

Blood Lead Levels in South African Inner-City Children

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Little is known about childhood lead absorption in South Africa. In this study a cross-sectional analytic survey was carried out to determine the blood lead levels and associated risk factors for inner-city, first-grade schoolchildren. Blood lead analyses, hematological and anthropometric measurements were conducted, and a pretested questionnaire was administered to parents to identify risk factors for lead exposure. In a detailed environmental study, daily air and dust samples were collected over a period of 1 year from several sites in the study area, contemporaneously with the blood and questionnaire surveys. Spatial and temporal variations in atmospheric lead were determined.

It was found that 13% of mixed race children, but no white children, had blood lead levels $\geq 25 \mu\text{g/dL}$, the U.S. action level. Air lead levels averaged around $1 \mu\text{g/m}^3$, and dust lead levels ranged from 410 to 3620 ppm. Environmental lead levels were significantly elevated near heavy traffic, where Environmental Protection Agency standards were exceeded mainly during winter months. Baseline exposure was of significance in influencing blood lead levels of children attending schools in direct proximity to heavy traffic, where blood lead levels were elevated irrespective of other influencing factors. Primary and secondary preventive measures are urgently needed in South Africa to reduce environmental lead exposure. At the time of the study, South Africa had one of the highest levels of lead in gasoline in the Western World, namely, 0.836 g/L. Although levels have subsequently been reduced, this is typical of the situation in many African countries today.

Introduction

There has been increasing worldwide concern about low-level lead exposure and its effects on young children. Longitudinal studies in the 1980s have shown that exposure to lead during the early stages of a child's development is linked to reduced gestational age, lowered birth weight, and deficits in later neurobehavioral performance (1). Due to the multifactorial nature of lead exposure, the evaluation of the relative importance of individual sources is very complex and likely to differ from one area to another and in different population groups.

Although there have been numerous studies on childhood lead absorption and associated risk factors worldwide, little is known about the extent of lead absorption in the South African population at large or among children. Preliminary zinc-protoporphyrin screening studies carried out among children in Cape Town have indicated that people living in certain inner city areas may be at risk of increased lead exposure (2). Blood lead levels of 6- to 8-year-old children attending one school in the area (Woodstock)

averaged around $22 \mu\text{g/dL}$, with 17% of children having blood lead levels $\geq 30 \mu\text{g/dL}$. There was also evidence of biochemical and behavioral abnormalities in children with raised blood lead levels (3).

This study was carried out in order to determine the blood lead distribution of first-grade schoolchildren living in the inner-city area of Woodstock. It was decided also to determine concentration levels and sources of variation in environmental lead in the area and to identify risk factors associated with increased blood lead concentrations of children.

Methods

Study Area and Study Population

Woodstock is an urban-residential area located in Cape Town's inner city. It comprises a variety of residential, commercial, and light-industrial land uses, situated some 3 to 5 km east of Cape Town's central business district. The major transport routes in the area comprise two highways and two heavily traveled through roads. Most traffic to and from the central business district passes through Woodstock.

Woodstock is a racially mixed area, one of the only "grey" areas in South Africa which has managed to stay open in spite of the Group Areas Act, which segregates residential areas in South Africa along racial and ethnic lines. In this respect the area is unique in South Africa. The area comprises predominantly mixed race and white groups, and while it is primarily a working class suburb, extremes of wealth exist, and the community is diverse

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with respect to culture and religion.

The study population comprised all first-grade children who lived and attended school in the study area. The entire study population (200 children) was included in the survey.

Blood Measurements

Following parental permission, given by 90% of children's parents, 5 mL blood was obtained by venipuncture from each child who was present at school on the day of the study. Four milliliters was stored in tubes containing heparin anticoagulant for blood lead analyses; a further 1-mL blood sample was stored in tubes containing EDTA anticoagulant for full blood count determinations.

