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U.S. Children's Exposure to Residential Dust Lead, 1999-2004: II. The Contribution of Lead-contaminated Dust to Children's Blood Lead Levels

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The opinions expressed in this paper do not necessarily represent those of the U.S. government.

Abbreviations:

AM – Arithmetic Mean

CI – Confidence Interval

DL – Detection Limit

GM – Geometric Mean

μg/dL – micrograms per deciliter

μg/ft^2 – micrograms per square foot

ng/ml – nanograms per milliliter

NHANES – National Health and Nutrition Examination Survey

PbB – Blood Lead Level

PbD – Dust Lead Loading

PIR – Poverty to income ratio

ppm – parts per million

R^2 –the proportion of variability in the dependent variable accounted for by the model

SE – standard error

U.S. CDC – U.S. Centers for Disease Control and Prevention

U.S. EPA– U.S. Environmental Protection Agency

U.S. HUD – U.S. Department of Housing and Urban Development

Outline of Section Headers:

Abstract

Background: U.S. Centers for Disease Control and Prevention collected health, housing and environmental data in a single integrated national survey for the first time in the U.S in 1999-2004.

Objectives: To determine how floor dust lead loadings (PbD) and other housing factors influence childhood blood lead levels (PbB) and lead poisoning.

Methods: We analyzed data from the 1999-2004 National Health and Nutrition Examination Survey (NHANES), including 2,155 12-60 month old children with PbB and PbD measurements. We used linear and logistic regression models to predict log-transformed PbB and the odds that PbB was ≥ 5 and ≥10 µg/dL at a range of floor PbD.

Results: The population weighted geometric mean PbB was 2.0 µg/dL (GSE=1.0). Age of child, race/ethnicity, serum cotinine concentration, poverty to income ratio, country of birth, year of building construction, floor PbD by floor surface and condition, window sill PbD, presence of deteriorated paint, home-apartment type, smoking in the home, and recent renovation were significant predictors in either the linear model (R^2 = 40%) or logistic model for 10 µg/dL (R^2 = 5%). At floor PbD = 12 µg/ft^2, the models predict that 4.6% of children living in homes constructed before 1978 have PbB≥ 10 µg/dL, 27% have PbB≥ 5 µg/dL and the geometric mean PbB is 3.9 µg/dL.

Conclusions: Lowering the floor dust lead standard below the current standard of 40 µg/ft^2 would protect more children from elevated blood lead levels.

Introduction

The U.S. Department of Health and Human Services' *Healthy People 2010* initiative has set a national goal of eliminating PbB≥10 µg/dL among children aged 1-5 years by 2010 (U.S. DHHS 2000). Blood lead levels used to define unsafe levels of exposure for children have decreased over the past few decades as additional evidence has demonstrated newly recognized adverse health effects, even at relatively "low" exposures (Canfield et al. 2003; Lanphear et al. 2005; U.S. CDC 1991). Childhood lead poisoning prevention efforts are sometimes called a "victory" in light of the dramatic reductions in population blood lead level (PbB). However, the magnitude of on-going exposures, the remaining large stores of lead sources (particularly paint in older housing), and the length of time it has taken to address such exposures show that much remains to be done if a true, lasting victory is to be achieved (Jacobs et al. 2002; Lanphear 2007; Levin et al. 2008). We present new data on dust lead loading (PbD) and childhood PbB from the National Health and Nutrition Examination Survey (NHANES) 1999-2004 and examine its implications.

The most important source of lead exposure for children today is from lead paint as it deteriorates or is disturbed and subsequently contaminates settled residential dust and soil (Lanphear et al. 1998; Reissman et al. 2002). Another important source of lead in dust and soil is the estimated 5.9 million tons of gasoline lead emitted from motor vehicles before its removal in the mid-1980s (Mielke 1999). Normal hand-to-mouth activity exposes young children to lead in the residential environment (Bornschein et al. 1987; Lanphear et al. 1998). In 1999 and 2001, respectively, the U.S. Department of Housing and Urban Development (U.S. HUD) and the U.S. Environmental Protection Agency (U.S. EPA) established a PbD standard for the home environment of 40 $\mu g/ft^2$ along with similar standards for window sill PbD (250 $\mu g/ft^2$) and lead in soil (400 parts per million (ppm) in play areas). The previous guidance from U.S. EPA was 100 µg/ft^2 for floor PbD (U.S. EPA 1995). Prior studies have firmly established the robust correlation of settled PbD on both floors and window sills with children's PbB (Davies et al. 1990; Lanphear et al. 1998; Wilson et al. 2007). However, analysis of exposure pathways shows that floor PbD has a direct effect on children's PbB, with sill PbD having an indirect effect as mediated by floor PbD (U.S. HUD 2004). Until recently, nationally representative data for PbD and PbB (Jacobs et al. 2002; U.S. CDC 2005) were only collected in separate surveys. But between 1999 and 2004, NHANES interviewers collected dust lead wipe samples and housing-related questionnaire data relevant to lead exposure from the homes of children aged one to five years. Blood samples from these children were collected at NHANES mobile examination centers and were analyzed for lead and other parameters. We examined the relationship between PbB in children and PbD on floors and windows sills and estimated PbB across the range of floor PbD in this nationally representative cross-sectional sample of children aged 1-5 years. This marks the first time that nationally representative data on environmental and biological measurements for lead have been obtained in a single integrated survey. A companion article in this issue presents the predictors of residential PbD.

