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Remediation of soil from lead-contaminated kindergartens reduces the amount of lead adhering to children's hands

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Risk related to contaminated soil is based on the oral intake of soil and dust among children. This exposure is a consequence of mouthing behaviour, which exposes children to whatever adheres to their hands or toys. This project compared hand exposure of children to lead following outdoor playground activities before and after an intervention. The intervention consisted of replacement of contaminated top soil from the most intensively used playground areas and coverage of bare soil with wood chips or grass. We included children from three kindergartens: one with very low levels of lead in soil and two kindergartens with an average lead concentrations in soil of 100–200 mg/kg. Measurements of lead in soil 5–7 weeks after interventions in two kindergartens verified that the interventions had effectively reduced the potential exposure to lead from the most intensively used areas of the playgrounds. The average lead concentration in soil after intervention was below 10 mg/kg. We found a good agreement between the average concentration of lead in soil and the amount of lead on the hands of the children. Thus, the exposure marker worked and had the advantage compared to a blood sample, that we could evaluate the effect of the interventions shortly after they were accomplished using a noninvasive method. The amount of lead on the hands measured in one of the two kindergartens after the remediation (0.73 μg) was not significantly different from the control kindergarten (0.58 μg). Children from the second kindergarten still had higher median exposures to lead (1.29 μg), but a large overlap existed with several children having lower amounts of lead on their hands than some children from the control kindergarten. Large variations in the amount of lead on hands were observed. Variations may reflect true differences in concentrations of lead in soil, but may also reflect different behavior and playing patterns. Our study demonstrated, that it was possible in a cost-effective way to reduce exposure significantly and to verify the effect with a sensitive, noninvasive method shortly after the interventions had been implemented.
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Introduction

Large areas with contaminated soil exist in the urban environment. Human risk assessment related to this exposure source is based on the oral intake of soil and dust among young children (2–5 years). This exposure is a consequence of the mouthing behaviour, which exposes the children to whatever adheres to their hands or toys. In most cases, the exposure will be a mixture of contaminants including heavy metals as well as more persistent organic pollutants. This study focuses on exposure to lead.

Most previous studies have used lead in blood as a quantitative measure of lead exposure, and remediation has repeatedly been demonstrated to reduce blood lead levels in children (Weitzman et al., 1993; Aschengrau et al., 1994; Hynes et al., 2001; von Lindern et al., 2003b). A blood lead level is, however, an aggregate exposure marker for exposure through food, drinking water, paint, inhalation of dust, as well as soil. Moreover, lead in blood not only reflects the sum of present environmental exposure but also mobilization of lead stored in bones. Modelling results suggest that bone-lead mobilization can impact blood-lead levels of young children for considerably long periods following an intervention (Rust et al., 1999). Thus, an intervention that reduces a 5-year-old child's total environmental lead exposure by 50% might, due to mobilized bone-lead stores, produce only a 25% decline in the child's blood-lead concentrations measured 12 months following the intervention (Rust et al., 1999). Therefore, blood lead may not be the optimal indicator for an immediate effect of an environmental intervention reducing lead in soil. We therefore quantified the source of exposure through analysis of lead in soil from playgrounds and lead in indoor dust, and the individual exposure through measurement of the amount of lead adhering to the hands of children after outdoor activities. Thus, this study will allow discussion on the effectiveness of an intervention regarding exposure and on the interindividual variation in exposure between children, but will not warrant discussion of potential health effects.

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Already a century ago, Gibson (1904) recognized that lead-contaminated house dust was a source of lead poisoning among children. Lead in outdoor soil on playgrounds is together with lead-contaminated house dust still the two major environmental sources of lead exposure for children (Lanphear et al., 1998). Models indicate that from 40% to 50% of the lead absorbed from soils and dusts is through house dust with approximately 30% directly from communitywide soils and 30% from the home yard and immediate neighbourhood (von Lindern et al., 2003a,b).

