Contribution of Social and Developmental Factors to Lead Exposure During the First Year of Life

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ABSTRACT. The social and developmental correlates of early lead exposure were explored in an interim analysis of data from an ongoing longitudinal investigation in Cincinnati. Regardless of the apparent net availability of lead in the infant's physical environment, parental behavior was still significantly associated with infant blood lead levels. However, this was only the case after infants in the study reached 6 months of age and beyond when prewalking progression and early walking made parental management all the more critical. Future lead screening and abatement programs should include supports for the caretaker-child relationship. *Pediatrics* 1985;75:1114–1119; *lead exposure, child development, caretaker-child interaction.*

High doses of lead carry serious hematologic, renal, gastrointestinal, and reproductive sequelae.[1-3] Lead is also neurotoxic, and acute lead encephalopathy can occur in children with whole blood lead levels above 80 μg/dL, and occasionally at even lower concentrations. At low to moderate levels of lead intoxication (eg, 10 to 49 μg/dL of whole blood) hematopoietic sequelae include aminolevulinic acid-dehydratase inhibition and increased erythrocyte protoporphyrin.[4] There are also data that suggest a depression of 1,25-dihydroxycholecalciferol at lead levels below 30 μg/dL of whole blood.[5]

The neurobehavioral effects of low to moderate lead exposure during childhood (eg, 10 to 49 μg/dL of blood lead) are not as well known. As indicated, these so-called asymptomatic levels of exposure sometimes carry hematopoietic effects.[4] However, the effects of low to moderate lead exposure on the CNS and behavior of children remain controversial.[6-8] The effects of low-level lead exposure on sensorimotor development in infants are also uncertain. In longitudinal studies, Bellinger et al[9] found a significant negative relationship between prenatal lead exposure (cord blood lead) and 6-month Bayley mental index scores, whereas Dietrich et al[10] failed to find any relationship between postnatal blood lead levels and Bayley mental index scores at 3, 6, or 12 months.

Metabolic balance studies have shown that younger animals and human infants absorb and retain a higher percentage of total ingested lead compared with adults.[11,12] Therefore, the infant may be at greater risk for lead-related health effects than a child or adult given equal exposure to the nonessential metal. Naturally, the period of infancy is also a critical phase for CNS development.[13] These two findings make the description of the biologic, physical-environmental, and social-developmental factors, which may contribute to early exposure, an especially important goal for research. The data generated by such scientific efforts can guide clinical and programmatic attempts to diminish the incidence of undue lead exposure in infants and young children. The focus of this report shall be on the social and developmental correlates, and possible social causes of early lead exposure.

Previous studies have shown that lead exposure at both moderate and higher levels is associated with less adequate socioeconomic circumstances,[14,15] poorer caretaking practices,[14,15] and lack of

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stimulation in the home.[16–18]

Some investigators have suggested that environmental deprivation may intensify mouthing behavior in infants and children, and thus result in an increased level of ingestion of lead-laden substances.[19–21] Such forms of deprivation are probably more common among poorer families living in substandard housing where lead is ubiquitous in the form of dust, soil, and peeling paint. At least one study has substantiated the suggested associations among environmental deprivation, mouthing behavior, and lead intoxication. Madden et al[22] exposed a group of young children hospitalized for asymptomatic lead poisoning to three play environments which differed in their stimulus complexity (eg, number and type of toys, availability of a playmate). Their results showed that significantly more mouthing behavior occurred in the impoverished play setting.

All of these previous studies have dealt with preschool-aged children. There are a lack of data on the social or familial correlates of exposure during early infancy. The purpose of the present study was to examine the relationship between social factors in the home environment (particularly aspects of the caretaker-infant relationship) and lead exposure in infants during the first year of life.

It was hypothesized that: (1) Lead exposure, even during early infancy, will be related to the quality of physical and social stimulation available to infants in their home environments; infants in poorer environments will exhibit higher blood lead levels. (2) The relationship between home environment and lead exposure will be most pronounced after infants are 6 months old, when the advent of crawling and early walking necessitates closer maternal supervision and structuring of the infant's daily activities.