Methods

Study Population. We analyzed data from three waves of NHANES (1999-2000, 2001-2002, 2003-2004). NHANES is a nationally representative cross-sectional household survey that uses a complex, stratified, multi-stage probability sampling design to track the health of the non-institutionalized civilian U.S. population. It has been a primary source of information about the national distribution of children's PbB. Details of the NHANES protocol and all testing procedures are available elsewhere (NCHS 2006a, 2006b, 2006c). Our dataset included 2,155 children aged 12 to 60 months with measured PbB. Only children living in housing built before 1978, which is when the U.S. banned the use of lead in residential paint, were included in the analysis of the influence of floor PbD on children's PbB (n=731).

Child, Household and Housing Characteristics. NHANES interviewers collected data on age, race/ethnicity, sex, socioeconomic measures (family and household income and poverty income ratio), and other self-reported health data through a structured household interview. Participants self-reported their race and ethnicity. In this analysis, a composite race-ethnicity variable was used: non-Hispanic white; non-Hispanic black; Hispanic; or other race. These variables, as well as the housing characteristic variables, are described in the companion article. The poverty income ratio (PIR) is the ratio of income to the family's poverty threshold (OMB 1978). PIR values below 1.00 are below the poverty threshold, while PIR values of 1.00 or greater indicate income above the poverty level. Variables on smoking behavior included the presence of smoking in the home, number of smokers, and the number of cigarettes smoked in the home per day. NHANES participants provided venous blood samples during their visit to the mobile examination center, which were analyzed for PbB, serum cotinine, ferritin, iron, and total iron binding capacity.

NHANES measured PbB using graphite furnace atomic absorption spectrophotometry. The laboratory detection limit (DL) was 0.3 µg/dL. Only 0.23 % of the sample results were below the DL. The DLs for cotinine were 0.05 ng/ml and 0.015 ng/ml for 1999-2000 and 2003-2004, respectively. For 2001-2002, there was a mixture of these two DLs. Twenty-six percent of the cotinine samples were below the DL. For all NHANES laboratory measurements, results below the DL were assigned the value of $DL/\sqrt{2}$.

Statistical Methods. Data were analyzed using SUDAAN (SUDAAN, Version 9.0.0) and SAS (SAS System for Windows, Version 9.1.3). We used a linear regression model to predict natural log-transformed PbB and logistic regression models to predict the probability that a child's PbB exceeded either 5 or 10 μg/dL. The models adjusted the parameter estimates for the clustering and unequal survey weights within NHANES. The modeling employed Taylor series expansion theory without degrees of freedom adjustments. Backward elimination of insignificant independent variables ($p>0.10$) was followed by additional steps to allow addition and/or removal of variables. To provide an accurate prediction of children's PbB without eliminating large fractions of the study sample due to missing values, we fit an intercept term for each variable that had a missing value. The overall p-value is the Type 3 F-test that captures the overall statistical significance of each variable included in the model. For categorical variables with missing values, the "missing" level was not included in this hypothesis test.

Because NHANES collected serum cotinine only for children aged three years and older, many more children had questionnaire-based smoking data available than serum cotinine measurements. Therefore, we gave questionnaire-based smoking variables priority over measured serum cotinine levels.

Geometric mean (GM) PbB peaks between 18 and 36 months of age, and slowly declines over the next few years with the rate of decline varying in different populations (Dietrich et al. 2001; Tong et al. 1996; Wasserman et al.1997). Based on the relationships between age and blood lead observed in these studies, we determined that a quartic function of child's age fit best.

Although most other analyses of the relationship between log PbB and log floor PbD were based on a linear relationship, the relationship may not be linear across the relatively low ranges observed in NHANES (Lanphear et al. 1998; U.S. EPA 1998, 2001). To investigate this further, we analyzed other datasets: the National Evaluation of the HUD Lead-Based Paint Hazard Control Grant Program (the Evaluation) (Galke et al. 2001; U.S. HUD 2004); the Rochester Lead-in-Dust Study (Rochester) (Lanphear et al. 1996a, 1996b); and the HUD National Risk Assessment Study (the RA Study) (Wilson et al. 2007). For each of these datasets and NHANES, we predicted log-PbB based on a cubic function of log floor PbD for children under age six (Table 1). The NHANES model accounted for clustering and unequal survey weights.

