A Pilot Study of Blood Lead Levels and Neurobehavioral Function in Children Living in Chennai, India

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The relationship between blood lead level and neurodevelopment was assessed in a pilot cross-sectional study of 74 4–14-year-old children in Chennai, India. Mean blood lead level was 11.1 µg/dL (2.5–38.3). The Binet–Kamath IQ test and the Wide Range Assessment of Visual Motor Activity (WRAVMA) were administered to 58 children. Teachers completed the Connor's Behavioral Rating Scale. Excluding two outliers, IQ and WRAVMA composite scores were inversely related to blood lead level, with an effect size of approximately 6 points decline for a 10-µg/dL increase in blood lead. Children in the highest and lowest blood lead quartiles had mean IQs of 95.6 ± 13.3 and 102.0 ± 22.5, respectively. Behavior ratings were not associated with blood lead level. Lead exposure is a significant problem among Indian children, with many having blood lead levels associated with increased neurodevelopmental risk. *Key words*: lead; neurobehavior; India.

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Many studies demonstrate that lead exposures that are not sufficient to produce clinical poisoning in children can, nevertheless, impair neurodevelopment. This can be manifested as reduced intelligence, poor school performance, and behavioral disorders.[1–3] The body of evidence is an internally consistent set of experimental studies in nonhuman species and observational epidemiologic studies conducted in many countries, including the United States, Great Britain, Germany, Italy, Greece, Australia, Mexico, Yugoslavia, New Zealand, Taiwan, and China.[4] Many countries have moved, on the basis of these data, to reduce population exposures to lead by reducing lead exposures in the workplace, by placing limits on the allowable limits of lead in gasoline, paint, solder, and other products, and by establishing standards for lead concentrations in environmental media such as air, water, and soils. In the United States, the blood lead level used as the screening-action guideline has declined steadily since the 1960s.[5] It is now 10 µg/dL, but might be decreased again in light of recent evidence.[6,7]

In India, lead has been used in industry and as a gasoline additive for many decades. Case reports and case series of lead poisoning have been published,[8,9] as have surveys of blood and tooth lead levels in hospital and clinic populations.[10–16] Epidemiologic studies of elevated blood lead levels in specific occupational groups such as jewelry workers,[17–19] traffic police,[20] and papier mache workers[21] have also been reported. Surveys of industrial workers, performed by the National Institute of Occupational Health, have demonstrated mean blood lead levels in excess of 40 µg/dL (the current U.S. OSHA standard) in iron foundry workers, glaze workers, type foundry workers, and battery plant workers.[22] Systematic surveys of the blood lead levels in non-occupational cohorts in India are relatively rare. Kaul[23] reported that 67% of children studied in Delhi and Jammu had blood lead levels exceeding 10 µg/dL, and 16.5% had values exceeding 20 µg/dL. In a cohort of pregnant women from Lucknow, Awasthi et al.[24] found a mean blood lead level of 14.3 µg/dL, with 19.2% of the women having blood lead levels higher than 20 µg/dL. In a survey of children from seven major cities in India, more than half of the 21,476 participants had blood lead levels that exceeded 10 µg/dL, and 14% had levels that exceeded 20 µg/dL.[25] Although lead-free gasoline was introduced in certain major Indian cities beginning in 1998,[26] lead exposure is likely to remain a problem because older vehicles continue to use leaded gasoline and because of the multimedia nature of lead sources and pathways.[4]

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The limited data available thus suggest that childhood lead exposure is a major public health problem in India. Nevertheless, no published study has investigated the neurodevelopmental morbidities associated with excess lead exposure in Indian children. While the numerous studies that have been conducted in other countries clearly point to the conclusion that lead exposure is likely to be having a substantial negative impact on the neurodevelopment of Indian children, it is possible that lead's impact in this setting is modified by specific genetic, dietary, and other host factors that are unique to India. Indeed, the modification of lead's effect on cognitive development by sociodemographic and cultural factors has been demonstrated.[27,28] We report the first epidemiologic study of the association between low-level lead exposure and neurodevelopment in a sample of Indian children.