Interventions to reduce exposure to lead from soil and dust are often based on guidance values and recommendations that may differ between countries and regions. Thus, the US EPA uses a level of concern at 400 mg/kg lead in bare residential soil, and recommends intervention for yards where higher levels of lead contamination are found (Hynes et al., 2001). Thus, at soil levels between 400 and 2000 mg/kg, the recommendation is to install raised-bed garden, install framed play and picnic area with perforated landscape cloth and wood chips 4–6 inches deep, and cover bare soil with wood chips if not a suitable site for grass (Hynes et al., 2001). Other superfund sites in US apparently use another guidance value of 500 mg/kg (Khoury and Diamond, 2003), which is parallel to general guidelines in South Australia, which prescribe home owner-maintained barriers and behavioural strategies at soil concentrations of lead within the interval of 500–2500 mg/kg (Maynard et al., 2003). The Danish EPA assess levels of lead in soil below 40 mg/kg as safe, state a cutoff value for lead in soil of 400 mg/kg, above which remediation should be initiated, and defines a guidance interval between 40 and 400 mg/kg. If lead in soil falls within this guidance interval, initiatives should be taken to reduce exposure of children to a level comparable to exposures occurring at soil concentrations less than 40 mg/kg. Lead concentrations in soil in central Copenhagen are generally within the guidance interval (40– 400 mg/kg) with relatively few and confined areas with above 400 mg/kg lead.

Reduced exposure can be achieved through changed behaviour of the children and/or changed environmental exposure. Interventions seeking to reduce intake of lead by educating parents about improved hygiene and behaviour so that children ingest less dirt have proved efficient in several exposure scenarios (Aschengrau et al., 1994; Kimbrough et al., 1994; Hilts et al., 1998; Maynard et al., 2003; von Lindern et al., 2003b). However, some data indicate that intervention may only be effective for children in the tail of the distribution, or approximately the 5–10% children with highest blood-lead levels (von Lindern et al., 2003b). This may be because these children are particularly vulnerable to excess absorption as they engage in atypical behaviours. The remaining 90–95% of the children with more typical behaviours will be less prone to modifications of their behaviour (von Lindern et al., 2003b). Interventions will therefore often need to involve behavioural changes through information and educational efforts, together with physical interventions to reduce lead levels in the environment.

The suggested interventions to reduce exposure to lead from soil described by different authorities are comparable although the level at which they are to be initiated differ (Aschengrau et al., 1994; Hynes et al., 2001; Maynard et al., 2003; von Lindern et al., 2003a,b). The present study evaluated the effect of a physical intervention in two kindergartens. Instead of replacement of all contaminated soil on the playgrounds, we replaced the topsoil (upper 15 cm) in those areas with most intense playing activities only, and covered these areas with uncontaminated soil and grass or wood chips on top of perforated landscape cloth. On steeper slopes, small terraces were introduced to keep the new soil material in place. The interventions were strictly related to outdoor exposure, and no specific effort was made to reduce indoor lead concentration. Indoor dust exposure was, however, estimated before and after outdoor interventions.

Two main issues were addressed in this study. We studied whether there was proportionality between the concentration of lead in soil and the amount of lead that adhered to the hands of children playing on this soil. Secondly, we evaluated whether interventions through physical changes on the playgrounds in two kindergartens, in accordance with recommendations from the Danish EPA, would reduce the amount of lead on the hands of children, and thereby potential exposure.

Materials and methods

Study Design

The project was an intervention study that compared the hand exposure of children to lead following outdoor playing activities before and after an intervention. We therefore included children from three kindergartens in Copenhagen, a city with approx. 700,000 inhabitants. One kindergarten with very low levels of lead in soil was used for comparison as were two kindergartens with lead concentrations in soil on the playgrounds within the Danish guidance interval (40–400 mg/kg). Further, a significant part of the playgrounds of the included kindergartens were covered with bare soil to allow for direct contact from the children. The study was planned to assess the hand exposure of a group of children from each kindergarten before and after an intervention in two of three kindergartens. Hand exposure of children from the control kindergarten was also assessed twice. As the weather would have a profound influence on the amount of soil adhering to the hands, the project was planned with an initial sampling period in late spring, intervention during the summer, and a second sampling period during early autumn. The two sampling periods have expected comparable weather conditions with mostly dry weather with temperatures around 16–22°C.