We predicted PbB at different PbD levels for children living in pre-1978 homes while controlling for other predictors of PbB using the aforementioned linear and logistic regression models and the population weighted averages of covariates (except floor and sill PbD). For categorical variables, the levels were weighted according to their population weighted relative frequency distribution. For continuous covariate variables with intercepts fit for missing values, the same percent of missing values observed in the population was assumed for the average risk values. For window sill PbD values, we used a linear regression based on unweighted data from homes built before 1978 (n=601). The correlation coefficient for the linear relationship between natural log transformed sill and floor PbD is 0.38 ($p<0.001$). The regression equation is:

ln(sill PbD)=2.654+0.524*ln(floor PbD) (r=0.38, mean square error= 2.78, SE for the intercept and slope are 0.070 and 0.053, respectively).

The GM PbB and the probability that PbB is ≥ 10 µg/dL and ≥ 5 µg/dL were predicted for floor PbD ranging from 0.25 to 40 µg/ft^2 using the linear and logistic regression models, respectively. Although exponentiation of the predicted logarithm of the PbB may slightly over-estimate the expected GM PbB, the large sample size minimizes the over-estimation (Teekens and Koerts 1972).

Results

Characteristics of the Study Population. Blood lead data were available for 2,155 children aged 12-60 months. The population weighted GM PbB was 2.3 μg/dL. Nine percent were ≥ 5 μg/dL, 2.03% were ≥ 10 μg/dL, and 0.35% were ≥ 15 μg/dL. The companion article presents the descriptive statistics for PbD and additional housing variables. This article presents descriptive statistics for variables found to be significant (p<0.10) in the blood lead model (Tables 2 and 3). The weighted distribution shows that approximately 57% of the sampled population was non-Hispanic white, 15% was non-Hispanic black, and 24% was Hispanic. The vast majority (97.43%) of the children were born in the U.S. Fifty-eight percent lived in a single-family detached house, while almost one-quarter lived in an apartment. Fifty-two percent of the homes for which data on the year of construction were available were built prior to 1978. Approximately 6% of homes were built prior to 1950 and had evidence of deteriorated paint (i.e., peeling, flaking, or chipping paint) inside. Ten percent of children lived in pre-1978 homes where window, cabinet, or wall renovation was completed in the past 12 months.

Blood Lead Modeling Results. Although the models to predict log-PbB based on a cubic function of log floor PbD indicated that the cubic terms are not significant for two of the three datasets (the HUD Evaluation and Rochester), the quadratic terms were significant for all four datasets (Table 1). Figure 1 presents the predicted functions for the four datasets from the 5th to 95th floor PbD percentiles for each study except NHANES, which goes up to the 99.5th percentile (24.2 μg/ft^2). The figure shows that the slope and curvature of the relationship between log floor PbD and log PbB observed for the NHANES data is similar to other studies.

Children's PbB is strongly predicted by floor PbD and surface type and condition of floor (Table 4), with higher PbB associated with uncarpeted floors that were not smooth and not cleanable. Differences in the effect of PbD on PbB for uncarpeted smooth and cleanable, low pile carpet and high pile carpet were not significant, so these surfaces/conditions were combined. Natural log-transformed windowsill PbD, poverty income ratio, and age were also significant predictors of PbB.

Non-Hispanic black children had significantly higher PbB than non-Hispanic whites ($p<0.001$). Country of birth was also a significant predictor of PbB, with Mexican-born associated with higher PbB ($p=0.003$). Children living in apartment buildings with 10 or more units were found to have lower PbB than children living in single family detached or attached dwellings ($p=0.005$ and $p=0.022$, respectively). As expected, children living in newer housing have significantly lower PbB compared to children living in housing built before 1940 ($p<0.001$). Children living in homes built prior to 1978 that had renovation (within the past 12 months), which often disturbs paint lead, had higher PbB ($p=0.045$).

Children who resided in a home where smoking occurred inside had significantly higher PbB than children who lived in homes with no smoking ($p=0.015$). Even after controlling for the presence of smoking in the linear model, increasing log cotinine concentrations were associated with increasing PbB ($p=0.002$).

Table 5 presents the logistic regression results for predicting PbB ≥ 5 µg/dL and ≥ 10 µg/dL. If a variable was significant in one logistic regression model but not the other model, the cells for the variable contain a dash ("-"). Although most of the variables that were significant in the linear regression model were also significant in the 5 µg/dL logistic regression model, the 10 µg/dL logistic regression model identified fewer significant predictors. The R^2 for the 5 µg/dL and 10 µg/dL logistic models were much lower than for the linear model (16% and 5% versus 40%, respectively). This result was due to the loss of information from using the dichotomous

PbB outcomes in the logistic regression models, and the small number of children observed with PbB ≥ 10 µg/dL. The odds of having a PbB ≥ 5 µg/dL and ≥ 10 µg/dL for non-Hispanic blacks were about twice that of non-Hispanic whites (OR=2.04 and 2.01, respectively). The odds of a PbB ≥ 5 µg/dL for children born in Mexico were 11.69 times that of children born in the U.S. However, country of birth was not a significant factor in predicting PbB ≥ 10 µg/dL. The odds of having a PbB ≥ 5 µg/dL were more than three times higher for children living in pre-1950 housing with renovation, compared to children living in other homes (OR=3.33). The odds of having a PbB ≥ 10 µg/dL were more than three times higher for children living in pre-1950 housing with deteriorated paint inside, compared to children living in other homes (OR= 3.53).