METHODS

Subjects

Infants born to parents residing in lead-hazardous areas of Cincinnati (areas where many older dwellings exist and where cases of lead poisoning are historically more common) were recruited at birth. High-risk pregnancies (eg, diabetes, substance abuse, epilepsy, mental disorder) and newborns (eg, 1,500 g or less birth weight, Apgar score less than 5 at five minutes, inborn errors of metabolism, Down syndrome) were excluded (Bornschein et al[23]). Eighty-two percent of the sample infants were black, and virtually all subjects were of the lower social classes and were receiving public assistance. Between 71 and 118 subjects were involved in this interim analysis of data from an ongoing longitudinal study. The unequal values for N reflected the longitudinal nature of these data and not the subject attrition at later ages.

Measures

Blood samples were drawn by either heel stick, finger stick, or venipuncture depending on the age and physical characteristics of the child. At 10 days of age, about 60% of the samples were obtained by heel stick, the remainder by venipuncture. Beyond 6 months of age, more than 80% of the samples were obtained via venipuncture, the remainder by finger stick. Contamination of finger stick or heel stick samples has not been a problem. At all ages, finger stick blood lead values were slightly lower than venipuncture values. This is opposite to what one would predict if lead contamination were a problem and was most likely due to a slight dilution of blood with tissue exudate. Samples were analyzed for lead by anodic stripping voltammetry using an extraction method.[24] Quality control procedures have been described by Bornschein et al.[23]

Infants whose blood lead level indicated undue exposure were scheduled for monthly rather than quarterly medical assessments. The mother was asked about the infant's activities at home (eg, play areas, incidence of pica) and whether she had moved to a new dwelling or made changes in child care arrangements. If changes in housing had occurred, a physical evaluation of the home was made to check sources and levels of lead (eg, lead in dust, paint, soil, etc). This information was then made available to the parent and the city health department. Diagnostic chelation or chelation therapy was considered by the study's pediatrician on an individual basis. Diagnostic chelation does not affect the overall blood lead profile because the reduction in whole blood lead is extremely small. Only one infant in the present study received a therapeutic chelation.

In this report, cumulative blood lead served as the main index of exposure. Cumulative blood lead is a measure of total postnatal exposure history derived from a calculation of the area under the fitted curve of each infant's blood lead profile (composed of age-concurrent blood lead values) from 10 days to the "target" ages for analysis of 3, 6, 9, 12, or 15 months. Cumulative blood lead is highly correlated with concurrent blood lead levels, but is used here as an index of exposure rather than single concurrent blood lead level as it represents an estimate of the infants' total lead exposure history and is less susceptible to the effects of transitory, acute increases in blood lead levels at any one point in time. For the correlational analyses, all cumula-

tive blood lead values were transformed to their natural logarithm to produce a more normal distribution.

The *Home Observation for Measurement of the Environment* (HOME) inventory[25] was used to assess the quality and quantity of social and physical stimulation available to the infant. The HOME combines interviewer's queries with direct observations to yield a single total HOME score and separate scores for each of the six subscales: (1) Mother's Emotional and Verbal Responsivity, (2) Avoidance of Restriction and Punishment, (3) Organization of the Physical and Temporal Environment, (4) Provision of Appropriate Play Materials, (5) Maternal Involvement with Child, and (6) Opportunities for Variety in Daily Stimulation. The measure was administered in the infant's home at age 6 months, and again at age 12 months. Each home visit was attended by two trained observers who independently scored the HOME. Interobserver reliability on the HOME was 96%. For this report, scores on the 6- and 12-month HOME were combined to derive a mean total HOME score and mean HOME subscale scores for each family. It was felt that this would provide a more stable estimate of the infant's first-year environment than a single score at either 6 or 12 months. However, for about 25% of the cases, only one home visit could be completed during the first year. Nevertheless, the lack of a second HOME evaluation for one quarter of the sample did not present a serious problem for data analyses because 6- and 12-month assessments were highly correlated in this sample ($r = .71$, $P < .001$).

