Seasonal Influences on Childhood Lead Exposure

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We conducted a study to examine seasonal changes in residential dust lead content and its relationship to blood lead in preschool children. We collected blood and dust samples (floors, windowsills, and carpets) to assess lead exposure. The geometric mean blood lead concentrations are 10.77 and 7.66 μg/dL for the defined hot and cold periods, respectively ($p < 0.05$). Lead loading (milligrams per square meter) is the measure derived from floor and windowsill wipe samples that is most correlated with blood lead concentration, whereas lead concentration (micrograms per gram) is the best variable derived from carpet vacuum samples. The variation of dust lead levels for these three dust variables (floor lead loading, windowsill lead loading, and carpet lead concentration) are consistent with the variation of blood lead levels, showing the highest levels in the hottest months of the year, June, July, and August. The regression analysis, including the three representative dust variables in the equations to predict blood lead concentration, suggests that the seasonality of blood lead levels in children is related to the seasonal distributions of dust lead in the home. In addition, the outdoor activity patterns indicate that children are likely to contact high leaded street dust or soil during longer outdoor play periods in summer. Consequently, our results show that children appear to receive the highest dust lead exposure indoors and outdoors during the summer, when they have the highest blood lead levels. We conclude that at least some of the seasonal variation in blood lead levels in children is probably due to increased exposure to lead in dust and soil. *Key words:* **blood lead level, childhood lead exposure assessment and reduction study (CLEARS), children, dust lead level, lead concentration, lead exposure, lead loading, seasonality.** *Environ Health Perspect* **108:177–182 (2000). [Online 10 January 2000]**
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Childhood lead exposure adversely affects cognitive and behavioral development (*1,2*). Currently, the Centers for Disease Control and Prevention (CDC) define blood lead (BPb) levels in children as elevated if they exceed 10 μg/dL. BPb levels are higher in the summer months than at other times of the year (*3–7*). On the basis of some animal experiments implemented by gavaging lead compounds over various seasons, it has been suggested that solar radiation, through its effect on the biosynthesis of vitamin D, may be the main reason for the seasonality of plumbism (*3,8*). It has also been suggested that vitamin D, which promotes calcium absorption, unfortunately may also promote lead absorption. In contrast, some investigators have found no relationship between vitamin D and blood lead levels (*9,10*) or have found an inverse relationship (*11,12*).

Household dust is a major source of childhood lead exposure. Several studies have shown that the elevated BPb levels of preschool children were strongly associated with elevated lead levels in house dust (DPb) (*13–20*). This association between BPb and DPb has been attributed to dust ingestion from the frequent hand-to-mouth behavior of young children (*21*). Flaking lead-based paint, road dust, garden soil, and airborne lead-bearing particles are believed to be the sources of lead in household dust. Source apportionment of lead in house dust has been conducted by using automated scanning electron microscopy (*22,23*) and by performing chemical mass balance analyses (*24*). In these studies, the exterior sources (street dust/soil) and lead-based paint appeared to be major contributors to residential environments.

The Childhood Lead Exposure Assessment and Reduction Study (CLEARS) was a randomized study which demonstrated that frequent cleaning of floors, windowsills, and carpets in houses could effectively reduce residential DPb (*25*). The study showed that reducing the levels of indoor exposure sources (i.e., household dust) via a cleaning program, combined with maternal education, resulted in reduced lead levels in children (*20*). The CLEARS data, showing a strong association between DPb and BPb levels, provided blood and dust data over the calendar year that allowed examination of the seasonality of DPb and BPb in urban environments. We hypothesized that the summer increase in BPb might result, at least in part, from increased levels of DPb.