Floor Dust Lead Thresholds. Table 6 presents the model predictions for average children living in a pre-1978 home for a range of floor PbD after controlling for the covariates described above. At a floor PbD of 6 µg/ft^2, the models predict that 2.7% of children have PbB≥ 10 µg/dL, 16.5% have PbB≥ 5 µg/dL and the GM PbB is 3.4 µg/dL. When floor PbD is 12 µg/ft^2, the models predict that 4.6% of children have PbB≥ 10 µg/dL, 26.8% have PbB≥ 5 µg/dL and the GM PbB is 3.9 µg/dL. The upper bound of the ninety percent confidence interval for a prediction approximates the 95% confidence interval upper bound for the prediction. For example, when floor PbD is 12 µg/ft^2, the 90% CI for the probability that PbB≥ 10 µg/dL is between 2.7 and 7.9%. This means that we are approximately 95% confident that the probability that PbB≥ 10 µg/dL is < 7.9%. The information presented assumes that floor PbD is equal to the specified value. If floor PbD is less than the specified value, the predicted GM PbB and probabilities would be lower than those in Table 6.

Discussion

We found the geometric mean PbB for children aged 12-60 months in the U.S. between

1999 and 2004 was 2 µg/dL and that 20 children per thousand had PbB ≥ 10 µg/dL. A prior study analyzing NHANES data collected in 1994 through 1998 found that 63 children per thousand had PbB ≥ 10 µg/dL (Bernard and McGeehin 2003). Our findings show that 81 children per thousand had PbB ≥ 5 µg/dL. Although there is a clear and significant decline over time in childhood lead exposure demonstrated by these prevalence estimates from NHANES, there is still an unacceptable number of children who are poisoned each year.

Age, race/ethnicity, poverty income ratio and year of construction of housing all significantly predicted PbB of children, which is consistent with other studies (Pirkle et al. 1994; U.S. CDC 2005). Prior studies also found that PbB is typically higher in African American children than white children (Lanphear et al. 1996a, 2002; Raymond et al. 2007) and is higher in children living in poverty and in older homes (U.S. CDC 2005).

Previous studies using NHANES data have also documented the relationship between exposure to tobacco smoke and PbB (Bernard and McGeehin 2003; Mannino et al. 2003). Similar to our finding that serum cotinine was associated with PbB ≥ 10 µg/dL, Mannino et al. (2003) found that high levels of serum cotinine (a biomarker of exposure to environmental tobacco smoke) for older children aged four to 16 years was associated with PbB ≥ 10 µg/dL.

Prior studies have not demonstrated that children living in apartment buildings with 10 or more units are more likely to have lower PbB than children living in single-family detached houses. Although apartment buildings with 10 or more units tended to be of more recent construction than single family detached homes and smaller apartment building (5%, 17% and 78% constructed before 1940, respectively), not all the effect of home-apartment type is captured by the year of construction because both variables are significant in the model. While other studies suggest that lead hazards are more likely to be found in rental units than in owneroccupied properties (Jacobs et al. 2002), it is possible that owners of large apartment buildings may have more resources available for scheduled maintenance programs, which could help address lead hazards, compared to owners of smaller apartment buildings and single family detached homes.

Despite having a relatively small number of children that were born outside of the U.S., our results indicate Mexican-born was a strong predictor of PbB. A previous study examining the PbB of children living along the U.S./Mexico border also found that children living in Mexico had higher PbB than children living in the U.S. (Cowan et al. 2006). This finding may reflect continued use of lead containing items imported from Mexico (e.g., pottery, foods, folk medicine) by families that recently resided there. Research has documented that use of these items can result in elevated PbB in children (U.S. CDC 1991).

Additionally, our study supports the association between PbB and renovation and floor and sill PbD, as expected. Other studies have shown that renovation activities can influence floor PbD (Reissman et al. 2002) and that floor PbD is a strong predictor of a child's PbB (Davies et al. 1990; Lanphear et al. 1998; Rabinowitz et al. 1985; Wilson et al. 2007). The U.S. EPA recently promulgated a regulation intended to control lead exposures from renovation (U.S. EPA 2008).

The rate of change in PbB with respect to floor PbD levels observed in this most recent NHANES analysis is similar to that found in three other studies analyzed here: the Evaluation, the RA Study and the Rochester Study (Table 1). These other datasets are from higher risk populations and therefore have higher PbD and PbB levels. The similarities in the PbB/PbD slope in the different studies indicate that it is reasonable to use the NHANES data to make inferences at higher floor PbD and PbB.