Kindergartens and Interventions

Kindergarten 1 (control) had 364 m^2 bare soil, 585 m^2 consolidated surface (areas covered with asphalt, concrete, flag paving, or grass), and 93 m^2 sand boxes. This kindergarten was situated in a suburban area of Copenhagen with limited traffic density and no industrial neighbours. No intervention was initiated here. Kindergarten 2 had 243 m^2 bare soil, 236 m^2 consolidated surface, and 29 m^2 sand boxes. This kindergarten was situated in central Copenhagen close to roads with high traffic density but no industrial neighbours with potential lead emissions. Topsoil (upper 15 cm) was removed from footpaths and other intensively used areas with bare soil, and replaced with uncontaminated soil on top of perforated landscape cloth. Eventually, these areas were covered with wood chips. Kindergarten 3 had 449 m^2 bare soil, 283 m^2 consolidated surface, and 80 m^2 sand boxes. This kindergarten was situated in central Copenhagen close to roads with high traffic density but no industrial neighbours with potential lead emissions. This kindergarten had a playground with many steep slopes, some covered with bushes other with bare soil. Areas with bushes were left, whereas the topsoil (upper 15 cm) in areas with bare soil was removed, covered with perforated landscape cloth and uncontaminated soil and/or wood chips. On steeper slopes, small terraces were introduced to keep the new soil material in place. The heights of existing frames were in some places increased to keep the new material outside the consolidated areas and to reduce the slope of some of the steepest parts of the playground.

Selection of Children

From all three kindergartens participation of an equal number of boys and girls were planned. The children were between three and six years old. The recruitment of children for the study was conducted in close collaboration with their parents and the personnel in the kindergartens. Based on estimates of coefficients of variation for measurement of lead on hands and the expected effect of interventions on the amount of lead on the hands, the number of samples from each kindergarten sufficient to observe a significant ($P < 0.05$, one-sided) difference was estimated to be at least 44.

Sampling

Lead in soil Surface (< 15 cm) soil samples were collected from 10 positions in each kindergarten. Sampling positions were selected to represent areas where the children would play most often according to the kindergartens staff. For kindergartens 2 and 3, soil samples were collected before and after the intervention.

Lead in indoor dust Six samples were collected before and after the intervention in each kindergarten. Samples were collected from the floor and window sill in the rooms where the children would be when they were inside. Children were out on the playground when the samples were collected. The sample collection followed the ASTM E 1728 procedure for wipe sampling. In brief, a cardboard frame with an inner area of 1 ft^2 was taped to the selected sampling position. The area was wiped three times with a single wipe tissue (Savett Intim. Cederroth, Albertslund, Denmark) (size: 13.5 cm × 20.5 cm). The tissues were stored and analyzed as tissues used for hand wiping (see below).

Lead on hands The right hand was wiped thoroughly with a perfume-free commercial wipe tissue (Savett Intim. Cederroth, Albertslund, Denmark) (size: 13.5 cm × 20.5 cm). Chemical analysis of the tissues demonstrated that the lead content was below the limit of detection ($< 0.05\,\mu g$, $n = 6$). The hand was wiped till it appeared clean. Special attention was given to the skin areas between the fingers and at the edges between nail and skin. Wipe samples were collected just after lunch (before the children went out to play on the playground) and after $1 - 1\frac{1}{2}$ h play on the playground. Samples were collected on 3–4 days from each kindergarten. A group of four persons did all the wipe sampling. The group practised the wipe procedure together in advance in order to standardize the procedure as much as possible.

Analysis

Lead in soil samples The samples were dried and small stones (> 5 mm) sieved from the soil. A subsample (5 g) was digested with nitric acid in a microwave oven according to the Danish standard method DS 259. The lead content was determined with ICP-AES. The limit of detection of the method is 3 mg lead per kg dry soil. The analytical between-day variation was 10%.

Lead in tissues Tissues were stored in 40 ml tightly capped plastic bottles until analysis. The tissues were digested according to a modified NIOSH method (NIOSH Method 7082: Lead by Flame AAS). In brief: The tissue was placed in a 100 ml Erlenmeyer flask and 18.0 ml concentrated nitric acid was added. The flask was covered with a watchglass and placed on a hotplate for 2 h (temperature ca. 100°C). After cooling, 5.0 ml hydrogen peroxide was added, and the solution was heated slowly to boiling (ca. 125°C). The solution was boiled to almost dryness (approximately 1 h). After cooling the residue was dissolved in 5% nitric acid and transferred to a 25.0 ml volumetric flask and 5% nitric acid added to the mark. The solution was filtered and the concentration of lead determined with ICP-AES. Results were subtracted an average blank (0.53 and 0.23 μg Pb in analytical runs before and after intervention, respectively) estimated by digesting and analysing blank tissues ($n = 6$ and 7, before and after the intervention). The recovery of the method was determined by measuring lead in the certified reference material NIST SRM 1648 (Urban particulate Matter). The average recovery (±SD) was 87 (±5.8)% ($n = 17$) and 89.1 (±5.3)% ($n = 13$) before and after the intervention, respectively. The limit of detection (LOD) was 0.05 μg lead. It was calculated as LOD = 3.3SD, where SD is the standard deviation of results obtained on a blank sample under repeatability conditions.