METHODS

Study Sample

The study sample consisted of 74 children with a mean age of 6.7 years (SD 2.1; range 4–14) from a rural primary school on the outskirts of Chennai, a large city (formerly called Madras) in the province of Tamil Nadu in southeastern India. Demographic characteristics and sources/pathways of lead exposures were collected by parent questionnaire. The questions were written in English and administered in Tamil, the primary local dialect, by a research assistant fluent in both languages. The demographic items included form (grade in school), premature birth, medical problems at birth, birth order, early feeding, marital status of parents, socioeconomic status (Kuppuswamy Socio-economic status scale [urban]),[29] and parental smoking. The mean maternal age at the time of the study child's birth was 24 years. Most fathers (93%) and more than half the mothers (62%) had at least a middle-school education. The median family income was less than or equal to rupees 1,687–2,260 per month (equivalent to USD $36–48), corresponding to low/middle-class socioeconomic status (Table 1).

The questionnaire also included 17 questions pertaining to possible sources of lead exposure, such as vehicular traffic volume near the home, water storage vessels, cookware, house paint, nearby industries, occupational sources, alternative medicines, and cosmetics.

This study was approved by the human subjects protection committees of the Harvard School of Public Health in Boston and the Sri Ramachandra Medical College (SRMC) in Chennai.

Exposure Asssessment

Lead level in a venous blood sample was determined using two LeadCare ™ blood lead analyzers.

TABLE 1 Demographic Characteristics of Children in the Study ($n = 31$)

Average maternal age at child's birth	24.0 years
Proportion of families with father and mother living together	97%
Father's education level	7% primary school education 74% middle/intermediate school 16% high school 3% bachelor's degree
Mother's education level	19% illiterate 19% primary school education 52% middle/intermediate school 3% high school 7% bachelor's degree
Father's occupation	13% unskilled laborer 32% semiskilled 23% skilled 29% clerical 3% semi-professional
Mother's occupation	90% unemployed or homemaker 3% semiskilled 7% clerical
Family income (in rupees)	7 % Rs. 675-1125 26% Rs. 1125-1687 16% Rs. 1687-2260 42% Rs. 2260-4500 9% more than Rs. 4,500
Sex	25.8% female
Age	58.1% 4–7 years 38.7% 8–10 years 3.2% 11–14 years
Class (grade)	22.6% 1st standard 29% 2nd standard 25.8% 3rd standard 22.6% 4th standard
Birth order	35.5% firstborn

Outcome Assessment

The test battery included the Binet–Kamath Intelligence test, the Wide Range Assessment of Visual Motor Abilities (WRAVMA),[30] and the Connors Behavioral Rating Scale (administered to both a parent and a teacher).[31] The neurobehavioral tests were administered by trained research assistants from the Master of Philosophy in Clinical Psychology and MBBS (medical) programs of the SRMC, and by a visiting fourth-year medical student from Emory University (U.S.A.). The research assistants were blinded to the children's blood lead levels.

The Binet–Kamath Test of Intelligence, which has been adapted for use on the Indian subcontinent, was

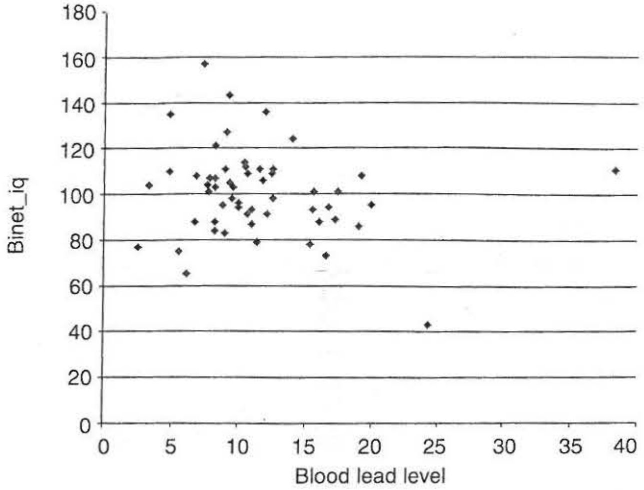

Figure 1—Scatterplot of IQs (Binet–Kamath test) and blood lead levels among all 54 children participating in a pilot study in Chennai, India.

administered in Tamil. A child's mental age (in months) was divided by his or her chronological age (in months) and multiplied by 100 to obtain the IQ score.