The current Federal floor PbD standard of 40 µg/ft^2 was established based on pre-1995 data from the Rochester Lead-in-Dust Study and a pooled analysis of 12 older epidemiological studies using slightly different methods (Lanphear et al. 1998; U.S. EPA 1998, 2001; U.S. HUD 1999). The Rochester cohort and most of the studies comprising the pooled analysis were based on high-risk children and housing. The pooled analysis estimated that 95.3% of children aged 6-36 months would be protected from having a PbB ≥ 15 µg/dL, using a floor PbD threshold of 40 µg/ft^2 and holding other sources of lead to their respective national averages in the residential environment (Lanphear et al. 1998). In the U.S. EPA analysis, the floor standard of 40 µg/ft^2 was established jointly with standards for lead in window sill dust, soil and interior paint to protect at least 95% of children aged 12-30 months from developing a PbB ≥ 10 µg/dL when the window sill and soil lead standards were also met (U.S. EPA 1998, 2001). Although the current 40 µg/ft^2 standard was based on protecting children from developing high PbB (i.e., PbB ≥ 10 µg/dL or ≥ 15 µg/dL), the importance of preventing lower childhood lead exposure is illustrated by research that has demonstrated significant lead-related IQ decrements in children with PbB < 10 µg/dL (Canfield et al. 2003; Lanphear et al. 2005).

A strength of our study is that we were able to show the relationship of a range of floor PbD levels on children's blood lead levels, while controlling for other significant predictors in a nationally representative sample of children. PbD and PbB from 1999-2004 were much lower than those observed in the earlier studies of higher-risk populations that were the foundation of the current floor PbD standard. In fact, these new data made the logistic model to predict PbB ≥ 10 µg/dL problematic, because only two percent of PbB (n=51 out of 2155) were ≥ 10 µg/dL. Consequently, the percent of variation (R^2) explained by the predictors in the 10 µg/dL logistic model was much lower than that of the linear model (R^2=5% versus R^2=40%). We present the logistic regression model for 5 µg/dL because no other PbB thresholds have regulatory significance and 11% of children had PbB ≥ 5 µg/dL (237 of 2155 children; R^2=16%). Iqbal et al. (2008) suggests that the threshold for elevated PbB may be lowered from 10 to 5 µg/dL and examines the impact of this reduction.

NHANES collected both health and environmental data from a nationally representative sample of children between the ages of 12 and 60 months: however, the NHANES data are not necessarily representative of the U.S. housing stock. Iqbal and collaborators found that for NHANES 1999-2002, a large number of children 1-5 years of age in NHANES (16.3%), had missing PbB values (2008). Non-Hispanic white children, home owners, children from households with high income levels and with health insurance had a higher percentage of missing PbB values. This may have inflated the estimates of geometric mean PbB and overestimated the prevalence of PbB ≥ 5 µg/dL and PbB ≥ 10 µg/dL.

In addition, NHANES collected only a single floor PbD measurement in each house. Although the single measurement was from the room in which the children spent the most time, the average of several floor dust samples would likely provide a more precise estimate of a child's total exposure.

This article examined PbB across a range of floor PbD. Floors were the focus of this article because an analysis of exposure pathways found that floor PbD has a direct effect on children's PbB while sill PbD has an indirect effect on children's PbB as mediated by floor PbD (U.S. HUD 2004). In the NHANES data analyzed in this article, floor PbD is more predictive of PbB than sill PbD (R^2=19.4% for floors, R^2=11.9% for sills, R^2= 23.0% for floors and sills combined). When floor PbD = 12 µg/ft^2, we show that 4.6% of children have PbB≥ 10 µg/dL (Table 6). Based on the logistic model for 10µg/dL, when floor PbD=12 µg/ft^2, sill PbD=90 μg/ft^2, and other covariates are at their national averages, the model predicts that 95% of children have PbB<10μg/dL. If homes have floor PbD below 12 μg/ft^2 and sill PbD below 90 μg/ft^2 less than 5% of children would have PbB≥ 10μg/dL.

The national estimate of the geometric mean (GM) floor PbD in U.S. housing for 1998-2000 was 1.1 μg/ft^2 (Jacobs et al. 2002). Furthermore, data from high-risk houses in the U.S. HUD evaluation study showed that PbD on floors continued to decline after the intervention, dropping from a GM of 14 μg/ft^2 immediately after intervention to a GM of only 4.8 μg/ft^2 six years after hazard control (Wilson et al. 2006). Together, these data demonstrate that floor PbD is well below the current federal standard of ≤ 40 μg/ft^2 for the vast majority of houses.

Historically, allowable PbD levels have declined, as research has progressed. In the early 1990's, Maryland enacted a floor PbD standard of ≤ 200 μg/ft^2 (Code of Maryland 1988). U.S. EPA issued guidance in 1995 lowering the floor PbD level to ≤ 100 μg/ft^2. And in 1999-2001, U.S. HUD and U.S. EPA promulgated a floor PbD standard of ≤ 40 μg/ft^2, which has remained unchanged. Our findings suggest that floor and window sill PbD should be kept as low as possible. Levels of PbD on floors between 6 μg/ft^2 and 12 μg/ft^2 can be expected to protect most children living in pre-1978 homes from having a blood lead level ≥10 μg/dL. Protection at lower blood lead levels would require lower PbD.

