelter, smelter emissions had decreased, and the population had aged. The mean in this group fell from 48·3 to 40·5 µg. per 100 ml. (table I), and in twenty-two of the forty-six children in the lead-absorption group the 1973 blood-level had fallen below 40 µg. per 100 ml. Accordingly, children in the lead-absorption group were divided into two subgroups on the basis of whether the blood-lead level did or did not remain ≥40 µg. per 100 ml., and various characteristics of the two subgroups were examined. They did not differ significantly in mean age (8·3 *v.* 8·4 years), language spoken (100% *v.* 95% Spanish-speaking), mean length of residence in the study area (6·9 *v.* 6·4 years), or socioeconomic index (64 *v.* 71, both in the lower-middle socioeconomic range). Children whose lead levels were ≥40 µg. per 100 ml. in both examinations did tend, however, to have lived closer to the smelter in 1972 (71% *v.* 23% within 1·6 km.), and they were more likely to have spent the first 2 years of their lives within 1·6 km. of the smelter (58% *v.* 14%). No significant differences were found between children in the two sub-

TABLE IV—RESULTS OF QUANTITATIVE NEUROLOGICAL TESTING=MEAN ± S.D.

Test	Lead-absorption group	Control group
Visual reaction-time (msec.):		
Dominant	29·2±9·9	26·3± 8·8
Non-dominant	29·2±8·6	26·3±10·2
Auditory reaction-time (msec.):		
Dominant	25·5±9·2	24·7±9·4
Non-dominant	26·8±9·0	24·0±7·2
2-plate tapping (no. of taps):		
Dominant	15·9±8·3	15·9±3·9
Non-dominant	14·7±7·5	14·9±4·1
Finger-wrist tapping (no. of taps):		
Dominant	46·4±13·4*	54·1±12·3
Non-dominant	41·2±12·4	45·5±10·8

* 0·001 < P < 0·01 by one-tailed *t* test.



Regression of finger-wrist tapping speed (dominant hand), by age and study group.

For lead-absorption group y (taps/10 sec.)=0·22x (age in yr.) +21·42 (*r*=0·55).

For control group y=0·22x+26·22 (*r*=0·67).

groups in the results of any medical, neurological, or psychological testing, and data from the subgroups are, therefore, combined.

Medical Data

Pica, colic, clumsiness, irritability, and convulsions were all reported by parents to have been more highly prevalent among children in the lead-absorption group than among controls (table III). None of the observed differences were, however, statistically significant. Neither hyperactivity nor other behavioural abnormality was significantly more common in either group as measured by parental questionnaire [14] or by the physician's examination.

Finger-wrist tapping was significantly slower in the dominant hand of children in the lead-absorption group (46·4 taps in 10 seconds *v.* 54·1, $P<0·01$) (table IV). To adjust these data for age, a regression of dominant-hand finger-wrist tap data against age was plotted for each group (see figure); the slopes of the resulting lines are nearly parallel. No other significant differences were found between the groups in the quantitative neurological testing.

Psychological Data

Full-scale I.Q. scores and verbal I.Q. scores showed no significant differences between the groups (table V). Results in the Bender gestalt test [17] and in the psychologists' evaluation of behaviour [19] also showed no significant differences ($P>0·05$). Analysis of performance I.Q. scores showed, however, that children in the lead-absorption group scored significantly below children in the control group in both the W.I.S.C. and the W.P.P.S.I. taken separately as well as in the two tests combined (table V). Mean performance I.Q. scores with W.I.S.C. and W.P.P.S.I. combined were 94·9 for the lead-absorption group and 102·7 for the control group ($P<0·01$). This difference in performance I.Q. scores resulted from the accumulation of differences in each of the eight subtests administered; the most significant differences were found in the W.I.S.C. coding subtest and in the W.P.P.S.I. geometric design subtest (table VI). The difference between the groups in performance I.Q. persisted when the groups were partitioned by sex (table VII).

TABLE V—WECHSLER INTELLIGENCE TEST SCORES = MEAN ± S.D.

Test	Lead-absorption group	Control group
W.I.S.C.[15]:		
Verbal I.Q.	83·47 ± 11·71	85·30 ± 15·27
Performance I.Q.	96·44 ± 13·74*	103·29 ± 17·87
Full-scale I.Q.	88·68 ± 12·64	93·29 ± 16·11
W.P.P.S.I.[16]:		
Verbal I.Q.	84·92 ± 11·60	84·47 ± 12·39
Performance I.Q.	90·67 ± 11·64*	100·27 ± 11·29
Full-scale I.Q.	86·17 ± 11·17	91·20 ± 11·88
W.I.S.C. + W.P.P.S.I.:		
Verbal I.Q.	83·85 ± 11·57	85·14 ± 14·69
Performance I.Q.	94·93 ± 13·35†	102·71 ± 16·79
Full-scale I.Q.	88·02 ± 12·21	92·88 ± 15·34

* $0·01 < P < 0·05$ by one-tailed *t* test.
† $0·001 < P < 0·01$.

TABLE VI—SUBTEST SCORES IN WECHSLER PERFORMANCE SCALES = MEAN ± S.D.

Subtests	Lead-absorption group	Control group
W.I.S.C.[15]:		
Picture completion	9·09 ± 3·04	9·81 ± 2·95
Block design	9·24 ± 3·61	9·86 ± 3·63
Object assembly	9·59 ± 2·68	10·21 ± 3·89
Coding	9·94 ± 3·23†	11·86 ± 3·54
Performance I.Q.	96·44 ± 13·74*	103·29 ± 17·87
W.P.P.S.I.[16]:		
Picture completion	9·58 ± 1·78	10·07 ± 2·46
Block design	8·33 ± 3·73	9·47 ± 2·10
Animal house	7·17 ± 3·46	8·80 ± 2·37
Geometric design	9·42 ± 2·64*	11·53 ± 2·36
Performance I.Q.	90·67 ± 11·64*	100·27 ± 11·29

* $0·001 < P < 0·05$ by one-tailed *t* test.
† $0·001 < P < 0·01$.