Blood samples were prepared and analyzed for lead in the standard way by the Red Cross Children's Hospital, Cape Town. Lead in blood samples was concentrated by chelation with ammonium pyrrolidine dithiocarbamate and extracted into methyl isobutyl ketone (MIBK). Following centrifugation, an atomic absorption spectrophotometer (Beckman 1272, M Model) was used to perform lead analyses.

Samples for quality control purposes were measured by the State Chemistry Laboratory, Cape Town. Both these laboratories participate in the National Quality Control Scheme. For both intra- and interlaboratory variations, the mean difference, ± 2 SD was within 5% of the mean value. In addition, there was no evidence of a systematic error; i.e., the difference between duplicate values was not related to the mean of the duplicate value.

Other hematological tests such as the determination of hemoglobin and hematocrit levels were performed using a Coulter counter model S.

Anthropometric Measurements

In order to obtain an objective measure of anthropometric status, height and weight measurements were performed on all children who underwent blood lead tests. Standard procedures recommended by the World Health Organization for measurements of children aged 6 to 10 years, were used for all anthropometric measurements (4).

Questionnaire Data

A pretested questionnaire covering a broad range of items relating to sources and mechanisms of exposure, sociodemographic factors, as well as medical factors, was administered to children's parents.

Environmental Lead Measurements

Atmospheric Lead. A comprehensive environmental monitoring program was instituted to examine spatial and temporal variations in lead. Three zones bounded by major highways or through roads were distinguished in the study area, and air monitors were placed in zones at sites thought to be representative of community exposure in the area (Fig. 1). Monitors were placed approximately equidistant (200 to 300 m) from the boundary roads in each of the three zones, and in addition, two air monitors were placed directly on major through roads with high density traffic.

Sampling points were at a height of 1.5 to 2 m from the curb. Samples were also obtained at certain schools for a limited monitoring period of 3 weeks. The sampling interval was generally 24 hr.

Suspended particulates were precipitated on cellulose membrane Millipore filters, 37 mm in diameter, with a pore size of 0.45 μm . Samples were taken at a flow rate of 1.5 to 2 L/min, yielding a total air volume of approximately 2 m³ per sample. In all, around 2000 air lead samples were obtained during the 1-year period of study.

Samples were prepared by hot acid digestion with 5 mL concentrated nitric acid and perhydrol, and a Perkin-Elmer model 5000 atomic absorption spectrophotometer was used to perform lead analyses.

For quality control purposes, a series of filter paper samples representing a range of different lead concentrations was cut into sections and analyzed by two different laboratories at the University of Cape Town and the Council for Scientific and Industrial Research (CSIR). Results revealed that differences between the two laboratories were within experimental error.

The preparation and analyses of all samples were performed without the analyst having prior knowledge of the nature of the site from where the sample was collected. Samples were analyzed in a random order, without regard to site or day of collection.

Dust Lead Measurements. Dust samples were collected from each of the air monitoring sites in the study area. Samples were obtained at 2-month intervals by vacuuming street pavements with a modified portable car vacuum cleaner. Collection procedures were pretested and standardized prior to the commencement of formal sampling. In order to avoid exposure to rain and redistribution by wind, dust sampling took place on relatively calm days after at least 2 days of dry weather. Samples were prepared by hot acid digestion with concentrated nitric acid and analyzed using a Varian atomic absorption spectrophotometer.

Traffic Volumes

Traffic counts were taken over a period of 2 weeks at each site using portable, automated traffic counters.

Statistical Analyses

Questionnaire Data. Bivariate analyses were carried out to examine the relationship between individual variables and blood lead concentrations, hematological parameters, or nutritional status. For the discrete variables, if the distribution of blood lead levels and other parameters was approximately normal for the two or more categories of the variable, a t-test or one-way analysis of variance was performed. If the distribution of blood lead levels was skewed, but the variances for the categories were not significantly different, a Mann-Whitney U-test or a Kruskal-Wallis test was performed. If the variances were significantly different, a median test was performed. To test for correlations between continuous variables and the various parameters, Pearson and Spearman correlation coefficients were determined. Multivariate analyses on certain of the questionnaire data were also carried out. A series of multi-way contingency tables were formed and log linear models used to analyze them.

