The New England
Journal of Medicine

Volume 300 MARCH 29, 1979 Number 13

DEFICITS IN PSYCHOLOGIC AND CLASSROOM PERFORMANCE OF CHILDREN WITH ELEVATED DENTINE LEAD LEVELS

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Abstract To measure the neuropsychologic effects of unidentified childhood exposure to lead, the performance of 58 children with high and 100 with low dentine lead levels was compared. Children with high lead levels scored significantly less well on the Wechsler Intelligence Scale for Children (Revised) than those with low lead levels. This difference was also apparent on verbal subtests, on three other measures of auditory or speech processing and on a measure of attention. Analysis of variance showed that none of these differences could be explained by any of the 39 other variables studied.

Also evaluated by a teachers' questionnaire was the classroom behavior of all children (2146 in number) whose teeth were analyzed. The frequency of non-adaptive classroom behavior increased in a dose-related fashion to dentine lead level. Lead exposure, at doses below those producing symptoms severe enough to be diagnosed clinically, appears to be associated with neuropsychologic deficits that may interfere with classroom performance. (N Engl J Med 300:689-695, 1979)

THE neurotoxic properties of lead at high dose are well known and not a subject of general controversy.[1,2] A source of considerable debate, however, is whether or not blood lead levels below those associated with obvious symptoms have adverse effects on the brain.[3,4] Because the symptoms of milder lead intoxication are not dramatic, and may therefore evade precise identification, many efforts have been made to determine whether these lesser levels of lead are associated with undetected neuropsychologic impairment.[5-11]

Among the reasons for discrepant conclusions in these earlier studies are the following methodologic difficulties shared to some extent by many of the reports:

Inadequate markers of exposure to lead. Most studies have relied on blood lead levels to classify subjects. Because blood lead is a marker of recent exposure, it may return to normal levels even though exposure was excessive. Errors are likely to occur, therefore, if blood lead is relied on to classify subjects after exposure has ceased.

Biased ascertainment of subjects. A study that attempts to provide conclusions applicable to the community at large must draw its sample from a representative population. Studies that select their subjects from health clinics, schools for the retarded or psychiatric clinics may not be representative of the population in general. Similarly, families who fear that their child has a deficit may respond to a study invitation in a systematically biased fashion, and either seek or avoid participation, depending on how the study is perceived.

Inadequate identification and handling of other confounding variables that affect development. A confounding variable is one that is differentially distributed in exposed and non-exposed groups and also affects the outcome under examination. Among the many potential confounders of effect of lead are genetic, perinatal, nutritional and socioeconomic variables. Because lead exposure is often associated with economic disadvantage, the multiple handicaps of poverty may frequently confound the effects of lead on development.

Insensitive measures of performance. Some studies have used group tests or mass screening examinations that cannot be expected to identify subtle degrees of neuropsychologic impairment. Sensitive measures are required to detect less than obvious deficit.

In this study we attempt to deal with these design issues while measuring neuropsychologic performance in relation to lead exposure in a group of children in the first and second grades, all of whom were considered asymptomatic for lead intoxication. Children were studied in two ways: those ranked in the highest and lowest 10th percentile for dentine lead concentrations were evaluated in the neuropsychologic laboratory. Their classroom behavior was also measured by teachers' ratings. In addition, all children whose teeth were analyzed had their classroom behavior evaluated by the same rating scale.

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The results of this study were reported in part at the Society for Pediatric Research, New York, NY, April 27, 1978.

Supported by a program project grant (HD-08945) from the National Institute of Child Health and Human Development.

Methods

Sample

The 3329 children attending first and second grades in the period between 1975 and 1978 in Chelsea and Somerville, Massachusetts, made up the population sampled. Children were asked to submit their shed teeth to the teacher, who then verified and recorded the presence of an appropriate fresh socket.