In a previous report[26] members of this research group showed that housing type (eg, public, nonrehabilitated private, rehabilitated private), age (eg, 19th century, pre-WWII 20th century), and condition (eg, satisfactory, deteriorating, or dilapidated) were strongly associated with blood lead levels in infants and young children. These data were based on external and internal environmental assessments of lead sources undertaken when infants in the present study were 7 months of age. Analyses of internal sources of lead and external inspections of housing revealed high correlations between housing type and levels of lead in paint, dust, and soils. Therefore, if HOME scores were correlated with such housing factors, any positive results could be seriously confounded with the distribution of hazardous sources of lead in the infant's physical environment. Therefore, one could not conclude that caretaker behavior played a direct role in the etiology of early lead intoxication. To determine whether such a confound existed, these housing data were included in the analyses. Housing assessments were conducted by trained observers who made external examinations of patient's residences (see Clark et al[26]).

RESULTS

Geometric means and standard deviations for current postnatal blood lead values during the first 15 months of infancy are shown in Table 1. Geometric mean blood lead values increased from 5.5 μg/dL at age 10 days to 16.8 μg/dL at age 15 months. Variability in levels of exposure was evident at all ages, and some individual blood lead values exceeded 30 μg/dL, indicating possible undue exposure.[27]

Arithmetic means and standard deviations for mean total HOME scores and HOME subscales for the first year are presented in Table 2. Means and standard deviations in this sample were similar to those reported by Caldwell and Bradley[25] for their Little Rock standardization group. In other words, the developmental environments in these generally poor families were not uniformly inadequate and showed a fair amount of variability.

As hypothesized, total HOME scores and at least

TABLE 1. Geometric Mean Current Blood Lead Values

Age	Mean Current Blood Lead (SD) (μg/dL)	Range (μg/dL)
10 d	5.5 (2.0)	1–29
3 mo	5.7 (2.0)	1–28
6 mo	7.7 (2.0)	1–34
9 mo	11.6 (1.9)	1–55
12 mo	15.2 (1.7)	5–46
15 mo	16.8 (1.7)	3–56

TABLE 2. Mean Total *Home Observation for Measurement of the Environment* (HOME) Scores and Subscales for First Year

Scale	Mean Score ± SD	Range*	Possible Score†
Total HOME	31.8 ± 4.7	17–42	45
Emotional and Verbal Responsivity of Mother	8.8 ± 1.6	3–11	11
Avoidance of Restriction and Punishment	5.7 ± 1.0	1–8	8
Organization of Physical and Temporal Environment	4.5 ± 1.4	1–6	6
Maternal Involvement with Child	4.6 ± 1.4	1–6	6
Opportunity for Variety in Daily Stimulation	2.7 ± 0.9	1–5	5
Provision of Appropriate Play Materials	5.5 ± 1.7	1–9	9

* Range indicates minimum and maximum scores achieved by study sample.

† Maximum possible score for total HOME and subscales.