Environmental Data. As air lead levels were not normally distributed, log transformations of the variable air lead were

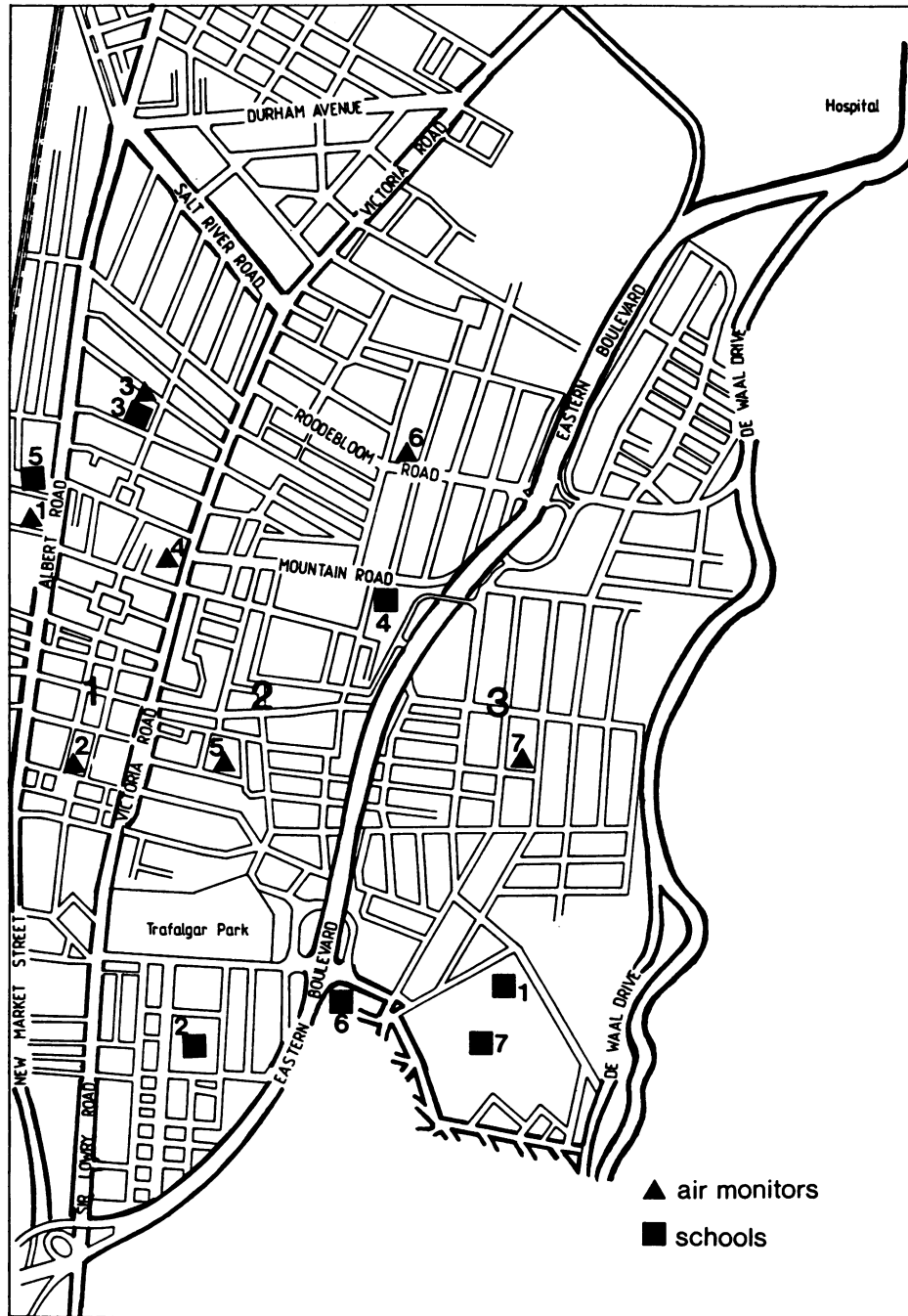


FIGURE 1. Location of air monitors and schools in the study area.