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Table 1. Models predicting children's log PbB based on floor PbD

Statistic	Term	Dataset: Evaluation [a]	NHANES	RA Study [b]	Rochester [c]
Regression	Intercept	1.664(0.073)	0.826 (0.023)	0.938(0.193)	1.168(0.194)
Coefficient (SE)	Log (floor PbD)	0.269(0.042) (p<0.001)	0.319(0.029) (p<0.001)	0.491(0.293) (p=0.096)	0.340(0.103) (p=0.003)
	$(\text{Log (floor PbD)})^2$	-0.022(0.006) (p=0.001)	0.033(0.008) (p<0.001)	0.003(0.117) (p=0.980)	-0.021(0.012) (p=0.083)
	$(\text{Log (floor PbD)})^3$	-	-0.014(0.004) (p<0.001)	-0.009(0.013) (p=0.498)	-
Overall p-value for Log (floor PbD)		(p<0.001)	(p<0.001)	(p<0.001)	(p<0.001)
R^2		6.9%	23.6%	23.3%	8.6%
Mean-square error		0.512	0.262	0.532	0.350
Number of children/units		1096	2065	203	205

SE = Standard error

[a] (Galke et al. 2001; U.S. HUD 2004)

[b] (Wilson et al. 2007)

[c] (Lanphear et al. 1996a, 1996b)

Table 2. Descriptive statistics for PbB, housing and demographic variables (NHANES 1999-2004)

		All Homes			Pre-1978 Homes		
			Weighted			Weighted	
Variable	Levels	N	GM(GSE)	AM(SE)	N	GM(GSE)	AM(SE)
PbB (µg/dL)	-	2155	2.03(1.03)	2.51(0.09)	731	2.16(1.03)	2.69(0.10)
Age in months	-	2155	33.6(1.01)	36.7(0.35)	731	33.4(1.02)	36.6(0.64)
Cotinine (ng/ml)	Missing	1326	-	-	449	-	-
	Non missing	829	0.18(1.14)	1.02(0.11)	282	0.18(1.18)	0.97(0.20)
Floor surface/condition[a] * floor PbD (µg/ft²)	Missing	90	-	-	0	-	-
	Not smooth & cleanable	25	1.70(1.47)	4.92(2.11)	8	1.26(1.69)	4.67(3.60)
	Smooth & cleanable or carpeted	2040	0.52(1.05)	1.34(0.14)	723	0.64(1.07)	1.78(0.31)
	All non-missing	2065	0.52(1.05)	1.34(0.14)	731	0.64(1.07)	1.80(0.31)
Poverty income ratio[b]	Missing	136	-	-	24	-	-
	Non missing	2019	-	2.07(0.05)	707	-	2.25(0.09)
Window sill PbD (µg/ft²)	Missing	537	-	-	130	-	-
	Non missing	1618	7.64(1.07)	57.8(9.42)	601	10.5(1.11)	71.8(14.8)

[a] Table 1 in the companion article presents descriptive statistics by the expanded groups of floor surface/condition
[b] Geometric Mean and Geometric Standard Error are undefined due to zero values.
GM= Geometric Mean, GSE= Geometric Standard Error, AM=Arithmetic Mean, SE=Standard Error

Table 3. Descriptive statistics for PbB, housing and demographic categorical variables (NHANES 1999-2004)

		All Homes			Pre-1978 Homes		
			Weighted Percent			Weighted Percent	
Variable	Levels	N	Missing Included	Missing Excluded	N	Missing Included	Missing Excluded
PbB ≥ 5µg/dL	No	1918	91.88	91.88	643	90.84	90.84
	Yes	237	8.12	8.12	88	9.16	9.16
PbB ≥ 10µg/dL	No	2104	98.29	98.29	708	97.97	97.97
	Yes	51	1.71	1.71	23	2.03	2.03
PbB ≥ 15µg/dL	No	2140	99.67	99.67	725	99.65	99.65
	Yes	15	0.33	0.33	6	0.35	0.35
Home-apartment type	Missing	39	1.77	-	7	0.47	-
	A mobile home or trailer	205	9.77	9.95	20	2.69	2.70
	One family house detached	1047	57.19	58.23	490	72.93	73.27
	One family house attached	218	9.21	9.38	82	9.93	9.98
	Apartment (1-9 units)	302	10.40	10.59	60	6.98	7.01
	Apartment (10+ units)	344	11.65	11.86	72	7.00	7.03
Year of construction	Missing	840	28.10	-	-	-	-
	1990 to present	287	19.61	27.28	-	-	-
	1978 to 1989	265	14.84	20.64	-	-	-
	1960 to 1977	304	14.35	19.96	300	39.43	39.43
	1950 to 1959	168	7.43	10.34	158	19.38	19.38
	1940 to 1949	82	4.27	5.94	76	11.00	11.00
	Before 1940	209	11.39	15.84	197	30.19	30.19
Anyone smoke inside the home	Missing	23	1.50	-	1	0.46	-
	Yes	430	20.78	21.09	159	22.59	22.69
	No	1702	77.73	78.91	571	76.95	77.31
Presence of deteriorated paint	Missing	239	7.87	-	0	-	-