Methods

The CLEARS, conducted from June 1992 through September 1995, was a randomized intervention study. Families with children 6–32 months of age who were at risk of lead exposure in the area of Jersey City, New Jersey, were recruited from a variety of sources. Participants in CLEARS with BPb levels ranging from 3 to 28 μg/dL were randomized to a Lead Intervention Group or an Accident Prevention Group (control group), and attempts were made to visit their residences at baseline and on two subsequent occasions over the ensuing year. Blood and dust samples were collected at these visits to assess the effectiveness of the intervention. Only the BPb and DPb data collected from the CLEARS control group were used to determine seasonal relationships. This restriction avoided confusion between the effects of seasonality and cleaning on DPb levels (*20,25*). The blood and dust sample sizes used for these analyses were not exactly the same as those in the previous published papers (*20,25*) because of the different criteria for inclusion (e.g., data with missing sampling dates were excluded, and data for extra home visits and for siblings of index children were included). The sample populations yielded 313 blood samples, 177 carpet samples, 413 floor wipe samples, and 214 windowsill samples from 135 children in 67 families. Nineteen families (28.4%) moved during the study, but because these moves were within the local area and samples were taken in the new residences at least 2 months after the move, they still met our requirement and were not removed from this analysis. Soil and street dust samples ($n = 205$) representing outdoor lead content were used to estimate the lead distribution in the urban area of Jersey City.

We examined the blood data for seasonality by plotting monthly BPb concentrations

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with corresponding outdoor and indoor average temperatures (Figure 1). The indoor temperatures were recorded during the home visits, whereas the outdoor temperatures were obtained from the Office of the New Jersey State Climatologist (*26*). According to the temperature profiles during CLEARS, we categorized dust and blood samples to the four seasonal groups: hot (June, July, and August), warm (April, May, and September), cool (March, October, and November), and cold (January, February, and December). Because of the limitation of data size, we divided the questionnaire data referring to children's outdoor activity patterns into two categories: hot–warm (April–September) and cool–cold (October–March).

Sample collection and analysis. Dust sampling included both wipe and vacuum techniques, and each was completed in the participating CLEARS homes. We sampled the interior activity areas most likely to be used by children (e.g., living rooms, bedrooms, and kitchens) to establish a metric of residential lead exposure (*27*). We used the Lioy–Weisel–Wainman (LWW) dust wipe sampler to collect dust on floors and windowsills. The collection efficiencies of the LWW sampling kit were tested in the laboratory and found to be approximately 100% and 87% for floors and windowsills, respectively (*28*). We modified a Data Vac II (Metropolitan Vacuum Cleaner Co., Suffern, NY) to collect dust from carpet and rugs. Collection efficiency for house dust was dependent of carpet type, relative humidity, and dust quantity, and data were adjusted using the algorithm developed by Wang et al. (*29*). Details of the wipe and vacuum sampling techniques have been described in previous papers on CLEARS (*25,30*).

All dust samples were microwave digested in 19% (v/v) spectrograde (wipe) or reagent grade (vacuum) nitric acid following a protocol of the U.S. Environmental Protection Agency (EPA) (*31*). We analyzed vacuum samples using flame atomic absorption spectroscopy (Model 3100, Perkin-Elmer, Norwalk, CT) at a wavelength of 283.3 nm. We used a graphite furnace atomic absorption spectrophotometer (Perkin-Elmer) or inductively coupled plasma-mass spectroscopy (Fisons Instrument VG PlasmaQuad, Middlesex, England) to analyze wipe samples (*25,30*). We checked calibration standards on every tenth sample run for quality control; National Institute of Standards and Technology (NIST) reference material 981 and 2711 (wipe) and 2710 (vacuum) were used for the quality assurance analyses. For both the wipe and vacuum samples, the acceptable instrument error was ± 20%, although most quality control analyses were ± 10%.

Blood specimens were obtained from participating children by venipuncture, using needles and vacuum tubes from lots that were prechecked for lead contamination. Sampling supplies were prepared by the CDC, Nutritional Biochemistry Branch, Atlanta, Georgia. Blood was collected by standard venipuncture into 3-mL lavender-top Vacutainer tubes (Becton-Dickinson, Franklin Lakes, NJ). We tried to obtain at least 1.5 mL of blood per sampling to assure sufficient quantity for processing and to avoid incomplete mixing with the anticoagulant (EDTA). Specimens were labeled and initialed by the collector immediately after sampling and were stored at 4°C. Samples were air-shipped on ice to Atlanta and analyzed for lead content by published methods (*32*).