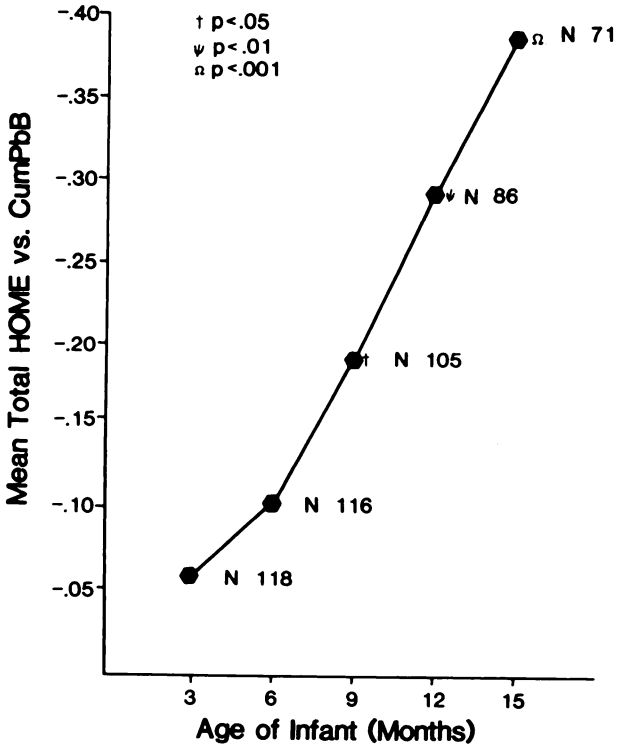

Fig 1. Change in correlation between mean total *Home Observation for Measurement of the Environment* (HOME) scores and cumulative blood lead (CumPbB) during first 15 months of life. Hexagon indicates correlation.

three subscales of the HOME were negatively correlated with cumulative blood lead at all ages. Infants with higher levels of lead exposure lived in generally less adequate developmental environments. However, as predicted, the strength of these negative correlations increased dramatically with age.

To illustrate, the change in correlations between mean total HOME scores for the first year and cumulative lead exposure up to age 15 months are presented in Fig 1. The negative correlations between cumulative blood lead and mean total HOME did not achieve statistical significance until after age 6 months when prewalking progression becomes well established in most infants. These correlations became progressively stronger with age. At age 15 months, when walking is generally well established, the highest negative correlation was achieved.

These results imply that those infants who receive the least parental care, stimulation, and supervision may be left more often in the presence of hazardous sources of lead (eg, on the floor where lead in dust, soil, and flakes of paint may be present), and may engage in more hand-to-mouth behavior as a result of understimulation. However, it also appears that parental behavior does not become a significant factor until the infant becomes mobile; when supervision by the caretaker becomes critical.

To determine which aspects of parental care and home environment were correlated with lead exposure, the relationship between mean HOME subscales and cumulative blood lead was explored. Three HOME subscales—Maternal Involvement with Child, Provision of Appropriate Play Materials, and Emotional and Verbal Responsivity of Mother—were negatively correlated with lead exposure at all ages. However, as with total HOME scores and cumulative blood lead, these correlations increased as the infants matured.

To illustrate, the change in correlation between significant mean HOME subscales for the first year and cumulative lead exposure to age 15 months are presented in Fig 2. The strongest correlations occurred after age 6 months. This was particularly apparent for the maternal involvement with child subscale. This subscale measures the extent to which the mother keeps her child within visual range during the interview and during her daily

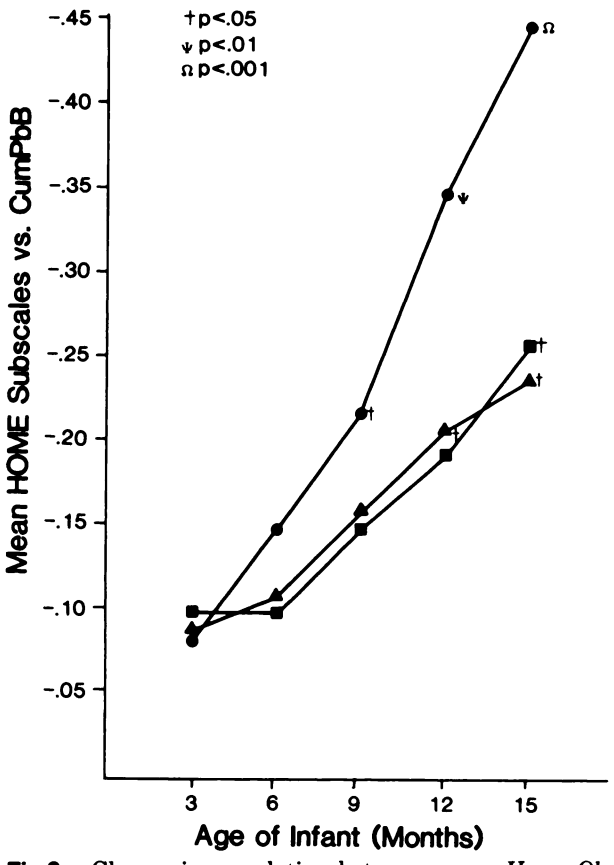

Fig 2. Change in correlation between mean *Home Observation for Measurement of the Environment* (HOME) subscales and cumulative blood lead (CumPbB) during the first 15 months of life. Circle indicates Maternal Involvement with Child, triangle indicates Provision of Appropriate Play Materials, and square indicates Emotional and Verbal Responsivity of Mother.

activities, structures her infant's activities, and takes a "teaching" attitude toward promoting early development.