performed to achieve normalization. One- and two-way analyses of variance techniques were used to test for differences between sites, seasons, days of the week, and interaction effects. A Kruskal-Wallis test was used to test for differences in dust lead concentrations between sites. Kendall and Spearman rank correlation coefficients were calculated to test for correlations between air lead concentrations, dust lead concentrations, and traffic density.

Results

The shape of the blood lead distribution curve approximated that of a bimodal distribution, with peaks at 10 and 16 $\mu\text{g}/\text{dL}$. After stratifying by ethnic group, it was evident that a marked difference existed in the blood lead concentrations of the two groups (Fig. 2). Each group's blood lead distribution was approximately normally distributed, with the white population having a mean of 12 $\mu\text{g}/\text{dL}$ and the mixed race population having a mean of

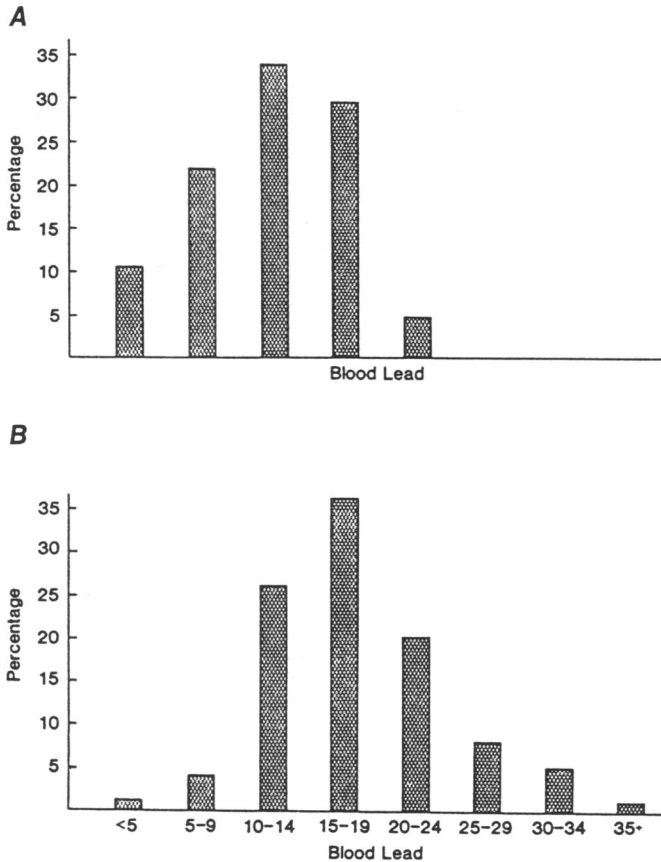


FIGURE 2. Blood lead concentration (microgram per deciliter) of (A) white pupils and (B) mixed race pupils.

18 µg/dL ($p = 0.0001$). Among the mixed race pupils, 13% had blood lead levels greater than or equal to 25 µg/dL, the U.S. action level (5). No white pupils had blood lead levels in this range. No significant differences in blood lead concentration were found with respect to gender or age.