We collected soil and street dust samples from children's outdoor primary activity areas (e.g., backyards and parks) and primary entryways outside the households (stairs, steps, and sidewalks). At least 10 g soil or dust was required for each sample. We used a paint brush and a dustpan to sample and transfer street dust to labeled Ziploc polyethylene bags (DowBrands, Indianapolis, IN). For soil sampling, we used a ring (4 in in diameter and 0.5 in in width) cut from polyvinyl chloride (PVC) tubing to circumscribe the soil by pressing it firmly into the ground; we then used a small plastic shovel to collect the soil and transfer it to a labeled Ziploc bag. The collection tools were cleaned between samplings to prevent sample contamination. The soil and street dust samples were delivered to the National Exposure Research Laboratory of the EPA (Research Triangle Park, NC) for lead analyses using X-ray emission spectroscopy (*33*).

Data analysis. We categorized data for the CLEARS control group by the previously defined seasonal groups. We geometrically transformed all the blood and dust data before performing statistical analyses because the data appeared log-normally distributed (*20,25*). The blood and dust data were analyzed by two independent approaches: individual samples and home visits. On the individual-sample basis, every blood or dust sample collected in the CLEARS control group was used as a unit in the statistical analyses regardless of correspondence between the blood and dust data. The individual sample-based analyses, which comprised as many valid samples as possible, helped establish the profiles of seasonal variation. When "home visit" was used as a unit in statistical analyses, interest focused on the relationships between blood and dust data. Thus, we only selected data that had corresponding blood and dust samples collected within a 2-month period. For home visits with multiple blood or dust samples, we used the geometric means of all the blood or dust data in the statistical analyses. Unpaired blood or dust data (i.e., no corresponding dust or blood data) were not used in the home visit-based analyses.

The individual sample-based data were first used to examine the seasonality of blood and dust data. We applied independent-sample *t*-tests (2-tailed) to examine the significances of mean comparisons for the blood and dust data between the four seasonal groups (hot, warm, cool, and cold). Spearman correlation analyses were completed for the home visit-based data to observe relationships between blood and dust data, and relationships between different dust samples (floors, windowsills, and carpets) within the dust data.

We performed multiple linear regression analyses using the home visit-based data to determine if any seasonal factors other than the DPb levels would affect children's BPb levels. Because not every house had both floor and carpet data available, we performed the analyses separately for carpeted and uncarpeted houses. Each analysis was conducted in two steps. First, a stepwise method

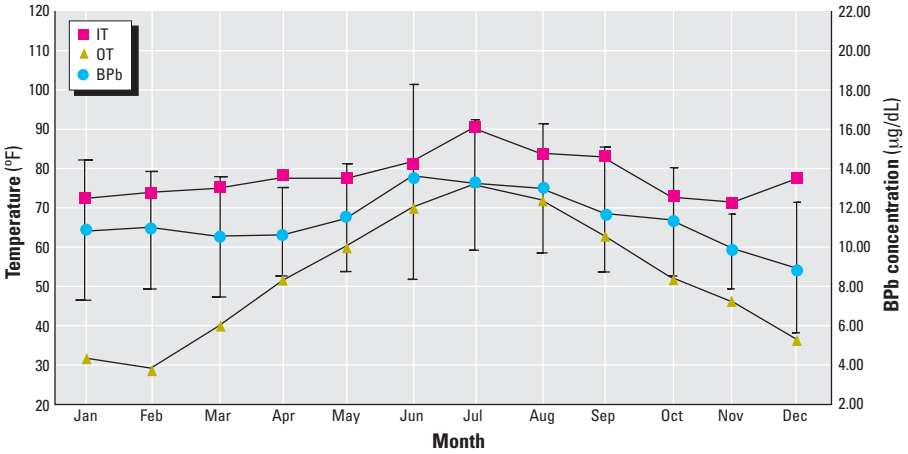

Figure 1. Monthly mean BPb concentrations versus indoor (IT) and outdoor (OT) temperatures. Error bars represent SD.

was applied to determine the regression equation for BPb and DPb levels by using the dust variables (lead concentration, lead loading, and dust loading) of floor, windowsill, and carpet samples as independent variables. Entry of the dust variables into a regression equation was determined by the significance of correlations between the dust variables and the BPb concentration. The most correlated dust variable was entered and the significance of the rest of the variables was then recalculated. The entering sequence was repeated until the significance criterion could not be met for an individual variable. The selection of dust variables for the regression analysis followed the commonly used criteria ($p \leq 0.05$ to enter and $p \geq 0.10$ to remove). In the second step, the seasonal variables (hot, warm, and cool), along with the previously determined dust variables, were forced into the regression analysis. The multiple linear regression model is

$$Y = B_0 + (B_1S_1 + B_1S_2 + B_3S_3) + (B_4X_1 + B_5X_2 + \ldots) \quad [1],$$

where Y represents log-transformed BPb concentration; S represents one of the seasonal variables (S_1 = hot, S_2 = warm, and S_3 = cool) and is coded 1 if the observation comes from the indicated season (otherwise it is coded 0); X represents one of the determined DPb variables (lead concentration, lead loading, or dust loading of floor, windowsill, or carpet samples); and B is a coefficient for each independent variable, while B_0 is constant.