Tooth Analysis

Teeth were cleansed ultrasonically, and any with fillings were discarded from consideration. The specimens were then mounted in a lead-free wax on the cutting stage of a Buehler low-speed saw. A 1-mm slice was taken from the central sagittal plane of each tooth at a single pass. The central slice was then placed on an anvil and split with a small chisel along a line from the pulp canal to the dentine-enamel junction. The larger portions of the slices, along with the residual adjacent segments, were filed in numbered pill boxes for later confirmatory analysis. The smaller portion, composed primarily of dentine, was then analyzed for lead by anodic stripping voltammetry.[12]

Classification of Subjects' Lead Exposure

Subjects whose initial tooth slice was in the highest 10th percentile (> 24 ppm) or lowest 10th percentile (< 6 ppm) were provisionally classified as having high or low lead levels respectively (Fig. 1). Whenever possible, a second dentine lead level, either from the opposite half of the initial slice or from the remaining tooth substance, was obtained. In addition, we attempted to obtain and analyze other shed teeth from each subject provisionally classified in either group. On all but one subject, more than one analysis was obtained. Agreement between replicate samples was required before the subject was included in the study. If three values were obtained, complete concordance was required. If four values were obtained, one discordant value was allowed but discarded from analysis. If agreement was not found, the subject was designated "unclassified" and excluded from data analysis. To be classified as high lead required a mean of all concordant samples greater than 20 ppm. To be classified as low lead required a mean of less than 10 ppm.

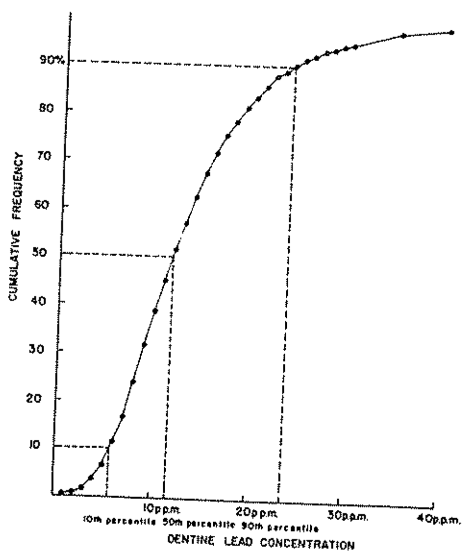

Figure 1. Cumulative Frequency Distribution of Dentine Lead Concentrations (3221 Specimens).
The points plotted are actual (unsmoothed) values.

Table 1. Reasons for Excluding Subjects and Distribution of Final Dentine Lead Levels in Included and Excluded Groups

Group		No.	Dentine Lead Level		
			Low	High	Unclassified
Provisionally eligible subjects:		524	258	187	79
Excluded from neuropsychologic testing:		254*	123	101	30
Bilingual home	84				
Not interested	57				
Moved	19				
Other†	94				
Total	254				
Subjects tested:		270‡	135	86	49
Excluded from data analysis:		112	35	28	49
Later tooth discordant	36				
Not discharged from nursery with mother, possible head injury, reported to have plumbism or bilingual home	76				
Total	112				
Cases scored & data analyzed		158	100	58	—

*Teachers' behavioral assessment available on 235.
†Infant at home, two working parents, etc.
‡Teachers' behavioral assessment available on 253.

Criteria for Exclusion

Parents of children with confirmed high and low levels were invited to participate in the further neuropsychologic evaluation of their child. Excluded, usually by telephone interview, were children from homes in which English was not the first language, whose parents either did not wish to participate, or were not able to participate for other reasons — e.g., an infant child at home or two working parents. Also excluded, after a medical history was obtained, were children whose birth weight was below 2500 g, who were not discharged at the same time as their mother after birth or who had a history of noteworthy head injury. Any child who had been diagnosed as lead poisoned was excluded. Some subjects, initially confirmed as having high or low lead levels, were later excluded from analysis because teeth subsequently submitted had values discordant from initial determinations (Table 1).

The Neuropsychologic Evaluation

The parent (usually the mother) and child were brought by taxi to the testing location. While the parent filled out a comprehensive medical and social history, received a 58-item questionnaire evaluating parent attitude in six areas and received a Peabody Picture Vocabulary I.Q. Test,[13] the child received a comprehensive neuropsychologic battery, administered in fixed order, beginning with the Wechsler Intelligence Scale for Children — Revised. The examiners were blind to the child's lead burden during the conduct of the examination and remained so until all tests were coded. After examination was completed and all tests scored, the principal investigator informed the parents of the child's lead status and counseled them about the proper course of action.

