Our children in day care: reducing exposure to environmental lead at day care centres

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We have characterized the exposure of 5-year-old pre-school children, in two areas of Pretoria, to lead in air and surface soil. The study was conducted at 30 pre-schools in Soshanguve and 24 in Pretoria East during July 2001. Exposure to lead in air, lead concentrations in surface soil and dust, and risk factors associated with inhalation exposure to the metal were determined by means of questionnaires, time– activity diaries, and lead concentrations in air, soil and surface dust. Pre-schools in Soshanguve had smaller playgrounds than in Pretoria East (382 vs 889 m^2 outdoors and 28 vs 70 m^2 indoors), had lower outdoor lead concentrations associated with total suspended particles (0.098 vs 0.145 $\mu g/m^3$), experienced higher lead loadings of indoor dust (173 vs 64 $\mu g/m^2$) and of outdoor soil (17.7 vs 6.9 $\mu g/g$), and were more often located adjacent to untarred roads. Pre-schools in Pretoria East were more often situated next to busy roads and were exposed to higher traffic volumes (421 vs 66 vehicles/hour). Mean air lead concentration indoors was lower than outdoors (0.08 vs 0.1 $\mu g/m^3$). Children in Soshanguve spent more time indoors (5.6 vs 5.2 hours/day). We recommend that cleaning practices at schools should not use appliances that disperse dust, to minimize the resuspension of lead contained in surface dust. Pre-schools should be sited away from busy or steeply sloping roads, where motor vehicle emissions are enhanced. Traffic volumes on roads close to where pre-schools are planned should be monitored in advance. If a school is adjacent to a source of lead pollution, the time children spend outdoors should be carefully limited.

Introduction

During day-to-day activities, everyone comes into contact with environmental pollutants through breathing air, drinking water, consuming food and encounters with soil or dust.[1,2] Lead is probably the best-known and most-studied of pollutants to which exposure occurs via multiple pathways. Environmental sources of lead include smelters, uncontrolled as well as controlled burning of solid waste, the combustion of biomass for cooking purposes, the incineration of refuse, and motor vehicle emissions.[3,4] Although falling in many developed countries, lead exposure remains a major public health issue in cities and industrialized areas in developing countries.[5] It is estimated that about 80–90% of lead in urban air in these areas is derived from leaded petrol.[6] Indeed, there is a relationship between traffic volume, proximity to highways, engine acceleration, wind direction and the amount of lead in the air.[4,7–9]

Children constitute one of the most sensitive groups in the population to environmental pollution exposure because of their particular stage of development, their exertion levels and consequently their relatively high metabolic rates.[10–12] Children's particular behaviour and the way they interact with the environment also influences the magnitude of their exposure to contaminants such as lead.[13] Crawling and exploring their surroundings with their mouth predisposes young children to a much higher intake of pollutants in dust. In addition, the very young may be at higher risk of exposure to environmental pollutants because of the specific micro-environments in which they are cared for. Exposure at facilities such as day care centres can be very different from their home environment. These sites may be near highways or on old industrial sites, as these tend to be cheaper to occupy than safer, residential sites. The highest average blood lead levels in children have been found in 5-year-olds because they tend to play for long periods in contaminated surroundings.[8] Health effects associated with children's exposure to lead include reduced intelligence, behavioural effects such as hyperactivity, inability to concentrate, poor school performance and anaemia.[14]

The data available on children's activities in South Africa are insufficient to allow adequate estimation of exposure to environmental contaminants. As a result, standardized exposure measures developed by the U.S. Environmental Protection Agency (EPA) are the only means to hand for conducting exposure assessments.[15] Given the differences in socio-economic circumstances as well as in climatic conditions between South Africa and the United States, the development of locally derived exposure estimates is necessary to increase the accuracy of estimates of environmental exposure in South Africa.

The study reported here was conducted to characterize the exposure of 5-year-old children attending pre-school facilities in Pretoria to lead in soil and air, in a first effort to devise local measures of exposure. The study also aimed to provide specific recommendations for the siting of future pre-school facilities and for potential future research aimed at deriving locally appropriate estimates of lead exposure in children.