The model yields a significance level (p-value) for each seasonal variable (S) in the presence of the dust variables. If all the seasonal variables are insignificant ($p > 0.05$), the BPb concentration is probably not affected by seasonal factors apart from DPb levels.

Results

The summary statistics for whole blood and dust data are shown in Table 1. The geometric mean of blood data is 9.56 µg/dL, with a peak concentration of 48.4 µg/dL. The indoor lead profiles are represented by floor, windowsill, and carpet samples, whereas the outdoor lead concentration are shown by soil/street dust samples. The mean lead concentrations of floor, windowsill, (wipe), and carpet (vacuum) samples are 613.0, 945.5, and 471.4 µg/g, respectively. Among the three types of dust samples, windowsill samples have the highest lead concentration, whereas carpet samples have the lowest lead concentration. This is probably because windowsills usually contain flaking paint chips or fragments to raise the mean concentration, and carpets are very likely to accumulate nonlead dust particles that may dilute the lead concentration. All of these mean lead concentrations are higher than the outdoor lead cleanup standard in New Jersey (400 µg/g). The mean dust loading for floor, windowsill, and carpet samples are 0.39, 0.70, and 6.86 g/m^2, respectively, demonstrating that carpets are a larger reservoir of dust than floors and windowsills. Lead loading, a product of lead concentration and dust loading, has geometric means of 0.24, 0.66, and 3.23 mg/m^2 for floors, windowsills, and carpets, respectively. The outdoor soil/street dust samples show high mean lead concentrations of 1,052 µg/g, 1.7, and 2.2 times higher than those of floor and carpet samples, respectively.

Results for seasonal groups. We reorganized all the blood and dust data according to the four seasonal groupings (Table 2). Blood lead concentrations decreased in the following order: hot, warm, cool, and cold. We found a difference in BPb of 3.11 µg/dL between the hot and cold groups. Lead loading for the floor and windowsill samples was highest in the hot group, although they were not significantly different from all of the other groups. Lead concentrations were high in the hot group for all three types of dust samples (floor, windowsill, and carpet), but they were low in windowsills and carpets in the warm group. In contrast, the carpet samples had higher levels of lead loading and dust loading during the cool and cold periods.

Correlations between dust samples. We examined correlations between floor, windowsill, and carpet samples within the dust data to determine the relationships between the three types of dust samples. There were 183, 122, and 122 sets for floor–windowsill samples, floor–carpet samples, and windowsill–carpet samples available for Spearman correlation analysis, respectively (Table 3). The correlation matrix of floor–windowsill samples did not yield many good correlations, but the one between lead loading on floors and windowsills was quite strong (r = 0.40). For the floor–carpet analysis, several good correlations ($r > 0.5$) were found in the correlation matrix. Floor lead concentration and lead loading were well correlated with carpet lead concentration. In addition, floor lead loading was strongly correlated with carpet lead loading (r = 0.55). The diagonal of the windowsill–carpet correlation matrix showed better correlation coefficients for the pairs of lead concentrations, lead loading, and dust loading than those between different dust variables of the windowsill and carpet samples.

Correlations between blood and dust data. There were 140 pairs of blood–floor dust samples, 134 pairs of blood–windowsill dust samples, and 95 pairs of blood–carpet dust samples available for Spearman correlation analysis. The three dust variables (lead

Table 1. General lognormal distribution parameters for all blood, floor, windowsill, and carpet samples for the seasonality analysis.