The WRAVMA includes three subtests, Drawing, Matching, and Pegboard. Brief instructions were given to the child in Tamil by the research assistant or by a teacher who had been trained to administer the tests. On the Drawing subtest, a child is asked to copy designs arranged developmentally in order of increasing difficulty. On the Matching subtest, the child is asked to match a target with one of four options that "goes best" with it. On the Pegboard subtest, the child is asked to place as many pegs as possible into a pegboard in 90 seconds. Scores on the three subtests are combined to derive a composite score for visual motor ability. All standardized scores are based upon U.S. population norms. No normative data for an Indian population could be identified.

The Connors' Behavioral Rating Scale (BRS), which was translated into Tamil by one of the bilingual research assistants, was completed by the teachers. One of the investigators (KB) reviewed the translation for accuracy. This scale consists of 39 questions, which yield scores for five aspects of a child's behavior: 1) Aggressivity, 2) Inattentiveness, 3) Anxiety, 4) Hyperactivity, and 5) Sociability. Each question is rated on a scale of 1–4, depending on whether the target behavior was present (1) not at all, (2) just a little, (3) quite a bit, and (4) very often. For each of the five subscales, scores for the pertinent questions were averaged to arrive at a mean BRS value for the child.

Statistical Methods

The blood lead levels of all 74 children were measured. Binet–Kamath IQ scores were available for 55 children, WRAVMA subtest scores for 55 children, Connors' BRS aggression and inattentiveness scores for 56 children, and Connors' BRS anxiety, hyperactivity, and sociability scores for 55 children. The associations between blood lead level and test scores were evaluated using linear regression. The coefficient for blood lead level represents the estimated change in test score for each 1-μg/dL increase in blood lead level. Parent questionnaire data on potential confounders were available for only 31 children, which limited our ability to construct multivariate models. To assess the extent to which the unadjusted estimates of the associations between blood lead levels and neurobehavioral test scores were confounded by other factors, we constructed a series of models that included blood lead level and one potential confounder at a time. The factors considered were maternal age, maternal education (illiterate or primary versus middle, intermediate, high school, or college), paternal education (primary or middle versus intermediate, high school, or college), average monthly income of family (less than 2,260 rupees versus more than 2260 rupees), sex, age, grade (1 or 2 versus 3 or 4), birth order (first-born versus later-born), and early feeding method (breast-only versus breast and bottle). These analyses were viewed not as definitive but as providing a sense of the confidence that can be placed in the unadjusted coefficients for blood lead level in relation to neurobehavioral test scores.

Two children were identified as outliers. One had a blood lead level of 38.3 μg/dL, more than 10 μg/dL higher than the next-highest level, and an IQ score of 111. The other child had a blood lead level of 25 μg/dL and an IQ score of 43. This IQ score was 20 points lower than the next lowest score. These two observations exerted inordinate influence on the results of the regression analyses. We therefore report analyses in which these children were both included and both excluded.

RESULTS

Blood Lead Levels

The children's blood lead levels ranged from 2.5 to 38.3 μg/dL, with a mean (SD) of 11.1 (5.6). All children but two had levels below 25 μg/dL.

Neurobehavioral Outcomes

Binet–Kamath IQ. The mean (SD) IQ scores including and excluding the two outliers were 100.4 (19.2) and 101.2 (17.8), respectively. Figure 1 is a scatterplot of blood lead level and IQ score, including all 54 children. The two outliers are evident. Figure 2 presents the scatterplot and least-squares linear regression line, excluding the two outliers. The crude coefficient for blood lead was –0.62 (95% CI = 1.84–0.59); $p = 0.31$). Adjusted for the potential confounders one at a time, the coefficients ranged from –1.10 (95% CI = –2.63–0.44; $p = 0.16$), adjusting for maternal age, to –0.47 (95% CI = –1.70–0.76; $p = 0.21$), adjusting for paternal education. The blood lead coefficient retained a negative sign when adjusted for all covariates, with a median value of –0.76. The mean (SD) IQ of children with blood lead levels in the highest quartile was 95.6 ± 13.3, compared with a score of 102.0 ± 22.5 for children with blood lead levels in the lowest quartile.