The following tests were administered as the neuropsychologic battery to the subjects who qualified and whose parents elected to participate in the detailed evaluation:

Psychometric intelligence. Wechsler Intelligence Scale for Children — Revised[14]: six verbal and six performance subtests.

Concrete operational intelligence. Piagetian conservation of number, substance and continuous quantity.[15]

Academic achievement. Peabody tests[16] of mathematics, reading recognition and reading comprehension.

Auditory and language processing. Sentence Repetition Test,[17] Token Test,[18] Seashore Rhythm Test[19] and Wepman Auditory Discrimination.[20]

Visual motor competence. Visual Motor Integration Test[21] and Frostig Test.[22]

Attentional performance. Reaction time under intervals of varying delay[23] and cognitive control battery.[24]

Motor co-ordination. Elements of the Halstead–Reitan Battery.[25]

Table 2. Comparison of Tested and Excluded Subjects on Teachers' Behavioral Rating Scale — the Numbers Show the Per Cent of Students in Each Group Receiving a Negative Response.

Item	Tested Group (%)	Excluded Group (%)
Distractible	26	34
Not persistent	15	19
Dependent	17	20
Disorganized	18	18
Hyperactive	9	7
Impulsive	13	14
Easily frustrated	18	23
Daydreamer	25	23
Not able to follow:		
Simple directions	7	12
Sequence of directions	19	24
Low overall functioning	17	25

Teacher's Behavioral Rating

The teacher of every child who gave a tooth was asked to fill out an 11-item forced-choice behavioral rating scale scoring the child as "yes" or "no" on the following questions:

1. Is this child easily distracted during his/her work?
2. Can he/she persist with a task for a reasonable amount of time?
3. Can this child work independently and complete assigned tasks with minimal assistance?
4. Is his/her approach to tasks disorganized (constantly misplacing pencils, books, etc.)?
5. Do you consider this child hyperactive?
6. Is he/she over-excitable and impulsive?
7. Is he/she easily frustrated by difficulties?
8. Is he/she a daydreamer?
9. Can he/she follow simple directions?
10. Can he/she follow a sequence of directions?
11. In general, is this child functioning as well in the classroom as other children his/her own age?

This form was completed by the teachers (who were blind to the lead level) after at least two months of classroom experience with the child. Sum scores (11 = good, 0 = poor) and item analyses were computed. The scale was obtained for the 2146 subjects who submitted at least one tooth. These 2146 subjects were then divided into six groups according to dentine lead level: Group 1, < 5.1 ppm; Group 2, 5.1 to 8.1 ppm; Group 3, 8.2 to 11.8 ppm; Group 4, 11.9 to 17.1 ppm; Group 5, 17.2 to 27.0 ppm; and Group 6 > 27.0 ppm. The boundaries were chosen to achieve a symmetrical distribution in each cell around the median.

Data from this rating scale were evaluated in three ways. Scores of participating and excluded subjects were first compared to evaluate any bias in sampling that might have occurred (Table 2). The incidence of negative reports on each item in relation to dentine lead level was then compared for the entire sample of 2146 subjects (Fig. 2). Finally, item and sum scores were compared for the 58 children with high and the 100 with low lead levels who received the neuropsychologic evaluation (Table 3).

Control Variables

Thirty-nine non-lead variables that could affect the subject's development were scaled and coded. A partial list is shown in Tables 4 to 6. The variables not included did not differ between groups. Data were obtained by a paper-and-pencil questionnaire. Parental socioeconomic status was estimated by a two-factor Hollingshead index.[26]

Data Analysis

The scores of children with high and low lead levels on 39 control variables were compared with use of the Student t-test. We then compared outcome measures in the 58 children with high and the 100 with low levels, using analysis of covariance (Statistical Package for the Social Sciences) with dentine lead level as the main effect, and the following covariates: mother's age at subject's birth; mother's educational level; father's socioeconomic status; number of pregnancies; and parental I.Q. We normalized outcomes for which age-normed scores were not available by regressing for age before analysis of covariance.