	No.	GM	GSD
Blood			
Lead concentration	313	9.56 µg/dL	1.8
Floor (wipe)			
Dust loading	413	0.39 g/m^2	3.0
Lead loading	413	0.24 mg/m^2	3.7
Lead concentration	413	613.0 µg/g	2.6
Windowsills (wipe)			
Dust loading	214	0.70 g/m^2	2.7
Lead loading	214	0.66 mg/m^2	5.1
Lead concentration	214	945.5 µg/g	3.5
Carpet (vacuum)			
Dust loading	245	6.86 g/m^2	3.6
Lead loading	245	3.23 mg/m^2	5.4
Lead concentration	245	471.4 µg/g	3.2
Soil/street dust			
Lead concentration	205	1,052 µg/g	2.6

Abbreviations: GM, geometric mean; GSD, geometric standard deviation.

Table 2. Blood and dust data of the four seasonal groups.

	Hot	Warm	Cool	Cold
Blood				
No.	89	81	68	75
Lead concentration (µg/dL)	10.77 (1.9)[a]	10.08 (1.6)	9.50 (1.6)	7.66 (2.0)*
Floor (wipe)				
No.	82	147	108	76
Dust loading (g/m^2)	0.40 (2.8)	0.39 (2.7)	0.38 (3.3)	0.37 (3.0)
Lead loading (mg/m^2)	0.31 (3.6)	0.23 (3.6)	0.23 (4.0)	0.19 (3.7)*
Lead concentration (µg/g)	766.6 (2.5)	588.7 (2.5)*	608.9 (2.8)	525.4 (2.5)*
Windowsills (wipe)				
No.	56	67	43	48
Dust loading (g/m^2)	0.70 (2.6)	0.82 (2.7)	0.57 (2.5)	0.68 (2.9)
Lead loading (mg/m^2)	0.84 (4.1)	0.65 (6.0)	0.48 (5.7)*	0.68 (4.3)
Lead concentration (µg/g)	1,214.3 (3.0)	795.8 (3.4)*	834.9 (4.1)	1,004.1 (3.8)
Carpet (vacuum)				
No.	75	52	56	62
Dust Loading (g/m^2)	4.43 (3.4)	6.59 (3.3)	9.56 (3.3)*	8.91 (3.9)*
Lead loading (mg/m^2)	2.61 (6.2)	2.01 (5.9)	5.05 (4.7)*	4.16 (4.2)
Lead concentration (µg/g)	589.3 (3.4)	305.6 (2.8)*	528.7 (3.5)	466.8 (2.6)

[a]Data presented are geometric means (geometric standard deviations).
*Significantly different from the hot group (p = 0.05).

concentration, lead loading, and dust loading) were compared with BPb concentrations (Table 4). The highest correlations between BPb concentration and lead loading were found for floor and windowsill samples (r = 0.41 and 0.37), whereas lead concentration was found best correlated with BPb concentration for carpet samples (r = 0.40). The slightly lower r value of windowsill–blood correlation may result from the variability of windowsill samples, which was reported by Adgate et al. (*29*) for CLEARS in the study of exposure metrics.

Regression analysis of blood and dust data. There were 74 sets of blood, floor, windowsill, and carpet data for the carpeted households and 46 sets of blood, floor, and windowsill data in the uncarpeted households available for the stepwise multiple linear regression analysis. The regression model included the three best correlated variables (floor lead loading, windowsill lead loading, and carpet lead concentration) in the equations and was completed for the carpeted households

$$\begin{aligned}\mathrm{Log}_{10}BPbC &= (0.47 \pm 0.15) \\ &+ (0.20 \pm 0.06)\mathrm{Log}_{10}CarpetPbC \\ &+ (0.11 \pm 0.04)\mathrm{Log}_{10}WindowsillPbL; \\ R^2 &= 0.28 \end{aligned} \quad [2],$$

and for the uncarpeted households

$$\begin{aligned}\mathrm{Log}_{10}BPbC &= (1.26 \pm 0.05) \\ &+ (0.31 \pm 0.06)\mathrm{Log}_{10}FloorPbL; \\ R^2 &= 0.40 \end{aligned} \quad [3],$$

where C = concentration and L = lead loading.