Methods

A cross-sectional study was conducted which included 216 children in 30 pre-school facilities in Soshanguve, representing a lower socio-economic area, and in 24 establishments in Pretoria East, representing a higher socio-economic area. The study was conducted during July 2001.

Sample selection

A list of pre-schools in Soshanguve and in Pretoria East was prepared from information obtained from the departments of Welfare and of Health, the Society for Pre-School Education and Care, and the Northern Pretoria Metropolitan Substructure. For Pretoria East, the telephone directory was used as an additional source of information. Furthermore, all schools identified in this manner were asked to scrutinize this list for completeness and to add names of existing pre-schools that were not included in the list. Pre-schools were eligible for inclusion in this study if they admitted 5-year-olds, if there were at least 20 children in total with four or more aged 5 years, and if they operated for at least 8 hours per working day. Schools that operated as 'after-school care' or 'mornings-only' facilities were excluded. A sample of 30 pre-schools from each area was aimed for.

In Soshanguve, a total of 168 (formal and informal) pre-schools were identified, from which 38 were randomly selected. For most, no contact details were available, and it was often not possible to determine eligibility for inclusion in the study without a site visit. Of the first 38 schools selected, six no longer existed, five could not be found, and nine did not fit the selection criteria, leaving 18 establish-

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ments from this first sample list. A second random sample of 22 pre-schools was subsequently drawn from the overall list. Of these, 10 did not fit the selection criteria, leaving 12 to be included for a total sample in Soshanguve of 30 pre-schools, all of which agreed to participate. In Pretoria East, it was often possible to contact pre-schools by telephone before a site visit to decide whether they matched the inclusion criteria. We attempted to contact all 63 known pre-schools within the borders of the study area in the first round. Of these, 36 were excluded: 13 because they could not be traced, 15 did not fit the inclusion criteria, and eight declined to participate in the study. After the final selection of 27 schools, two withdrew without reason and one was found to be too small on a first visit. Only 24 pre-schools eventually participated in the study, giving a response rate in Pretoria East of 71%.

The pre-schools were the unit of sampling for the measurement of environmental lead, whereas individual children selected in the second phase of the investigation were the unit of sampling for assessment of activity patterns. Four children were selected randomly at each school to accommodate the time needed by field workers to observe each child. Children were included if they were aged 5 and did not have an apparent physical disability that could inhibit him or her from normal movement as judged by the teacher. If the class teacher considered that a child had an acute disease on the day of the survey that could hamper his or her mobility, then this child was also excluded. Children who attended the pre-school for less than 6 hours a day were also excluded. In total, 216 children were chosen in the two areas: 120 in Soshanguve and 96 in Pretoria East.

Measurements to estimate environmental lead exposure

We did not measure biological levels of lead but evaluated exposure potential as a proxy indicator for actual lead uptake. A combination of 'time–activity patterns' and micro-environmental lead concentration data was then used to approximate inhalation exposure of children to lead in air. Lead concentrations in soil were used as a proxy for soil ingestion.

Time–activity diaries. Time–activity diaries were kept for each child monitored, to determine activity levels and periods spent by children in different settings. Each child was assigned a different coloured badge to simplify the observation process. Personal information about the child was requested from the teacher. The time–activity diary was subsequently completed during the day, indicating location and type of activity for every 15-min period of observation.

Questionaires. A questionnaire was developed to collect information on factors associated with exposure at pre-school facilities, as well as information that could help to distinguish exposure-related differences between the two study areas and between the various pre-school facilities. Field workers interviewed the principal or teacher in charge and, where possible, one other member of staff.

Lead concentrations in air, soil, and surface dust. Total suspended particulate matter (TSP) was monitored indoors and outdoors, using battery-operated Gil Air Constant Flow Air personal samplers (Gilian® Instrument Corp.). One monitor was placed in each location: indoors in the room where the 5-year-olds spent most of their time and outdoors on the playground, as close as possible to the fence closest to the road, over a period of at least 8 hours. Filter preparation for lead analysis was performed according to NIOSH method 7105.[16] Surface soil samples were collected and analysed according to EPA method 3050B.[17] These soil samples were collected from at least one representative location in the playground, a sandpit if present, and near the air sampler. Surface dust measurements were collected and digested according to NIOSH methods 9100 and 7105, respectively.[16,18] Samples were taken in at least three locations indoors (from the floor of the play area, a bookshelf and from a window sill). Analyses of all samples were conducted by Perkin Elmer ELAN 6000 inductively coupled plasma–mass spectrometry.