Frequency of negative reports on teachers' behavioral ratings was evaluated by chi-square test, both for the 158 subjects with high and low lead levels and for the entire sample of 2146 subjects as well. Non-lead covariates were not controlled in these analyses. Sum scores of teachers' ratings for subjects with high and low lead levels were compared by analysis of covariance with the covariates listed above.

Results

Dentine Lead Levels in Somerville and Chelsea

Of the total population of 3329 eligible children, 2335 (70 per cent) submitted at least one tooth for analysis (Fig. 1). Although the distribution of dentine lead levels in the first slice was closely balanced between high and low concentrations, more subjects with initially high values required reassignment as "unclassified" on the basis of later analyses. As a result, the final sample was composed of a larger number of subjects with confirmed low lead levels (Table 1).

Twenty-three subjects with "high dentine lead" and 58 with "low dentine lead" were discovered to have had blood lead determinations in an earlier screening project (1973-1974, four to five years before

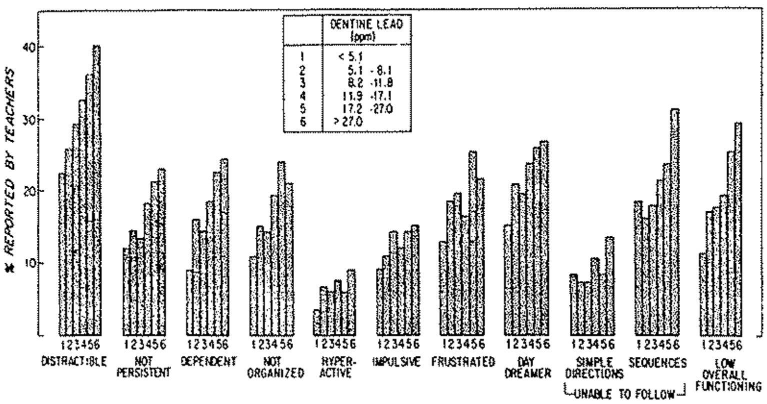

Figure 2. Distribution of Negative Ratings by Teachers on 11 Classroom Behaviors in Relation to Dentine Lead Concentration.

The group boundaries were chosen to obtain symmetrical cell sizes for the median (Groups 1 and 6 = 6.8 per cent, Groups 2 and 5 = 17.6 per cent, and Groups 3 and 4 = 25.6 per cent).

Table 3. Comparison of High and Low Lead Subjects on Teachers' Behavioral Rating Scale. The Numbers Show the Per Cent of Students in Each Group Receiving a Negative Response.

Item	Low Lead (%)	High Lead (%)	P Value
Distractible	14	36	0.003
Not persistent	9	21	0.05
Dependent	10	23	0.05
Disorganized	10	20	0.14
Hyperactive	6	16	0.08
Impulsive	9	25	0.01
Easily frustrated	11	25	0.04
Daydreamer	15	34	0.01
Does not follow:			
Simple directions	4	14	0.05
Sequence of directions	12	34	0.003
Low overall functioning	8	26	0.003
Sum score (mean)	9.5	8.2	0.02*

*Analysis of covariance.

shedding teeth). Their records were obtained and previous blood levels in the two groups compared. The mean blood lead level in 1973-1974 was 35.5±10.1 μg per deciliter for the group with high dentine lead and 23.8±6.0 μg per deciliter for the group with low dentine lead ($P<0.001$, by two-tailed t-test). The highest blood lead level in the children with high dentine lead levels was 54.0 μg per deciliter.

Evaluation of Sampling Bias

The teachers' behavioral assessment was available for 253 of the 270 children who did participate in the neuropsychologic evaluation and for 235 of the 254 who did not participate. Comparison of dentine lead levels (Table 1) and teachers' scores (Table 2) in tested and excluded subjects demonstrated that the two groups did not differ in either lead exposure or classroom behavior.