Standardized coefficients (β), an indication of the importance of independent variables to the dependent variable, indicate that carpet lead concentration is more important than windowsill lead loading in relation to BPb concentration in the carpeted home (Table 5). The form of the model used is consistent with the work of Rust et al. (*34*), who indicated that the log-linear model should be the default model for developing BPb–DPb relationship. To determine seasonal factors on the relationship between BPb and DPb, we added the seasonal variables (hot, warm, and cool) to the regression equations; the resultant equations were

$$\begin{aligned}\mathrm{Log}_{10}BPbC &= (0.40 \pm 0.17) \\ &+ (0.20 \pm 0.06)\mathrm{Log}_{10}CarpetPbC \\ &+ (0.10 \pm 0.04)\mathrm{Log}_{10}WindowsillPbL \\ &+ (0.10 \pm 0.06)Hot + (0.07 \pm 0.06)Warm \\ &+ (0.06 \pm 0.08)Cool; \\ R^2 &= 0.31 \end{aligned} \quad [4]$$

for the carpet households and

$$\begin{aligned}\mathrm{Log}_{10}BPbC &= (1.16 \pm 0.08) \\ &+ (0.32 \pm 0.06)\mathrm{Log}_{10}FloorPbL \\ &+ (0.16 \pm 0.10)Hot + (0.09 \pm 0.09)Warm \\ &+ 0.17 \pm 0.09)Cool; \\ R^2 &= 0.46 \end{aligned} \quad [5]$$

for the uncarpeted households.

The addition of seasonal variables made little change in the R^2 values. Standardized coefficients (β) of the seasonal variables were smaller than those of the selected dust variables for both the carpeted and uncarpeted regression equations and were not statistically significant (Table 5). The weak improvement in R^2 values and the insignificance of seasonal variables indicate the absence of evidence for a seasonal effect over and above that measured by DPb.

Outdoor activity patterns for two seasonal groups. There were 29 and 27 households with questionnaires completed during the hot–warm and cool–cold periods, respectively. Data for weekdays and weekends are shown separately in Figure 2. Only 20% of the families let their children play outdoors on either weekdays or weekends for more than 1 hr during the cool–cold period. However, during the hot–warm period, 48% and 66% of the families, respectively, allowed their children to play outdoors for more than 1 hr on weekdays and weekends. Playing outdoors for 2–5 hr was common during the summer. Such outdoor play obviously provided opportunity for contact with lead present in street dust or soil.

Table 3. Spearman correlation coefficients derived between floor, windowsill, and carpet dust data.

	PbC	Dust loading	Lead loading
Floor			
Windowsill (n = 183)			
PbC	0.32	0.17	0.32
Dust loading	0.21	0.17	0.32
Lead loading	0.34	0.19	0.40
Carpet (n = 122)			
PbC	0.51	0.26	0.53
Dust loading	0.05**	0.39	0.31
Lead loading	0.34	0.44	0.55
Windowsill			
Carpet (n = 122)			
PbC	0.45	0.05**	0.31
Dust loading	0.10**	0.43	0.31
Lead loading	0.34	0.37	0.42

n = Numbers of sample pairs.
**Not significant (p > 0.05).

Table 4. Spearman correlation coefficients of blood concentration and corresponding dust data.

	No.[a]	r	Probability
Floor			
Dust loading (g/m^2)	140	0.23	0.006
Lead loading (mg/m^2)	140	0.41[b]	< 0.001
PbC (μg/g)	140	0.24	0.005
Windowsill			
Dust loading (g/m^2)	134	0.26	0.003
Lead loading (mg/m^2)	134	0.37[b]	< 0.001
PbC (μg/g)	134	0.29	0.001
Carpet			
Dust loading (g/m^2)	95	-0.04	NS
Lead loading (mg/m^2)	95	0.22	0.033
PbC (μg/g)	95	0.40[b]	< 0.001

NS, not significant.
[a]No. is number of sample pairs. [b]Best correlation coefficient of each sample type.

Discussion

The BPb values in the Jersey City children were highest in the warmer half of the year and peaked in the summer months (June, July, and August). Our finding of high BPb concentrations in the summertime agrees with previous studies (*3–7*). In addition, the associations between BPb and DPb were consistent with lead studies conducted over the last two decades (*13–19*).