Statistical Analysis

Multivariate statistical analysis was carried out using the SAS version 8.02 (SAS Institute, Cary, NC, USA). Statistical models were accepted if the residuals conformed to a Gaussian distribution (Shapiro–Wilk). Univariate comparisons of non-Gaussian distributions were carried out using the nonparametric statistics (Mann–Whitney).

Ethics

The project was approved by the Regional Ethics Committee for Copenhagen and Frederiksberg counties. Written information was given to all parents, and a prerequisite for participation of a child was a signed approval from the parents. Employees from the kindergartens as well as parents were given written as well as oral information on study results.

Results

In total, 10 soil samples from the most intensively used parts of the playgrounds were analysed from each of the three kindergartens before and after remediation. The analyses before remediation demonstrated that the kindergarten acting as control had very low concentrations of lead in soil (average 12 mg/kg), whereas the analyses from the other two kindergartens confirmed that soil levels of lead were within the guidance interval (average 100–127 mg/kg; Table 1). However, as illustrated by the maximal concentrations given in Table 1, the results also demonstrated that lead was not evenly distributed throughout the playgrounds. The remediations were evaluated with a new measurement of lead in soil after interventions. These results confirmed that the lead concentrations were now comparable to the control kindergarten (Table 1). An important notion is, however, that interventions as well as soil samples were focused on the most intensively used areas. Thus, the soil levels of lead at those parts of the playground seldom used by the children would be expected to be unchanged and probably within the same concentration range as the measurements from before intervention.

Lead in indoor dust from the control kindergarten (0.46 μg/ft^2) was about nine times lower than the other kindergartens reflecting the lower outdoor levels (Table 2). We have no explanation for the very low amount of lead sampled at kindergarten 2 before intervention. After intervention, the mean levels of lead in indoor dust at kindergarten 2 and 3 were unchanged (4 μg/ft^2; Table 2). The maximal values for lead in indoor dust demonstrate good intrakindergarten agreement between measurements, and indicate that variations in indoor dust levels of lead are less than in outdoor soil levels of lead (Table 2).

The planned number of participating children from each kindergarten was 44 before and after the interventions, respectively. Sampling at the kindergartens took place over a period of two to three weeks to allow for changing weather conditions as well as for logistic reasons. Principally, we did not exclude any child from participating in the study given

Table 1. Concentration of lead in soil at the most intensively used areas of the playgrounds of three kindergartens before and after remediation.

	Control	Kindergarten 2		Kindergarten 3	
		Before	After	Before	After
Average (range)	12 (4.6–20)	100 (3.9–230)	5 (1.5–20)	127 (22–450)	9 (7.4–13)
Median (Q1–Q3)	12 (9.5–14.8)	64 (32–167)	1.5 (1.5–6.2)	78 (45–167)	8.4 (7.6–8.8)

Only playgrounds on kindergarten 2 and 3 were remediated between the two measurements. Results are given in mg lead/ kg dry soil and based on 10 samples from each sample site. Q1–Q3: interquartile range.

Table 2. Concentration of lead in indoor dust from the three kindergartens before and after remediation.