Table 4. Comparison of Non-Lead Variables in High and Low Lead Groups.

Variable	Low Dentine Lead	High Dentine Lead	P Value*
General			
%Male	49.5	55.9	NS‡
%White	97.0	98.3	NS
%Father head of household	77.2	67.8	NS
%Completed immunizations	98.0	98.3	NS
%Positive pica history	10.9	28.8	0.008
Physical variables at date of testing			
Age (mo)	87.2±7.7†	90.7±8.4	0.009
Height (cm)	126.6±6.3	126.4±6.3	NS
Weight (kg)	25.8±4.9	26.5±4.6	NS
Head circumference (cm)	51.8±1.6	51.7±1.5	NS
Skinfold:			
Right arm (mm)	9.5±3.5	9.8±4.2	NS
Left arm (mm)	9.5±3.4	9.7±4.2	NS
Past medical history			
Birth weight (g)	3,400.0±448.6	3,346.0±514.0	NS
Length of infant hospital stay (days)	4.9±1.8	4.4±1.5	NS
Birth order	2.4±1.7	2.7±2.0	NS
No. of hospital admissions	0.47±1.2	0.42±1.6	NS

*2 tail. †Mean ± S.D. ‡Not significant.

Control Variables

Children with high and low lead levels were quite similar in most non-lead variables measured (Tables 4-6). The following variables, which differed at $P<0.1$, were controlled as covariates in analysis of covariance: fathers' socioeconomic status (consisting of education and occupation score); mothers' age at subjects' birth; number of pregnancies; mothers' education and parental I.Q.

Outcome Measures

Children with high lead levels performed significantly less well on the Weschler Intelligence Scale (Table 7), particularly the verbal items, on three measures of auditory and verbal processing (Table 8), on attentional performance as measured by reaction time under conditions of varying delay (Table 8 and Fig. 3) and on most items of the teachers' behavioral rating (Table 3).

Table 5. Comparison of Parental Non-Lead Variables in High and Low Lead Groups.

Variable	Low Dentine Lead	High Dentine Lead	P Value*
No. of pregnancies	3.3±1.8†	3.8±2.3	0.10
Mother's age at subject's birth (yr)	26.2±5.5	24.5±5.8	0.07
Mother's social class (2-factor Hollingshead)	4.1±0.8	4.2±0.8	NS
Mother's education (grade)	11.9±2.0	11.4±1.7	0.08
Mother's occupation	5.5±1.1	5.5±1.3	NS
Father's age at subject's birth (yr)	28.8±7.1	27.5±7.9	NS
Father's social class (2-factor Hollingshead)	3.8±1.0	4.1±0.8	0.02
Father's education (grade)	12.7±2.8	11.1±2.3	0.001
Father's occupation	4.7±1.6	5.0±1.2	NS
Parent IQ	111.8±14.0	108.7±14.5	NS

*2 tail. †Mean ± S.D. ‡Not significant

As compared to controls, children with high lead levels appeared particularly less competent in areas of verbal performance and auditory processing. They had lower scores on all tests of the Seashore Rhythm Test, which requires the subject to discriminate whether pairs of tone sequences of increasing complexity are alike or different. In the Token Test the task is to respond to verbal instructions of increasing complexity and to manipulate tokens of different shapes and colors. The four subtests are presented in order of increasing complexity and difficulty. The Sentence Repetition Test, which requires the immediate repetition of previously uttered sentences of increasing length and syntactic complexity, was also sensitive to the effect of lead exposure.

The ability of subjects with high lead levels to sustain attention was clearly impaired, as measured by reaction time at varying intervals of delay. Their reaction time was significantly slower on Blocks 2 and 3 (at 12 seconds' delay) as well as on Block 4 (at three seconds' delay). This final block was administered after about 15 minutes of repetitive testing, when subjects began to become distracted.