WRAVMA. The mean (SD) scores on the Drawing subtest including and excluding the two outliers were 109.3 (19.3) (16.1) and 109.6 (19.2), respectively. The crude coefficient for blood lead was –0.44 (95% CI = –1.76–0.88; $p = 0.51$). With adjustment for confounders, it ranged from –1.18 (95% CI = –2.7–0.34; $p = 0.12$) to –0.32 (95% CI = –1.64–0.99; $p = 0.62$). The median adjusted coefficient was –0.88.

The mean (SD) scores on the Matching subtest including and excluding the two outliers were 83.5 (16.1) and 83.7 (15.1), respectively. The crude coefficient for blood lead was –0.95 (95% CI= –1.96–0.06; $p = 0.06$). With adjustment for confounders, it ranged from –1.32 (95% CI = –2.68–0.04; $p = 0.06$) to –0.84 (95% CI = –1.84–0.15; $p = 0.09$). The median adjusted coefficient was –1.18.

The mean (SD) scores on the Pegboard subtest including and excluding the two outliers were 107.7 (15.1) and 101.1 (14.2), respectively. The crude coefficient for blood lead was –0.83 (95% CI = –1.78–0.12; $p = 0.09$). With adjustment for confounders, it ranged from –0.99 (95% CI = –2.22–0.25; $p = 0.11$; $p = 0.11$) to –0.68 (–2.00––0.63; $p = 0.29$). The median adjusted coefficient was –0.89.

The mean (SD) Visual Motor Composite scores including and excluding the two outliers were 99.3 (18.7) and 99.7 (17.6), respectively. The crude coefficient for blood lead was –0.91 (95% CI = –2.12–0.30; $p = 0.14$). It ranged, after adjustment, from –1.52 (95% CI = –2.89––0.14; $p = 0.03$) to –0.80 (95% CI = –1.98–0.51; $p = 0.18$). The sign of the blood lead coefficient remained negative with adjustment for all covariates. The median adjusted coefficient was –1.34. The mean (SD) Visual Motor Composite score of children with blood lead levels in the highest blood lead quartile was 94.1 ± 18.8, compared with 102.9 ± 18.3 for children in the lowest blood lead quartile.

Connors' Rating Scale. Blood lead level was not significantly associated with any of the scores yielded by the BRS.

Analyses Including the Two Outliers

For the Binet–Kamath instrument, the crude coefficient was –0.58 (95% CI = –1.48–0.33; $p = 0.21$). For the Drawing subtest of the WRAVMA, the blood lead coefficient was –0.22 (95% CI = –1.14–0.71; $p = 0.64$). For the Matching subtest, the crude coefficient for blood lead was –0.38 (95% CI = –1.14–0.39; $p = 0.33$). For the Pegboard subtest, the crude coefficient for blood lead was –0.41 (95% CI = –1.13–0.30; $p = 0.25$). For the WRAVMA Composite score, the crude coefficient for blood lead was –0.39 (95% CI = –1.29–0.52; $p = 0.39$).

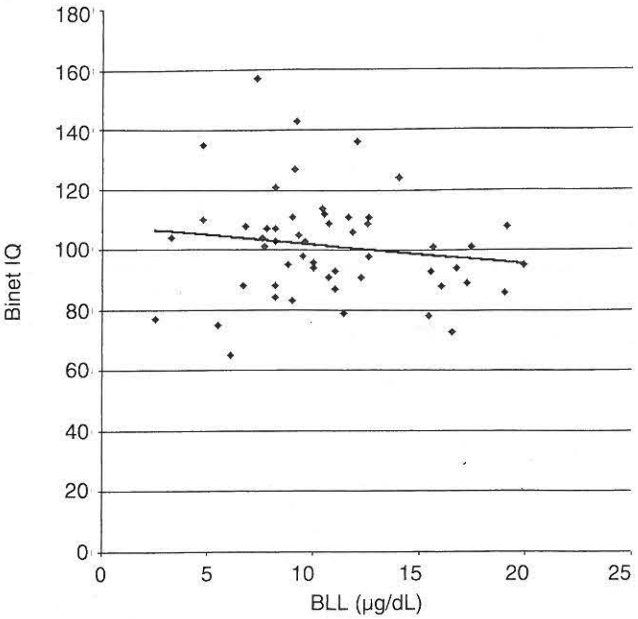

Figure 2—Scatterplot of IQs (Binet–Kamath test) and blood lead levels, excluding two children who were outliers. One child had a blood lead level of 38.3 μg/dL, and the other child had an IQ of 43. The best-fit linear regression line is shown.