	Control	Kindergarten 2		Kindergarten 3	
		Before	After	Before	After
Average (range)	0.46 (<LOD–0.99)	0.17 (<LOD–0.61)	4.05 (0.65–8.72)	4.02 (0.09–8.73)	4.07 (2.00–6.75)
Median (Q1–Q3)	0.50 (<LOD–0.74)	0.10 (<LOD–0.18)	2.42 (1.8–7.0)	3.57 (2.93–4.57)	4.17 (2.8–4.77)

Only playgrounds on kindergarten 2 and 3 were remediated between the two measurements. Results are given in μg/ft^2 and based on six samples from each sample site. Q1–Q3: interquartile range. <LOD: less than 0.05 μg Pb.

that the parents had agreed. Thus, on some days more children wanted to participate while on other days fewer children. The first sampling from the control kindergarten included 43 children (19 boys), and the second sampling 58 children (25 boys). The samplings from kindergarten 2 included 59 children (26 boys) before intervention and 50 children (24 boys) after intervention. The samplings from kindergarten 3 included 50 children (24 boys) before intervention and 46 children (28 boys) after intervention. Altogether we reached the calculated sample size and had similar distributions between boys and girls both within and between kindergartens. The only exception was in kindergarten 3 after intervention, where more boys than girls participated. All children were 3–6 years old.

During the two sampling periods before and after remediation, the weather was generally dry with temperatures between 16°C and 20°C, although one particular sampling day at the control kindergarten had more humid conditions.

The effects of intervention and gender on lead on the hands were investigated in a multivariate model. Since weather conditions (dry or humid) may influence dust adherence to the hands this factor was also included in the model. To ensure Gaussian-distributed model residuals, the natural logarithm to the amount of lead was used as the dependent variable. With all results ($N = 306$) in the model, both gender and intervention came out as significant. Boys had slightly higher levels of lead on their hands compared to girls (35% higher, $P = 0.033$), and after remediation of the play grounds the lead was significantly lower (62% of the level before remediation, $P < 0.001$). The effect of remediation was the same on both kindergartens (the interaction term of intervention and kindergarten was not significant). As the residuals of this model deviated from the Gaussian distribution, observations below the limit of detection were taken out as well as one extreme value (lead on hand 44 μg) belonging to a boy who had declared that he got dirty on purpose. Applying the same model to the remaining data ($N = 289$) yielded more or less the same estimates for the effects of remediation (after level was now 57% of before level, $P < 0.001$) and gender (boys were now 32% higher than girls, $P < 0.005$). Moreover, the residuals did not deviate significant from a Gaussian distribution. The residual variation (between-children differences) was estimated to 42%.

We could not control for age in the statistical model, because this information was not collected (the age distribution of children in Danish kindergartens is very narrow, 3–6 years). In order to check for any age effect, for example, due to turnover of children between the two sampling occasions, the above statistical analysis was repeated and limited to those children that participated on both occasions. The estimates of the effects and their significance did not change substantially (remediation: after level was 57% of before level, $P < 0.001$; gender: boys were 54% higher than girls, $P < 0.001$). We therefore conclude that the effect of lead on the hands observed for the remediation of the playgrounds is not due to different age distributions before and after remediation.

The individual measurements illustrated on Figure 1 demonstrate good agreement between the different sampling days, except for the third day of sampling from the control kindergarten (Figure 1, note the logarithmic scale of the