inside pre-1950 home[a]	Yes	121	5.99	6.50	112	15.64	15.64
	No	1795	86.14	93.50	619	84.36	84.36
Window, cabinet or wall renovation in pre-1978 home[b]	Missing	176	6.02	-	9	0.64	-
	Yes	175	9.72	10.34	166	26.34	26.51
	No	1804	84.26	89.66	556	73.02	73.49
Window, cabinet or wall renovation in pre-1950 home[c]	Missing	174	5.97	-	7	0.49	-
	Yes	70	3.98	4.23	65	10.69	10.74
	No	1911	90.05	95.77	659	88.82	89.26
Race/ethnicity	Non-Hispanic white	618	57.09	57.09	252	64.14	64.14
	Non-Hispanic black	634	15.32	15.32	188	12.54	12.54
	Hispanic[d]	837	23.82	23.82	265	20.01	20.01
	Other	66	3.77	3.77	26	3.31	3.31
Country of birth	Missing	4	0.19	-	1	0.09	-
	United States	2088	97.25	97.43	715	98.28	98.38
	Mexico	39	0.87	0.87	7	0.43	0.43
	Elsewhere	24	1.70	1.70	8	1.19	1.19

[a]Yes= Presence of deteriorated paint inside AND pre-1950 home, No=No deteriorated paint inside OR post-1950 home.
[b]Yes = window, cabinet or wall renovation AND pre-1978 home, No= No renovation OR post-1978.
[c]Yes = window, cabinet or wall renovation AND pre-1950 home, No= No renovation OR post-1950.
[d] 66% of Hispanics are Mexican-Americans

Table 4. Linear model results for log children's PbB (n=2155, R^2=40%)

Variables	Overall P-Value	Levels	Estimate (SE)	P-value
Intercept	0.172		-0.517(0.373)	0.172
Age (in years)	<0.001	Age	2.620(0.628)	<0.001
		Age^2	-1.353(0.354)	<0.001
		Age^3	0.273(0.083)	0.002
		Age^4	-0.019(0.007)	0.008
Year of construction	0.014	Intercept for missing	-0.121(0.052)	0.024
		1990 to present	-0.198(0.058)	0.001
		1978 to 1989	-0.196(0.060)	0.002
		1960 to 1977	-0.174(0.056)	0.003
		1950 to 1959	-0.207(0.065)	0.003
		1940 to 1949	-0.012(0.072)	0.870
		Before 1940	0.000	-
Poverty income ratio	<0.001	Intercept for missing	0.053(0.065)	0.420
		Slope	-0.053(0.012)	<0.001
Race/ethnicity	<0.001	Non-Hispanic white	0.000	-
		Non-Hispanic black	0.247(0.035)	<0.001
		Hispanic	-0.035(0.030)	0.251
		Other	0.128(0.070)	0.073
Country of birth	0.002	Missing	-0.077(0.219)	0.728
		United States (50 states or DC)	0.000	-
		Mexico	0.353(0.097)	<0.001
		Elsewhere	0.154(0.121)	0.209
Floor surface/condition*	<0.001	Intercept for missing	0.178(0.094)	0.065

log floor PbD		Not smooth & cleanable	0.386(0.089)	<0.001
		Smooth & cleanable or carpeted	0.205(0.032)	<0.001
Floor surface/condition* (log floor PbD)^2		Not smooth & cleanable	0.023(0.015)	0.124
		Smooth & cleanable or carpeted	0.027(0.008)	0.001
Floor surface/condition* (log floor PbD)^3		Uncarpeted not smooth & cleanable	-0.020(0.014)	0.159
		Smooth & cleanable or carpeted	-0.009(0.004)	0.012
Log window sill PbD	0.002	Intercept for missing	0.053(0.040)	0.186
		Slope	0.041(0.011)	<0.001
Home-apartment type	<0.001	Intercept for missing	-0.064(0.097)	0.511
		Mobile home or trailer	0.127(0.067)	0.066
		A One family house detached	-0.025(0.046)	0.596
		A One family house attached	0.000	-
		Apartment (1-9 units)	0.069(0.060)	0.256
		Apartment (10+ units)	-0.133(0.056)	0.022
Anyone smoke inside the home	0.015	Missing	0.138(0.140)	0.331
		Yes	0.100(0.040)	0.015
		No	0.000	-
Log cotinine concentration (ng/dL)	0.004	Intercept for missing	-0.150(0.063)	0.023
		Slope	0.039(0.012)	0.002
Window, cabinet or wall renovation in a pre-1978 home	0.045	Missing	-0.008(0.061)	0.896
		Yes	0.097(0.047)	0.045
		No	0.000	-

SE = Standard Error

Table 5. Model results for log odds children's PbB ≥ 5µg/dL and ≥ 10 µg/dL (n=2155, R^2=16% and 5%)[a]