These results imply that those infants who lack such supervision and involvement from their mothers are more likely to be exposed to and ingest lead-laden substances. The increasing negative correlation between Provision of Appropriate Play Materials, and Emotional and Verbal Responsivity of Mother subscales and cumulative blood lead are in accord with previous findings.[22] Those infants who receive less physical and social stimulation may engage in more hand-to-mouth behavior and thus ingest larger quantities of lead-laden dust, soil, paint flakes, or other materials.

Correlational analyses between housing age, type, condition, and total HOME scores and subscales revealed only zero-order relationships. Therefore, caretaker behavior was probably not confounded with the net availability of lead in the infant's physical environment. Because the two major study hypotheses were supported, inferences about the causal role of caretaker management and stimulation in lead exposure can be made with some confidence.

SUMMARY AND CONCLUSIONS

The relationship between the infant's caretaking environment and lead exposure during the first year of life was explored in an interim analysis of data from an ongoing longitudinal study in Cincinnati. The level of physical and social stimulation available to the infant and degree of maternal involvement as measured by the HOME scale were negatively correlated with lead exposure. This confirms the findings of previous studies, especially Milar et al[18] who also used the HOME, that the caretaker-child relationship plays a significant role in early lead exposure. Infants living in poorer developmental environments tended to have higher blood lead levels. However, the correlations between home environment and exposure to lead were only statistically significant after infants were 6 months of age. These findings suggest that after infants become mobile and sources of lead become accessible due to the increased breadth of the infant's environment and the normal increase in hand-to-mouth behaviors, caretaker behavior and the level of stimulation in the home play an important role in the etiology of early exposure to and ingestion of lead-laden substances. While factors in the physical environment play key roles in the etiology of lead intoxication (e.g., housing conditions, domestic hygiene) these results imply that education for parenthood and other supports for the caretaking relationship should be included in future lead screening and abatement programs.

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REFERENCES

1. Chisolm JJ Jr, O'Hara DM (eds): *Lead Absorption in Children.* Baltimore, Urban & Schwarzenberg, 1982
2. Lynam DR, Plantanida LG, Cole JF (eds): *Environmental Lead.* New York, Academic Press, 1981
3. Singhal RL, Thomas JA (eds): *Lead Toxicity.* Baltimore, Urban & Schwarzenberg, 1980
4. Moore MR, Meredith PA, Goldberg A: Lead and heme biosynthesis, in Singhal RL, Thomas JA (eds): *Lead Toxicity.* Baltimore, Urban & Schwarzenberg, 1980, pp 79–117
5. Mahaffey KR, Rosen JF, Russell WC: Association between age, blood lead concentration, and serum 1,25-dihydroxycholecalciferol levels in children. *Am J Clin Nutr* 1982;35:1327–1331
6. Bornschein RL, Pearson DT, Reiter L: Behavioral effects of moderate lead exposure in children and animal models: 1. Clinical studies. *CRC Crit Rev Toxic* 1980;8:43–100
7. Bornschein RL: Design considerations for prospective studies of lead's effect on behavioral and cognitive development, in Mahaffey K (ed): *Health Implications of Typical Levels of Lead Exposure: Dietary and Environmental Sources.* Amsterdam, Elsevier, in press 1985
8. Smith M, Delves T, Lansdown R, et al: The effects of lead exposure on urban children: The Institute of Child Health/Southhampton Study. *Dev Med Child Neurol* 1983;25(suppl)
9. Bellinger D, Leviton A, Waternaux C, et al: Methodological issues in modelling the relationship between low-level lead exposure and infant development: Examples from the Boston lead study. Paper presented at the Second International Conference on Prospective Studies of Lead, Cincinnati, April 10, 1984
10. Dietrich KN, Pearson DT, Krafft KM, et al: Postnatal lead exposure and early sensorimotor development. Paper presented at the Second International Conference on Prospective Studies of Lead, Cincinnati, April 10, 1984
11. Alexander FW, Clayton BE, Delves HT: Mineral and trace metal balances in children receiving normal and synthetic diets. *Q J Med* 1974;43:89–94
12. Ziegler EE, Edwards BB, Jensen RL: Absorption and retention of lead by infants. *Pediatr Res* 1978;12:29–34
13. Rourke BP, Bakker DJ, Fisk JL, et al: *Child Neuropsychology.* New York, Guilford Press, 1983
14. Stark AD, Meigs JW, Quah RF, et al: Family operational co-factors in the epidemiology of childhood lead poisoning. *Arch Environ Health* 1978;33:222–225
15. Stark AD, Quah RF, Meigs JW, et al.: Relationship of sociodemographic factors to blood lead concentrations in New Haven children. *J Epidemiol Community Health* 1982;36:133–139
16. Pueschel SM, Cullen SM, Howard R, et al: Pathogenetic considerations of pica in lead poisoning. *Int J Psychiatry Med* 1977–78;8:13–24
17. Hunt TJ, Hepner R, Seaton KW: Childhood lead poisoning and inadequate child care. *Am J Dis Child* 1982;136:538–542
18. Milar CR, Schroeder SR, Mushak P, et al: Contributions of the caregiving environment to increased lead burden of children. *Am J Mental Deficiency* 1980;84:339–344