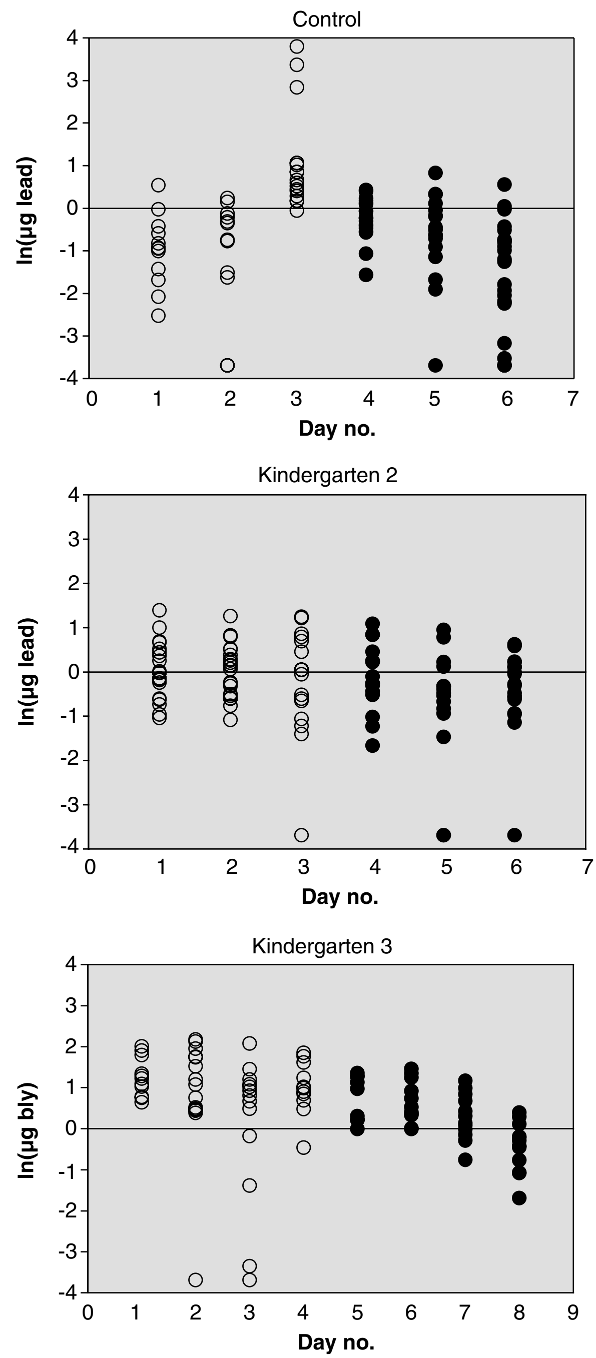

Figure 1. Amount of lead adhering to a hand after outdoor activities on a playground. Data are given from the individual sampling days at the three kindergartens. Results from individual children before and after remediation are shown as open and filled circles, respectively.

ordinate axis). This day was a wet day, and demonstrates why it is necessary to control for the weather conditions in the statistical model (above). In order to compare the different kindergartens and the effect of the intervention the summary tables (Table 3) were prepared with results including and excluding this wet day. Another observation from the individual measurements in Figure 1 was that in all three kindergartens a few children had almost no soil/lead on their hands after playing outside.

Summary statistics of lead in hand measurements are given in Table 3 for all kindergartens before and after the intervention. Univariate comparisons of the medians in Table 3 corroborate the conclusions of the multivariate statistical analysis. The median values of lead on hands of children from kindergarten 2 (1.04 μg Pb) as well as kindergarten 3 (2.76 μg Pb) were significantly different and higher than those of the control kindergarten (0.42 µg Pb) when the wet day was excluded (Table 3). When the wet day was excluded, our result also demonstrated that there was no difference in the amount of lead adhering to the hands of children from the control kindergarten between the two sampling periods (Table 3). The remediation of the two other kindergartens did, however, significantly change the median levels of lead adhering to the hands of the children (Table 3). The amount of lead on the hands measured in kindergarten 2 after the remediation was now not significantly different from the control kindergarten. Children from kindergarten 3 still had higher median exposures to lead, but a large overlap existed with several children from the control kindergarten having higher amounts of lead adhering to their hands than some children from kindergarten 3, and *vice versa*.

As a measure of comparison, the amounts of lead on the hands of children before they went out for playing were analysed. The results were comparable for all three kindergartens and the median amounts varied between 0.3 and 0.6 μg and were not affected by the interventions. In comparison with these numbers, after the intervention the children from the control kindergarten and those from kindergarten 2 did not have exposures that significantly increased their load of lead on the hands after playing outside on the playground. Children from kindergarten 3 still approximately doubled the amount of lead adhering to the hands during outdoor activities at the playground.

Discussion

Measurements of lead in soil 5–7 weeks after the interventions in kindergarten 2 and kindergarten 3 verified that the lead on the hands of the children decreased by approximately 40% on average. Hence, interventions had effectively reduced the potential exposure to lead from the most intensively used areas of the playgrounds. However, exposure of a child to lead from soil is a combination of direct exposure from the soil and indirect exposure through indoor dust. As lead in paint does not occur in kindergartens in Denmark, the environmental source of lead in indoor dust is expected to originate from outdoor sources. The present study did not demonstrate any reduction in indoor dust levels following intervention in the two kindergartens. The reason is probably that the interventions were strictly focused on soil, and did not include intensive cleaning of consolidated surfaces, playing tools, or indoor areas. Thus, preventive efforts to reduce exposure will have to include proper cleaning of indoor areas as well in order to take full advantage of the outdoor interventions, although indoor dust levels will be expected to decrease with time as our study, in agreement with previous studies, has demonstrated a

Table 3. Lead on childreńs hands after outdoor playing activities on playgrounds from control kindergarten and kindergarten 2 and 3 before and after intervention.