Seasonal distributions of dust data. Consistent with BPb concentrations, floor and windowsill samples showed high levels of lead loading for the hot group. In a study of chemical mass balance source apportionment for CLEARS (*24*), almost 50% of household lead dust came from street dust and soil, and 33% and 17% came from lead-based paint and airborne lead particles, respectively. Thus, almost two-thirds of the lead in house dust appeared to be derived from outdoor sources. Because pathways of dust entry into the home, such as human and pet activities and opening of doors and windows, are affected by the seasons, changes in indoor lead content would be anticipated between the summer and winter seasons. The high indoor DPb levels occur in summer because contaminated outdoor sources may contribute more lead to indoor dust. However differences in the dust data found among the four seasonal groups were not all statistically significant. One reason may be the existence of lead-based paint in the homes. Thirty-three percent of lead mass in household dust came from lead-based paint, which contributed lead particles to the home regardless of season. The nonseasonal contribution of lead paint could decrease the seasonal variability of household lead dust and probably reduced the DPb difference caused by seasonal changes of the exterior lead sources.

We found an interesting trend for carpet dust and lead loading in this study. Carpets and rugs are known to be reservoirs for dust. In the four seasonal groups, dust loading and lead loading are higher in the warm, cool, and cold groups than in the hot group. The cool and cold sets include periods of snow, during which people carry mud or soil that adhers to their shoes or boots into their houses. Therefore, during the cool and cold periods, carpet dust loading reaches its maximum, probably reflecting large amounts of mud or soil brought into the houses on shoes.

Relationships between floor, windowsill, and carpet dust data. The correlations between lead levels found on the sampling locations reflect the different sources of lead-laden dust present in the home (Table 3). The positive correlation of floor and carpet samples may indicate the sharing of the same main source of lead that came from outdoor dust and soil. Floor samples are not well correlated with windowsill samples, which could reflect different cleaning schedules or the contribution of paint to the windowsill measurements. Carpet samples are better correlated with windowsill samples than are floor samples, perhaps because carpets are able to hold more dust, including leaded paint chips.

Relationships between blood and dust data. We completed analyses of blood and dust data to determine what dust variables were best correlated with BPb concentration. The results indicate that lead loading (micrograms per square meter) on windowsills and floors is well correlated with children's BPb concentration, whereas DPb concentration (micrograms per gram) has the best correlation with BPb concentration for carpet samples (Table 4). Lead loading (milligrams per square foot or milligrams per square meter) has been widely used in previous studies to represent the DPb levels because it shows the most correlation with BPb concentration (*13,14,16,17,25,30*). The results for floor and windowsill samples (wipe) agree with most previous studies on lead loading; however, the results for carpet samples (vacuum) suggest that lead concentration was a better indicator of lead risk than lead loading. Floors or windowsills are usually smooth and flat and do not have a large quantity of dust deposited on them [geometric mean < 1 g/m^2 (*25*)]. When children contact those surfaces, the amount transferred to the hand may be limited by the amount of dust present. Thus, the actual lead loading on the floor or windowsill may substantially influence BPb concentration in children.

Carpets and rugs trap and store large amounts of dust in their fibers [geometric mean = 6.86 g/m^2 (*25*)]. In contrast to a vacuum cleaner, children's hands are not able to contact the dust present deep in the carpet or rug. Thus, the lead uptake from carpets or rugs should be far lower than that predicted by the total lead loading of carpets or rugs. However, lead concentration in the carpet becomes important. Because children's routine home activities may yield a nearly constant contact with dust in the carpet, lead concentration in the carpet may be a better prediction of BPb concentration than is carpet lead loading. This result is supported by the work of Laxen et al. (*35*), who used lead concentration to predict BPb rather than lead loading when a vacuum method was applied. In addition, the results are consistent with those of Lioy et al. (*25*), who indicated that lead in the carpet or rug accumulated over time and provided a substantial proximate source in the home. The results suggest that old, dirty carpets should be replaced and new carpets should be vacuumed on a regular and frequent basis to help reduce lead exposure.

The identification of dust variables that were best correlated with BPb concentration was helpful in the examination of the seasonality of lead exposure. The representative dust variables, floor lead loading, windowsill lead loading, and carpet lead concentration, all showed the highest levels for the hot group (Table 2). This finding was consistent with the BPb concentration, which had the highest mean value in the hot group. The seasonal distribution of DPb levels may have an impact on the seasonality of lead exposure.