Table 6. Parental Attitude Scores in High and Low Lead Subjects.*

Control Variable	Low Dentine Lead	High Dentine Lead
Parental aspirations for child	19.7±5.6†	19.5±4.6
Home learning environment	37.6±6.3	37.1±5.4
Parental attitude toward school:		
Resignation	17.4±3.4	17.1±2.9
Futility	17.8±2.7	17.7±2.5
Conservatism	20.3±2.2	20.4±1.9
Parental attitude toward child	34.4±4.3	34.5±4.8
Parental restrictiveness	19.1±2.1	19.4±2.2

*No significant differences found. †Mean ± SD.

Teachers' reports of classroom behavior showed that children with high lead levels were rated significantly poorer on nine of 11 items, and that the sum score of these subjects was lower.

Teachers' Behavioral Rating on Entire Study Sample

Teachers' behavioral ratings were available for 2146 (92 per cent) of the 2335 children who submitted teeth. The frequency of negative teachers' ratings for every item increased with increasing dentine lead level, and was not limited to the group with highest lead levels (Fig. 2).

Discussion

The confidence with which the performance deficits reported here can be attributed to past lead exposure depends on whether this investigation has successfully addressed the four methodologic issues raised earlier (lead markers, sampling bias, confounding variables and sensitive outcome measures).

The classification of earlier lead exposure according to dentine lead levels has been validated in a number of earlier studies. Lead exists in dentine in a closed storage system. Tooth lead levels in baboons do not change after a pulsed dose of ^{203}Pb.[27] They are elevated in children with unequivocal plumbism,[28] urban children living in the "lead belt"[29] and those who live in decaying homes, or intact homes near a major lead processor.[12] Tooth lead levels also vary in relation to the concentration of lead in the domestic water supply and the duration of exposure to that water.[30]

In our present study, the small number of blood lead levels in subjects drawn four to five years before tooth shedding documents the point that children with higher tooth lead levels tended to have had higher blood lead levels years previously.

Table 7. Full-Scale and Subtest Scores of the Wechsler Intelligence Scale for Children (Revised) (WISC-R) for High and Low Lead Subjects.

WISC-R	Low Lead (Mean)	High Lead (Mean)	P Value*
Full-scale IQ	106.6	102.1	0.03
Verbal IQ	103.9	99.3	0.03
Information	10.5	9.4	0.04
Vocabulary	11.0	10.0	0.05
Digit span	10.6	9.3	0.02
Arithmetic	10.4	10.1	0.49
Comprehension	11.0	10.2	0.08
Similarities	10.8	10.3	0.36
Performance IQ	108.7	104.9	0.08
Picture completion	12.2	11.3	0.03
Picture arrangement	11.3	10.8	0.38
Block design	11.0	10.3	0.15
Object assembly	10.9	10.6	0.54
Coding	11.0	10.9	0.90
Mazes	10.6	10.1	0.37

*These 2-tail P values are those for any single comparison between high & low lead groups. It should be remembered that when a large no. of simultaneous comparisons are made between 2 groups of subjects, the probability that a "significant" result may be found is larger than the P value for the single test. An approximate & conservative adjustment for this fact may be obtained if the reported P value is multiplied by the no. of simultaneous tests. In this sense the "full-scale IQ" above constitutes a single test, & the "verbal IQ" and "performance IQ" constitute a pair of simultaneous tests. Within the verbal WISC there are 6 simultaneous tests, and within the performance WISC there are another 6 simultaneous tests. Thus, with the conservative adjustment described above the following P values would be obtained: full-scale IQ, P = 0.03; verbal IQ, P = 0.06; & digit-span, P = 0.12.

Table 8. Verbal Processing Scores and Reaction Times in High and Low Lead Subjects.

Test	Low Lead Values (Mean)	High Lead Values (Mean)	P Value*
Seashore Rhythm Test			
Subtest A	8.2	7.1	0.002
Subtest B	7.5	6.8	0.03
Subtest C	6.0	5.4	0.07
Sum	21.6	19.4	0.002
Token Test			
Block 1	2.9	2.8	0.37
Block 2	3.7	3.7	0.90
Block 3	4.1	4.0	0.42
Block 4	14.1	13.1	0.05
Sum	24.8	23.6	0.09
Sentence-Repetition Test	12.6	11.3	0.04
Reaction time under varying intervals of delay			
Block 1 (3 sec)	0.35±0.08†	0.37±0.09	0.32
Block 2 (12 sec)	0.41±0.09	0.47±0.12	0.001
Block 3 (12 sec)	0.41±0.09	0.48±0.11	0.001
Block 4 (3 sec)	0.38±0.10	0.41±0.12	0.01