19. Chisolm JJ Jr: Childhood lead intoxication: Diagnosis, management, and treatment. *Medical Times* 1970;98:92–106
20. Lourie R: Prevention of lead paint—or prevention of pica? *Pediatrics* 1971;48:490–491
21. Lin FU JS: Vulnerability of children to lead exposure and toxicity. *N Engl J Med* 1973;289:1224–1233
22. Madden NA, Russo DC, Cataldo MF: Environmental influences on mouthing in children with lead intoxication. *J Pediatr Psychol* 1980;5:207–216
23. Bornschein RL, Hammond PB, Dietrich KN, et al: The Cincinnati prospective study of low level lead exposure and its effects on child development. *Environ Res*, in press 1985
24. Morrell G, Giridhar G: Rapid micromethod for blood lead analysis by anodic stripping voltammetry. *Clin Chem* 1976;22:221–223
25. Caldwell BM, Bradley RH: *Administration Manual: Home Observation for Measurement of the Environment.* Little Rock, University of Arkansas at Little Rock, 1978 (manual available from authors)
26. Clark S, Succop PA, Bornschein RL, et al: Quality of housing as a determinant of environmental lead exposure and pediatric blood lead levels. Paper presented at the Second International Conference on Prospective Studies of Lead, Cincinnati, April 9, 1984
27. Center for Disease Control: Preventing lead poisoning in young children. *J Pediatr* 1978;93:709–720

PARENTS' RIGHT TO DECIDE

Dave and Debbie Bailey, a couple in Orange, Calif., were given 45 minutes to decide the fate of the 20-ounce infant that had just been born to them 16 weeks prematurely. Knowing that most such infants die eventually, and that half of the survivors suffer some handicap, they tearfully resolved to let nature take its course. But their doctor obtained a court order to continue treatment to keep the infant alive at any cost. As Andrew Malcolm of The Times reported, the hospital's ethics committee backed the doctor in every respect except allowing the parents to believe their choice would be decisive. . . .

No baboon heart could have been implanted in Baby Fae if her parents had denied consent. Why should not the Baileys have had the same veto over the rescue of their child? . . . Like Procrustes, who stretched or cut his guests to fit a single-size bed, public policy seems to accord all infants an absolute right to life, not just by divine will but by all conceivable medical heroics. Parents can be given too much choice, but none at all seems too little.

Submitted by Student

From Wade N: Procrustes' cradle. *The New York Times*, Nov 16, 1984.