Blood Lead Concentration by School and Residential Zone

As can be seen from Figure 3, considerable variation in the blood lead concentrations of pupils existed between schools. The variation in blood lead levels between schools was statistically highly significant ($p = 0.0001$). Among the mixed race schools, the median blood lead levels at schools 2, 5, and 6 were 18, 21, and 20 µg/dL, respectively; these were higher than at schools 1 and 7, which had median blood lead levels of 13 µg/dL. Among the white population, the median blood lead level at school 3 was 8 µg/dL; this was considerably lower than at school 4, which was 13 µg/dL; this difference was statistically significant ($p = 0.0004$). Further analyses revealed that the blood lead levels of mixed race children resident in zone 3 differed from those resident in zones 1 and 2. The median blood lead level in zone 3 was 13 µg/dL, while children resident in zone 1 and 2 had a median blood lead level of 18 µg/dL (refer to Fig. 1 for position of schools and zones).

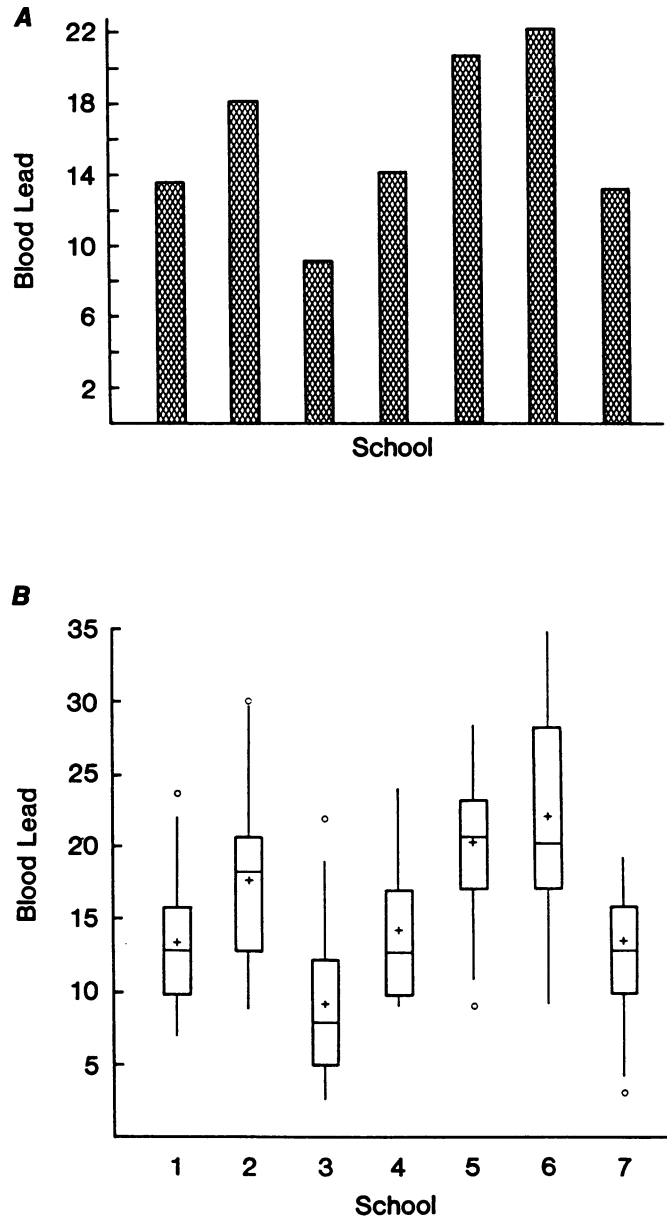


FIGURE 3. Blood lead concentrations (microgram per deciliter) by school. (A) Bar graph, (B) box plot.

Questionnaire Data

The overall response rate for the questionnaire was 80% for the mixed race group and 63% for the white group. No statistically significant difference in the blood lead concentrations of the respondents versus the nonrespondents were found among the white or mixed race populations. White subjects differed from mixed race subjects with respect to several sociodemographic, cultural, and economic factors. For instance, while both mixed race and white subjects in the area are predominantly working class, the annual mean income level among mixed race subjects was substantially lower than among whites. Whites were also better educated and lived in larger homes with smaller families. While small differences in nutritional status and other

hematological factors were also noted among the groups, these were minor and not clinically significant.