DISCUSSION

The high prevalence in our study sample of blood lead levels that are considered in many parts of the world to be elevated confirms previous studies suggesting that chronic low-level lead exposure in children is a potentially significant public health problem in India.[23,25] Indeed, half of the children in our sample had blood lead levels above 10 μg/dL, an observation that is all the more striking in light of the fact that the mean age of the children was more than 6 years, well beyond the range of 18–30 months in which the blood lead levels of children in other countries typically peak.[32,33] Moreover, the children were recruited from a school located in an outer suburb of Chennai, and presumably were exposed to less lead from vehicular sources than they would have been had they attended a school in the inner city. Our study extends the literature on lead poisoning in Indian children by demonstrating that performance on neurodevelopmental tests was inversely related to blood lead levels over the range of 2.5–20 μg/dL (upper bound of range excluding the two outliers). The children with higher blood lead levels achieved significantly lower IQ scores, replicating the findings of many international studies.[34] Although the regression coefficients for blood lead, adjusting for potential confounders one at a time, generally did not reach statistical significance, the median coefficient, a decline of 7 to 8 IQ points per 10-µg/dL increase in blood lead, is similar in size to the coefficients observed in some studies,[6,35,36] and larger than those observed in others.[37,38] Had our sample been only slightly larger, a decline of this size would have been statistically significant. Blood lead level was also inversely related to children's visual–motor scores. This latter finding is also similar to those reported in other studies.[39-42]

Our findings in this pilot study must be interpreted in light of several limitations. First, because it was a cross-sectional study, we cannot be certain of the causal direction of the associations observed. However, the large body of experimental animal and prospective human studies demonstrating similar associations renders plausible the inference that the children's exposures to lead preceded the onset of their neurodevelopmental impairments

Second, the limited data we had on the children's lead exposure histories do not enable us to identify the lead dose necessary to produce neurodevelopmental impairments. As noted above, the children's blood lead levels measured at the time of study enrollment might underestimate the blood lead levels they experienced in their first few postnatal years, when children's vulnerability to lead is usually assumed to be greater. Unless these children maintained their rank order in terms of blood lead level between the particularly sensitive time in infancy and the time that they contributed a blood sample for our study, the concurrent blood lead levels might be poorly correlated with these past exposure levels, introducing exposure misclassification. Such nondifferential misclassification would likely bias the associations between blood lead level and neurobehavioral scores towards the null. On the other hand, some recent data provide reason to doubt that it is only blood lead levels in the early years that are most predictive of children's later neurobehavioral performances.[6,38,43] Nevertheless, our study can support only weak inferences about quantitative aspects of the pertinent dose–effect relationships, specifically the minimum blood lead level at which a decrement in neurobehavioral scores can be detected.

Third, the poor parental response in filling out the parental questionnaire assessing demographics and potential covariates limited our ability to adjust the associations between blood lead level and neurobehavioral scores for potential confounding. Adjusting, one at a time, for the potential confounders we measured provided little evidence that the crude estimates were biased. Nevertheless, some potentially important confounders, such as parent IQ, were not measured. Furthermore, it is possible that our strategy of adjusting for covariates one at a time left residual confounding and that the coefficients for blood lead level would have decreased more had we been able to adjust simultaneously for multiple potential confounders.

Fourth, two of the outcome measures, the WRAVMA and Connor's Behavioral Rating Scale, have been normed only on U.S. population norms. While the mean scores thus might not provide valid estimates of the skills of Indian children in these domains, the standard deviations were approximately the same as in the U.S. standardization sample. This dispersion in the scores thus provided the variability needed for the evaluations of the study hypotheses to be internally valid.

On the basis of these pilot results, we are initiating a study in Chennai in which we will enroll 750 children aged 4 to 6 years, conduct more comprehensive assessments of neurobehavioral function, and measure more potential confounders, such as parental IQ, quality of the home environment, and nutritional status. We will also evaluate whether certain genetic polymorphisms, such as those for aminolevulinic acid dehydratase, the C282Y/H63D hemochromatosis genes, and the apoE4 gene, alter a child's vulnerability to lead-associated neurobehavioral dysfunction.

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