Traffic density counts. As traffic volumes were not available from the traffic department for most of the streets on which the schools were located, traffic counts were conducted at each establishment over three 15-min periods during the days of the survey — at 07:30, 13:00 and 16:00 — using hand-held counters.

Data entry and analysis were performed using the software packages Epi Info 6.04 and Stata 6. Uni-, bi- and multivariate analyses were conducted to identify factors with greatest predictive value for environmental lead exposure in children.

Twenty third- and fourth-year environmental health students from Technikon Gauteng North in Soshanguve were trained as field workers. They physically sampled lead in air and soil, were responsible for observational procedures such as traffic counts, administered the questionnaire and completed the time–activity diaries.

Sample collection and analyses were performed using best practice methods described elsewhere.[16–18] Field and laboratory blanks were taken for quality assurance. The accuracy and completeness of information captured with the questionnaires were evaluated by interviewing more than one person at a school, where possible. This was used during data entry to check discrepancies in responses. The principal investigator checked the completeness of questionnaire responses throughout the period of data collection, conducted continuous site visits, and was available for assistance throughout the study should field workers encounter unanticipated problems.

Informed consent was obtained from the pre-school principals. Furthermore, the study was approved by the Research Ethics Committee of the Faculty of Health Sciences at the University of Pretoria (S126/2001).

Results

The mean time spent indoors was significantly higher in Soshanguve (5.6 h/day) than in Pretoria East (5.2 h/day) ($P <$ 0.05, s.d. = 1.5 vs 1.2 h/day, $n = 216$). There was also a significant difference in the average size of indoor play areas (28.3 vs 69.5 m^2; s.d. = 14 vs 48 m^2, $n = 54$) and play areas outdoors (382 vs 889 m^2; s.d. = 406 vs 805 m^2, $n = 54$) between pre-schools in the two areas ($P < 0.05$).

The mean air lead concentrations indoors (measured as TSP) were lower than outdoors (0.08 vs 0.1 $\mu g/m^3$, $P < 0.07$; s.d. = 0.01 vs 0.24 $\mu g/m^3$, $n = 54$). Outdoor lead concentrations associated with TSP were significantly lower in Soshanguve (0.098 $\mu g/m^3$) than in Pretoria East (0.145 $\mu g/m^3$, $P < 0.05$, s.d. = 0.17 vs 0.17 $\mu g/m^3$, $n = 54$). Furthermore, significantly fewer pre-schools in Soshanguve were situated close to busy roads (3 vs 13, $P < 0.05$) with the average traffic count being significantly lower in Soshanguve (66 vs 421 vehicles/h, $P < 0.05$).

Overall mean lead loadings in surface dust indoors (173 vs 64 $\mu g/m^2$, $P < 0.05$) as well as average lead concentrations in surface soil outdoors (17.7 vs 6.9 $\mu g/g$, $P <$ 0.05) were consistently higher in Soshanguve than in Pretoria East. Pre-schools in Soshanguve were generally more often located adjacent to untarred roads and had 'dusty' playgrounds. Information on the age of school buildings was not recorded in this study but may be estimated from general information on housing: formal housing in Soshanguve began in about 1972, while informal housing, including corrugated iron structures, began to be erected in the early 1990s (E. Aphane, Acacia City Council, pers. comm.)

Various other factors that were investigated as potential explanations for higher lead loadings in surface dust and for higher concentrations in soil gave unclear results. In view of the lower level of infrastructural development in Soshanguve, we expected that the latter would be a more dusty area than Pretoria East and with more resuspended dust, but no conclusive evidence for this was found. Also, we anticipated higher background levels of lead in soil in Soshanguve. However, surveys conducted by the Council for Geosciences indicated that the mean background lead concentrations in soil from the area around pre-schools in Soshanguve were lower than the mean for Pretoria (Pretoria East was not surveyed as such) (H. Maritz, Council for Geosciences, pers. comm.). Dust loadings on window sills, on the other hand, were substantially higher in Soshanguve than in Pretoria East (558 vs 100 μg/m^2, $P < 0.05$). This was possibly due to different cleaning practices in the two areas — the amount of dust on window sills in Soshanguve was much higher as these sills are often very narrow and rough and are seldom, if ever, cleaned. It has been reported that lead accumulates indoors, especially on window sills, which are not cleaned as frequently as floors.[7]