	Mean ± SD (μg Pb)	N	Median (μg Pb)	Range (μg Pb)	Q1–Q3 (μg Pb)
Before intervention					
Control	3.03 ± 8.13	43	0.88	< LOD[a]–44.1	0.39–1.72
Control[b]	0.52 ± 0.42	26	0.42	< LOD[a]–1.72	0.19–0.75
Kindergarten 2	1.24 ± 0.88	59	1.04[c]	< LOD[a]–4.02	0.55–1.66
Kindergarten 3	3.30 ± 2.26	50	2.76[c]	< LOD[a]–8.80	1.66–4.68
After intervention					
Control	0.65 ± 0.49	58	0.58	< LOD[d]–2.29	0.27–0.944
Kindergarten 2	0.92 ± 0.67	50	0.73*	< LOD[d]–2.95	0.9–1.25
Kindergarten 3	1.62 ± 1.29	46	1.29**	< LOD[d]–4.28	0.82–2.36

[a] < LOD: less than 0.05 μg Pb. Q1–Q3: interquartile range.
[b] Data from round 3 (before intervention) excluded.
[c] Significantly different from median of control[b] ($P < 0.001$; Mann–Whitney test).
[d] LOD: level of detection. Q1–Q3: Quartiles limiting the central 50% of observations.
* Significantly different from median before intervention ($P < 0.05$; Mann–Whitney test).
** Significantly different from median before intervention ($P < 0.001$; Mann–Whitney test).

reasonable agreement between level in outdoor soil and levels in indoor dust.

The individual measurements of lead in soil before remediation demonstrated a considerable variation within kindergartens 2 and 3 (Table 3). Some of this variation is caused by differences between boys and girls, boys having approximately 30–35% more lead on their hands. However even after controlling for this difference, statistical modelling demonstrated that the variation between the children was 42%. These differences are, however, characteristic of the diffuse lead contamination in cities where contamination is a combination of traffic-generated pollution originating before lead was removed from gasoline and minor point sources related to industrial waste. Despite these variations, we found a good agreement between the average concentration of lead in soil and the amount of lead on the hands of the children. Thus, the exposure marker worked and had the advantage compared to a blood sample, that it was noninvasive and that we were able to observe the effect of the interventions shortly after they were accomplished.

Large variations in the amount of lead on hands may reflect true differences in concentrations of lead in soil as individual children may play in more or less contaminated places on the playground, and may also reflect different behaviour and playing patterns on the playground. This may, for example, be the reason for the systematic differences between boys and girls. The large variations in individual values may be illustrated by the fact that a significant number of children from kindergarten 3 — the kindergarten with the highest soil lead levels also after remediation — had less lead on their hands than the average child from the control kindergarten. Different playing activities among children within the same kindergarten as well as between kindergartens were subsequently verified by employees from the three kindergartens. These findings stress the importance of a sufficient large sample size to incorporate these inherent differences in the playing patterns of children.

The three extreme values obtained at the control kindergarten as well as the generally higher average value from the wet day underscores the high sensitivity of this method for day-to-day variations in playing activities as well as weather conditions. This may be seen as an advantage as well as a disadvantage, but needs to be taken into account when the method is used. As we selected dry days for our sampling, we potentially may have underestimated the average exposure for periods with changing weather conditions.

We choose to use dry days only, as the purpose of the present study was not to describe variations in exposure over time for different weather conditions, but to verify that a specific intervention would reduce exposure. The interventions were limited in extent and cost, but had an immediate and verifiable effect on hand exposure. We cannot, however, exclude that the effect will decrease with time in case the replaced topsoil is mixed with the underlying still contaminated soil. A perforated landscape cloth between the contaminated soil and the new topsoil should reduce this risk of mixing, but the long-term effect will have to await follow-up studies.

The present study was an exposure assessment study and neither considered how much of the lead on the hands that was ingested by the individual child nor the actual bioavailability of the specific lead source. However, our study demonstrates that it was possible in a cost-effective way to reduce exposure significantly and verify the effect in a sensitive, noninvasive way shortly after the interventions were implemented.

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