*2 tail. See footnote to Table 6. The conservative adjustment for multiple simultaneous comparisons would yield the following P values: Subtest A of the Seashore Rhythm Test, P = 0.006; Block 4 of the Token Test, P = 0.20; & Blocks 2 & 3 of the Reaction Time Test, P = 0.004.

†Seconds – mean ± SD.

Subjects with high and low lead levels accepted for neuropsychologic evaluation in this study are an unbiased sample of children with lead burdens of this order in their communities. Subjects tested in this study do not differ in gender, prevalence of elevated dentine lead levels or classroom behavior from those excluded.

The problem of potentially confounding variables was handled by comparison of subjects on a large number of variables and by control, in the biostatistical analysis, for those differing between samples. Groups with high and low lead levels who were evaluated in this study were remarkably alike in most of the 39 non-lead variables measured, and only differed at $P<0.05$ on three variables: fathers' education, fathers' socioeconomic status and subjects' age at time of testing.

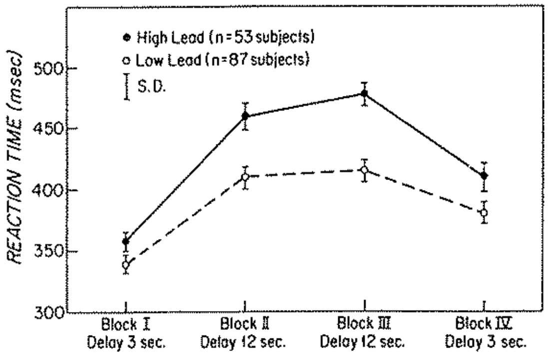

Figure 3. Reaction Time under Varying Intervals of Delay. "Delay 3 sec." indicates a three-second period between a warning signal (the spoken word, "ready") and the onset stimulus. Each subject received six trials in each block.

In this study, outcome measures that appear to be most sensitive to lead effects are those evaluating verbal and auditory processing, attention (as measured by reaction time) and classroom behavior. At the relatively low dose experienced by our exposed group, verbal and attentional processes appear most vulnerable.

Other investigators[5,7] have reported that lead effects are most evident in the performance areas of the Wechsler Intelligence Scale for Children — Revised, and in perceptual and motor function. The differences in the expression of the effect of lead may reflect many factors, including magnitude and duration of exposure and age at time of exposure.

Reaction time under varying intervals of delay is one measure of the attentional process.[23] Needleman[31] found that boys seven and eight years old with earlier blood lead levels higher than 50 μg per deciliter had longer reaction times at trial Blocks 2, 3 and 4 than controls whose earlier blood levels were less than 30 μg per deciliter. This replicated finding suggests that disturbances of attentional function are a consistent effect of lead exposure. The validity of this finding is further supported by the teachers' reports of increased distractibility, increased prevalence of daydreaming, lack of persistence, inability to follow directions and lack of organization in subjects with high lead levels. These behaviors are often found in children labeled as "hyperactive." Hyperactive behavior is a frequent sequel of frank lead poisoning,[7,32] and is suspected of being an effect of lead at lower dose.[33] The items of hyperactivity and impulsivity, however, were reported relatively infrequently at all levels of dentine lead (Fig. 2). Although the frequency of these two behaviors is related to dentine lead burden, it appears that teachers in our study were reluctant to apply these labels to their students. The deficit of attention in the children with high lead levels demonstrated here may be responsible in part for impaired verbal learning.

The teachers' behavioral rating scale was found to be sensitive to the degree of lead exposure on almost all items across the entire range of dentine lead levels in a dose-related fashion. This observation suggests that lead may increase the risk of undesirable behaviors in the classroom at doses considerably below those found in our group with high lead levels.