The stepwise regression model yielded equations (Equations 2 and 3) for the carpeted and uncarpeted households; in both models, the BPb concentration was a function of DPb level. The two revised equations (Equations 4 and 5), which were derived by adding seasonal variables, did not improve the regression models significantly for the carpeted or uncarpeted households. This suggests that the seasonality of the lead exposure in CLEARS results primarily from the seasonal distribution of DPb exposure and that other plausible factors (e.g., high vitamin D levels in summer) did not have a significant independent influence on the seasonality of BPb levels. Our results agree with the work of Koo et al. (*10*), who found no direct relationship between vitamin D metabolism and BPb levels in children with low to mild lead exposure.

Outdoor activity pattern on lead exposure. Although preschool children spend most of the time indoors, spending a few hours outdoors could have an impact on the seasonality of lead exposure because time spent outdoors is associated with children's BPb levels (*36*). According to the questionnaire, the outdoor activity patterns are significantly different in the hot–warm and

Table 5. Coefficients of multiple linear regression.

	Unstandardized coefficients		Standardized coefficients	
	B	SE	β	*p*-Value
Carpeted households				
Before seasonal variables				
Constant	0.47	0.15		0.003
Log_{10}(CarpetPbC)	0.20	0.06	0.37	< 0.001
Log_{10}(WindowsillPbL)	0.11	0.04	0.29	0.007
After seasonal variables				
Constant	0.40	0.17		0.019
Log_{10}(CarpetPbC)	0.20	0.06	0.38	< 0.001
Log_{10}(WindowsillPbL)	0.10	0.04	0.27	0.015
Hot	0.10	0.06	0.20	0.105
Warm	0.07	0.06	0.14	0.251
Cool	0.06	0.08	0.10	0.414
Uncarpeted households				
Before seasonal variables				
Constant	1.26	0.05		< 0.001
Log_{10}(FloorPbL)	0.31	0.06	0.63	< 0.001
After seasonal variables				
Constant	1.16	0.08		< 0.001
Log_{10}(FloorPbL)	0.32	0.06	0.65	< 0.001
Hot	0.16	0.10	0.24	0.107
Warm	0.09	0.08	0.16	0.311
Cool	0.17	0.09	0.31	0.062

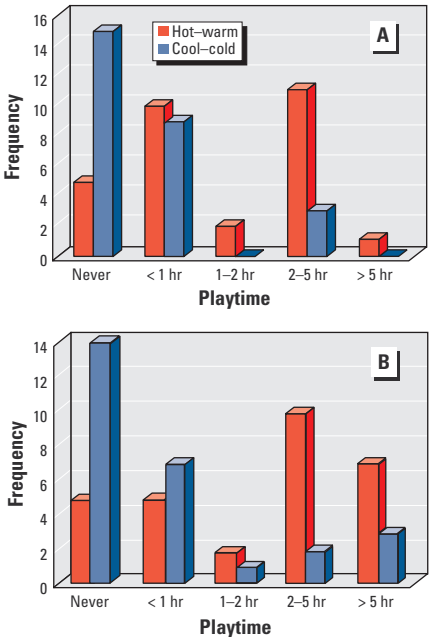

Figure 2. Outdoor activity patterns for the hot–warm and cool–cold periods for (*A*) weekdays and (*B*) weekends.

cool–cold periods. During the hot–warm period, more than 50% of families let their children play outdoors at least 2 hr on weekdays; even more families allow their children to play outdoors on weekends. The outdoor lead sources, street dust and soil, were approximately two times higher in mean lead concentration than the indoor lead sources (Table 1). Thus, children playing outdoors are subject to higher lead doses than those staying indoors. During the cool–cold period, children do not play outdoors very often and are less likely to contact street dust or soil directly. Consequently, the increased outdoor activity in summer may contribute to higher lead exposure and higher BPb concentration.

Conclusions

In this study, we found that the summer months are associated with higher BPb concentrations in preschool children and higher DPb levels in their homes. Furthermore, outdoor lead exposure in the summer is greater than that in the winter. Among several measurements of indoor DPb contamination, floor lead loading, windowsill lead loading, and carpet lead concentration show the highest levels in the hottest months (June, July, and August), and are most strongly correlated with BPb concentration. After entering these variables in a regression model, other seasonal factors have not been observed to have a significant relation to children's BPb concentrations. In addition, outdoor activity patterns provide more opportunity for exposure to contaminated outdoor dust and soil in summer than in winter. We conclude that this pattern of increased summertime lead exposure contributes to, and may largely account for, the higher BPb levels seen at this time of year.

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