Among mixed race pupils, the two exposure variables with the smallest *p*-values, school and residential area, were entered into a multiway contingency table with the variable socioeconomic status to examine the partial association between these variables. The partial association between blood lead level and school was significant, taking into account the effects of residential area and socioeconomic status. From Figure 1 it can be seen that schools 5 and 6 were situated in direct proximity to high density traffic. Similarly, among white pupils, school 4 was situated in direct proximity to the highway.

Environmental Lead

Annual air lead means at sites varied 3-fold from less than 0.5 to above 2 $\mu\text{g}/\text{m}^3$. The average lead concentration (all sites together) for the study area as a whole was 1.1 $\mu\text{g}/\text{m}^3$. Air lead concentration at sites directly on major roads was significantly higher than at other sites. For example, average lead concentrations were approximately 2-fold higher at sites 1, 4, and 6 situated on major roads than at sites 2, 3, 5, and 7, situated 200 to 300 m away from major roads (Table 1).

There was also considerable temporal variation in air lead levels, with levels increasing significantly during the winter (when blood sampling took place), when they were on average twice as high (Fig. 4). A statistically significant relationship at the 5% level existed between air lead levels and traffic volumes ($r = 0.9429$) (Table 2). Results of the 3-week monitoring periods at the mixed race schools revealed that air lead levels at schools 5 and 6 (situated in the immediate proximity of high density traffic) were higher than at schools situated away from traffic.

Differences in lead concentrations in dust samples also existed within and between sites. For instance, dust lead concentrations varied from 410 to 3620 ppm at the various sites. Mean dust lead concentrations were considerably higher at sites on major roads compared with sites away from major roads. A correlation existed between dust lead and air lead concentrations, which was statistically significant at the 5% significance level ($r = 0.8857$) (Table 2).

Discussion

Although much variation in blood lead levels occurs in various parts of the world (and it is difficult to make direct comparisons), it would appear that the blood lead levels of these inner-city children are more comparable to those of American (6) and Australian children (7), than, for example, British (8) or Scandinavian children (9), where blood lead levels are considerably lower. Virtually no information exists on blood lead levels in inner-city children from other parts of Africa, but the blood lead levels of these children were found to be significantly higher

Table 1. Annual air lead concentration at sites on and away from major roads.

	Sites on major roads (1,4,6)	Sites away from major roads (2,3,5,7)
Mean, $\mu\text{g}/\text{m}^3$	1.5	0.8
Standard deviation, $\mu\text{g}/\text{m}^3$	1.3	0.8
Median, $\mu\text{g}/\text{m}^3$	1.2	0.5

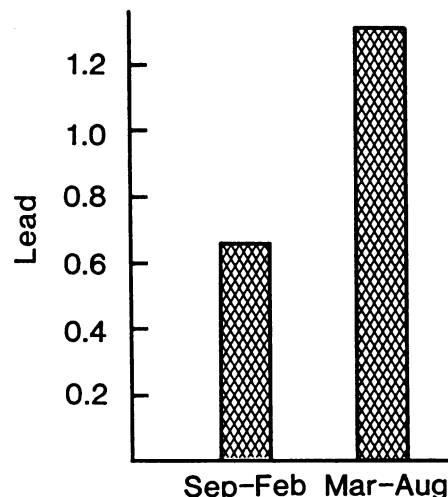


FIGURE 4. Six-month air lead concentrations (microgram per cubic meter) for all sites combined.

Table 2. Mean dust lead, air lead, and traffic levels at sites.

Site	Dust lead, ppm	Air lead, $\mu\text{g}/\text{m}^3$	Traffic, cars/day
1	2,900	1.3	17,675
3	790	0.9	907
4	3,620	2.1	> 20,000
5	2,580	0.7	241
6	3,250	1.3	7,752
7	410	0.4	260

than those of children aged 6 to 8 years, living in a semi-rural area of South Africa, which averaged around 11 $\mu\text{g}/\text{dL}$ (2).