Conclusions

Children in Soshanguve spent more time indoors than those in Pretoria East pre-schools. This was probably related to the differences in availability and size of indoor and outdoor play areas, and may have important consequences for health. Lead in air indoors was significantly lower than outdoors. This is consistent with findings from other studies, as sources of environmental lead contamination are generally found outdoors.[6]

We found that environmental lead levels in air were in all cases below the WHO annual average guideline of 0.5 μg/m^3. The higher air lead exposure found around pre-schools in Pretoria East is probably caused by the higher traffic density and by their greater proximity to busy or steep roads and crossings. This study suggests, therefore, that exposure to lead in air is more accurately predicted by traffic density than by socio-economic status, although these are not independent factors.[4,19] Indeed, it has been demonstrated elsewhere that a major source of lead in interior house dust is emissions from motor cars using leaded fuel. Lead concentrations associated with house dust increase with traffic density and with the age of the building, indicating that built structures act as traps for lead-containing dust.[3,20] On the other hand, surface dust loadings and mean soil concentrations of lead were higher in Soshanguve than in Pretoria East, exceeding the EPA guideline for surface dust of 1000 μg/m^2 in three samples, all three from window sills. The highest soil lead concentration of 103 μg/g did not exceed the Dutch soil investigation criterion of 300 μg/g. The reasons for higher soil concentrations may have to do with proximity to industrial sources of lead contamination, but this was not investigated in this study. The higher concentration of lead in surface dust may be explained by additional factors such as a lack of cleaning protocols in less formal pre-schools, the use of building materials that are less easily maintained in a dust-free state, and possible lack of access to electrical and vacuum cleaning equipment.

Recommendations

Although this study was not able to generate South African standards for environmental lead exposure in children, because of a lack of resources, it did demonstrate the need for specific South African estimates of exposure, and it does provide a clearer understanding of the main risk factors involved in lead uptake by children in pre-schools. Consequently, the following observations and recommendations are made with respect to the planning, building, and siting of pre-schools in the future:

- Busy roads, intersections, and steeply sloping roads are responsible for the enhanced emission of lead from motor vehicles. Traffic volumes on roads close to intended sites for pre-schools should therefore be monitored in advance. These schools should not be built where there is the possibility of excessive lead contamination from whatever source; parents should consider this in the selection of a pre-school for their children. Where possible, the materials and designs used in school buildings should minimize dust collection. Furthermore, cleaning practices in pre-schools should not use appliances and methods that disperse dust, so as to reduce exposure to resuspended lead. Ideally, cleaning should be done when the children have left for the day, so that contaminated atmospheric particles have time to settle before the children return. The floor and furniture should be cleaned last, to minimize exposure to resuspended lead.
- Should a pre-school be located near sources of environmental lead (and other) pollution, the time that children spend outdoors should be limited.
- As this study found high soil lead concentrations in Soshanguve, and as this was also reflected in the lead levels in pit sand at pre-schools there, it is wise to measure actual lead levels at sites in the area before any future building starts and to monitor it regularly thereafter.

It is essential that exposure-related factors affecting pre-school children are quantified more, so that South Africa can develop its own exposure standards. The following aspects seem to be the most important to monitor: 1) soil and air lead concentrations in terms of distance from busy roads; 2) reasons for the differences in lead in soil and surface dust in Soshanguve compared to Pretoria East; 3) details of conditions and practices at South African pre-schools, including overcrowding of classrooms, type of activities the children engage in, the dusty environment, and frequency of hand washing. The impact of all these factors on exposure and eventual uptake of lead pollution should be investigated.

Further investigation should permit the development of measures comparable to exposure guidelines devised by the EPA for use in the United States. We have only touched the surface of exposure assessment in different micro-environments for South African pre-school children; further research will assist in providing the knowledge base needed to improve exposure assessments for our children.

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