The defined "no-effect" levels for children exposed to lead has undergone a steady downward revision over the past three decades as new data have shown effects at lower doses. Currently, the Center for Disease Control has defined a blood lead level of 30 μg per deciliter as the threshold for undue lead absorption.[2] Among the reasons for this evolution in medical judgment has been the demonstration of the inhibitory effect of lead at extremely low concentrations on enzymes such as δ-aminolevulinic acid dehydratase[34] and brain adenylcyclase[35] and on mitochondrial function.[36] Piomelli[36] has recently reported that elevation of free erythrocyte protoporphyrin begins to occur in children at blood lead levels of 15 μg per deciliter. Although many investigators believe that alterations in free erythrocyte protoporphyrin, adenylcyclase, and δ-aminolevulinic acid dehydratase are among the first signs of impaired tissue function and therefore represent adverse health effects, it has been questioned whether at the lower levels of lead these alterations are health effects or merely biochemical events of little consequence.

The impaired function of children with high lead levels, demonstrated in the neuropsychologic laboratory, mirrored by disordered classroom behavior, appears to be an early adverse effect of exposure to lead. Permissible exposure levels of lead for children deserve re-examination in the light of these data.

We are indebted to Janice Adams, Margaret Nichols and Ruth Barrett, who performed the psychological tests, and to Lee Davidowski and Hamdi Maksoud, who analyzed the dentine specimens, to the teachers, principals and nurses of Somerville and Chelsea, Massachusetts, and to the late Dr. James Bryant, of the Somerville Board of Health, for help in the early days of the study.

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EPIDEMIC TOXOPLASMOSIS ASSOCIATED WITH INFECTED CATS

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Abstract In October, 1977, an outbreak of toxoplasmosis occurred in patrons of a riding stable in Atlanta, Georgia; 37 became ill with toxoplasmosis or had serologic evidence by indirect fluorescent-antibody test of acute infection with *Toxoplasma gondii* (titer ⩾1:4096 or a positive fluorescent-antibody test for toxoplasma antibodies). Forty-nine additional patrons did not become ill. Two of the three adult cats from the stable were seropositive for toxoplasma, which was also recovered from the tissues of two kittens and four mice trapped near the stable. Patrons who spent most of their time at the end of the stable where a cat had defecated had the highest incidence of infection. Patrons who attended the stable daily had a higher attack rate than those who attended less frequently. No common meals were consumed, and dietary history eliminated meat as the source of infection. The data suggest that toxoplasma oocysts were the source of the infection. (N Engl J Med 300:695-699, 1979)

BOTH infection and disease are well documented for persons who have consumed toxoplasma in raw or inadequately cooked meat.[1,2] More recently, the role of cats shedding toxoplasma oocysts as a source of human and animal infection has been widely publicized.[3] Although most investigators acknowledge that oocysts are probably infectious for human beings, there is little evidence linking infection by oocysts with clinical disease in human beings.[4]

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Dr. Dubey is the recipient of a grant (AI-15919) from the National Institute of Allergy and Infectious Diseases, National Institutes of Health.

BACKGROUND

On November 11, 1977, a physician in Atlanta, Georgia, informed us about a patient with high fever and headache whom he had recently diagnosed as having toxoplasmosis. This patient informed us that she was aware of several people with similar symptoms who had all attended one local horseback-riding stable. We obtained serum from eight of those patrons, and all of them had high toxoplasmosis titers. This finding prompted a more thorough investigation.

The stable (Stable 1), located in DeKalb County, Georgia, consists of a 26-ha (65-acre) pasture, an outdoor riding arena and a 70-stall barn with a large indoor riding arena. The floor of the indoor arena is covered with a fine silt, which is watered and dragged as needed and occasionally bulldozed. The last bulldozing had occurred on September 3, 1977. The indoor arena was extensively used by pupils and instructors of a riding school, and most patrons visited the stable frequently.

METHODS AND RESULTS

Within a three-week period we interviewed all patrons of Stable 1, using a standardized questionnaire, and, when possible, serum specimens were obtained. Respondents were questioned about personal illness, illness of family contacts, activities at the stable, eating habits and exposure to cats.