This study showed that considerable intra-urban variations in blood lead levels exist. Differences in blood lead levels between ethnic groups were demonstrated and have also been reported from the U.S. (6), but are not as apparent in the U.K. (10). Differences in overall socioeconomic status are likely to be important factors differentiating the blood lead distributions of the two groups. Social factors may interact with environmental factors and cause socially disadvantaged groups to be at increased risk of lead exposure. While small differences in nutritional status and other hematological factors were noted between the groups, these were minor (not of clinical significance) and unlikely to have been of overriding significance in influencing blood lead concentrations. Other unmeasured biological parameters may, however, be significant.

Much controversy has existed about the role of gasoline-derived lead in contributing to the body lead burden. Elucidating its influence on blood lead has proved very difficult. The strong association demonstrated here between blood lead levels and the geographic position of schools with respect to traffic density was striking. It was evident that both white and mixed race pupils attending schools in the immediate proximity of heavy traffic had blood lead levels 5 to 7 $\mu\text{g}/\text{dL}$ higher than children attending schools away from traffic. As indicated, there remained a statistically significant association between blood lead levels and schools when socioeconomic factors and other confounders were taken into account. No significant difference in overall nutritional status was found between schools, which could explain the

observed phenomena. There were also no differences at schools with respect to flaking paint (all the classrooms were in a state of good repair). Baseline exposure in the environment is therefore likely to have been of considerable significance in influencing blood lead levels of children attending schools in direct proximity to traffic.

With respect to environmental lead measurements, it was interesting to note that considerable variation may occur on a microscale within an urban area of only 2 km² in size. In general, air and dust lead levels were significantly elevated at sites situated on major roads. At such sites, the U.S. EPA 3-month standard of 1.5 µg/m³ was exceeded, mainly in winter months. In the U.S. and U.K. nearly all urban sites report averages below 1 µg/m³ (8,11). Concentrations of lead in street dust are typically in the range 500 to 5000 ppm (8), similar to those reported in this study.

There is a wealth of published data on the relationship between environmental lead (particularly air lead) and blood lead, but much of it is difficult to interpret due to methodological weaknesses such as lack of representativeness of air lead *vis a vis* human exposure situations. The results of this study underscore the need for detailed knowledge of spatial and temporal variations in air lead levels, which has considerable implications for air monitoring strategies and epidemiological studies concerned with the relationship of exposure to environmental lead and the impact on human populations.

In a recent major review of the relationship between air lead and blood lead levels, the EPA concluded that differences of up to 2 µg/dL may occur for every 1 µg/m³ increase in air lead concentration in children (12). Brunekreef estimated that an increase of around 3 to 5 µg/dL for every 1 µg/m³ of air lead occurred (13), but the majority of studies he reviewed did not control for confounding factors such as socioeconomic status. Duggan has estimated that blood lead levels in children may rise by as much as 5 µg/dL for every 1000 ppm lead in dust (14).

It is thus probable that both direct inhalation of aerosols and, more importantly, indirect ingestion of lead-rich dust would have contributed to children's blood lead levels in this study. At the time of this study, South Africa had one of the highest levels of lead in gasoline in the Western World (0.836 g/L). Subsequent to this study, levels were lowered progressively to the current 0.4 g/L.

In the light of recent evidence linking lead at increasingly lower blood lead levels (around 15 µg/dL) to deficits in children's neurobehavioral performance (1,15), primary and secondary preventive measures are urgently needed in South Africa. Better control of an all-pervasive source such as lead in gasoline would provide a larger margin of safety for those sections of the

population unduly exposed. At the same time, control of other sources such as lead in paint (there is no national legislation), canned foods, and drinking water is also needed. Secondary preventive strategies to identify high risk children should also be implemented. With the balance of risk to health tipped in favor of significant adverse effects in infants and young children at low exposure levels, vigilant control of lead is needed in South Africa.

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