TABLE VII—WECHSLER PERFORMANCE I.Q. SCORES (W.I.S.C. PLUS W.P.P.S.I.) BY SEX = MEAN ± S.D.

Sex	Lead-absorption group	Control group
M	95·7 ± 14·5*	103·7 ± 17·2
F	93·5 ± 11·2*	101·3 ± 16·3
Total	94·9 ± 13·3†	102·7 ± 16·8

* $0·01 < P < 0·05$ by one-tailed *t* test.
† $0·001 < P < 0·01$.

TABLE VIII—PERFORMANCE I.Q. AND FINGER-WRIST TAPPING SPEED AMONG CHILDREN WITHOUT HISTORY OF PICA

Tests	Lead-absorption group	Control group
Performance I.Q.:		
W.I.S.C.	95·83 ± 14·40*	102·93 ± 18·15
W.P.P.S.I.	92·22 ± 11·77	99·93 ± 11·64
W.I.S.C. + W.P.P.S.I.	95·00 ± 13·77*	102·36 ± 17·09
Finger-wrist tapping, dominant (no. taps)	47·0 ± 14·0†	53·9 ± 12·5

* $0·01 < P < 0·05$ by one-tailed *t* test.
† $0·001 < P < 0·01$.

Discussion

Our findings indicate that chronic absorption of particulate lead sufficient to produce blood levels of 40–80 µg. per 100 ml. may result in a subtle but statistically significant impairment in the non-verbal cognitive and perceptual-motor skills [21] measured by the performance scale of the Wechsler intelligence tests [15,16] (table V) and subclinical impairment in the fine motor skills measured by the finger–wrist tapping test [7] (see figure).

These results need careful interpretation since observed differences could have derived from variation between the groups in matched characteristics, particularly in age or sex (table I). In defence of the data, it should, however, be noted that performance I.Q. scores were age-adjusted [15,16] and that the difference in finger–wrist tapping persisted when scores were plotted against age (figure). The performance I.Q. differences persisted also when the groups were stratified by sex (table VII). There is the added possibility that the impairment could have preceded and perhaps predisposed to the lead absorption. Pica, which may be a manifestation of such impairment,[3,4] was more common in the lead group than in the controls, though considerably less frequent than in children with exposure to lead-based paint [1,7,9]; perhaps the low prevalence of pica in El Paso indicates that it is less necessary there than elsewhere as a mechanism of lead intake given the almost ubiquitous availability to particulate lead near the smelter; Sayre et al.[22] suggest that the normal hand-to-mouth activity of young children is sufficient to account for considerable absorption of lead in a high-lead environment. A further argument against a central role for pica in explaining these data is that performance I.Q. and finger-wrist tapping scores changed but little when children without a history of pica were examined separately (table VIII).

Two previous studies [8,10] of neuropsychological function in children living near smelters, one from El Paso,[10] have produced negative results. This variation reflects the difficulty inherent in this sort of evaluation, but may also stem in part from differences in study design. In each of the previous investigations, the high-lead group was defined geographically in terms of proximity to the smelter, rather than by blood-lead level. Thus, in each case the exposed group contained numerous children with blood-lead levels <40 μg. per 100 ml. In addition, in one of those studies,[8] children in the exposed and non-exposed groups seem not to have been closely matched by socioeconomic status.

Several previous neurological and psychological studies among children presumed to have obtained their lead from paint have shown subtle abnormalities ranging from nerve-conduction deficits to behavioural difficulties.[3–6] The negative findings in other such studies might be explained by differences in populations and perhaps also by the notion that lead ingestion from paint begins at a later age and lasts a shorter time than the chronic intake from air and dust that prevails in El Paso [11]; the first months of life and even the prenatal months may well be critical periods in neuropsychological development.[23,24] Another possible factor, not explored in this study, is that absorption of other metals such as cadmium and arsenic, which are emitted by the El Paso smelter,[11,12] could have augmented any adverse effects due to lead. Differences in test sensitivity may also have contributed to negative findings; neither the Stanford-Binet test,[3] the Denver developmental screening test,[9] nor the full-scale Wechsler test [8] seem to evaluate non-verbal cognitive function and perceptual-motor function as thoroughly as the performance scale of the Wechsler test.[25] A series of neurological and psychological studies similar to those conducted in El Paso is now under way among children living near a lead smelter in Idaho.

The biological and developmental significance of our findings is not clear. We obtained no data correlating performance I.Q. with school performance or other functions. The decreased finger–wrist tapping speed may be functional evidence of low-grade motor neuropathy among children in the lead-absorption group. Palsy of the wrist and ankle extensors is an early sign of chronic lead poisoning in adults,[1] and clinical weakness of the distal arm muscles has been reported in children with increased lead absorption.[5] Also, minimal conduction defects in distal-extremity nerves have been noted among apparently symptom-free adults with occupational exposure to lead,[26,27] as well as among children with asymptomatic elevation of body lead burden.[6]

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Addendum

J. Perino and C. B. Ernhart (*J. Learning Disabil.* 1974, 7, 26) have studied psychological function in thirty symptom-free preschool children in New York City with blood-lead levels between 40 and 70 μg. per 100 ml. They found general cognitive, verbal, and perceptual abilities to be decreased compared with fifty control children with blood-lead levels between 10 and 30 μg. per 100 ml.