		PbB ≥ 5µg/dL			PbB ≥ 10µg/dL		
Term	Levels	Overall p-value	Estimate (SE)	P-value	Overall p-value	Estimate (SE)	P-value
Intercept		0.005	-13.004(4.365)	0.005	0.048	-14.170(6.976)	0.048
Age (in months)	Age	0.007	18.783(7.069)	0.011	0.068	14.703(11.140)	0.194
	Age^2		-10.455(4.039)	0.013		-6.801(6.673)	0.314
	Age^3		2.358(0.959)	0.018		1.170(1.687)	0.492
	Age^4		-0.189(0.081)	0.024		-0.066(0.149)	0.659
Poverty income ratio	Intercept for missing	0.006	0.319(0.444)	0.477	-	-	-
	Slope		-0.267(0.099)	0.010		-	-
Race/ethnicity	Non-Hispanic white	0.003	0.000	.	0.038	0.000	.
	Non-Hispanic black		0.712(0.303)	0.023		0.696(0.373)	0.068
	Hispanic		-0.468(0.336)	0.171		-0.590(0.513)	0.257
	Other		-0.048(0.928)	0.959		-0.118(1.002)	0.907
Country of birth	Intercept for missing	0.002	-0.518(1.140)	0.652	-	-	-
	United States		0.000	-	-	-	-
	Mexico		2.459(0.641)	<0.001	-	-	-
	Elsewhere		0.113(1.145)	0.922	-	-	-
Log floor PbD	Intercept for missing	<0.001	0.989(0.410)	0.020	<0.001	1.405(0.630)	0.031
	Slope		0.807(0.133)	<0.001		0.710(0.155)	<0.001
Log window sill PbD	Intercept for missing	0.056	0.466(0.336)	0.172	0.071	1.234(0.653)	0.066
	Slope		0.198(0.080)	0.017		0.242(0.102)	0.022
Home-apartment type	Intercept for missing	0.029	-0.434(0.727)	0.553	0.048	1.638(0.802)	0.047
	Mobile home or trailer		-0.078(0.428)	0.857		0.480(0.605)	0.432
	One family house detached		-0.373(0.295)	0.214		0.212(0.357)	0.556

	One family House Attached		0.000	-		0.000	-
	Apartment (1-9 units)		-0.276(0.361)	0.449		0.334(0.508)	0.515
	Apartment (10+ units)		-1.022(0.326)	0.003		-1.173(0.569)	0.045
Window, cabinet or a wall renovation in pre-1950 home	Missing	0.004	-0.052(0.320)	0.872	-	-	-
	Yes		1.203(0.399)	0.004		-	-
	No		0.000	-		-	-
Presence of deteriorated paint inside a pre-1950 home	Intercept for Missing	-	-	-	0.019	-0.012(0.292)	0.968
	Yes		-	-		1.263(0.520)	0.019
	No -	-	-	-		0.000	-
Log cotinine concentration (ng/dL)	Intercept for missing	<0.001	-0.299(0.378)	0.434	0.006	-1.074(0.931)	0.255
	Slope		0.483(0.117)	<0.001		0.455(0.153)	0.005

[a] Approximate R^2 from Cox-Snell methodology

Table 6. Estimated PbB for children living in pre-1978 housing by floor PbD (NHANES 1999-2004)

Floor PbD ($\mu g/ft^2$)	Percent of Homes ≥ Floor PbD	GM PbB (90% CI)[a]	Probability(%) PbB ≥ 10μg/dL (90% CI)[b]	Probability(%) PbB ≥ 5μg/dL (90% CI)[c]
0.25	79.1%	1.7(1.6,1.8)	0.2(0.1,0.6)	1.1(0.7,1.8)
0.50	55.4%	1.9(1.8,2.0)	0.4(0.1,1.0)	2.1(1.4,3.1)
1.00	30.5%	2.2(2.1,2.3)	0.6(0.3,1.5)	3.8(2.7,5.5)
1.50	21.8%	2.4(2.3,2.6)	0.9(0.4,1.9)	5.4(3.7,7.9)
2	16.7%	2.6(2.4,2.8)	1.1(0.6,2.2)	6.9(4.6,10.2)
4	8.0%	3.1(2.8,3.4)	2.0(1.1,3.5)	12.1(7.7,18.5)
5	4.9%	3.3(2.9,3.6)	2.3(1.3,4.1)	14.4(9.0,22.2)
6	4.2%	3.4(3.0,3.8)	2.7(1.5,4.7)	16.5(10.2,25.6)
7	3.7%	3.5(3.1,4.0)	3.0(1.7,5.3)	18.5(11.3,28.7)
8	3.5%	3.6(3.2,4.1)	3.4(2.0,5.8)	20.3(12.3,31.7)
9	3.3%	3.7(3.3,4.2)	3.7(2.1,6.4)	22.1(13.3,34.4)
10	3.0%	3.8(3.3,4.3)	4.0(2.3,6.9)	23.8(14.2,36.9)
12	2.5%	3.9(3.4,4.5)	4.6(2.7,7.9)	26.8(16.0,41.5)
14	2.1%	4.0(3.5,4.7)	5.2(3.0,9.0)	29.6(17.5,45.5)
16	1.4%	4.1(3.6,4.8)	5.8(3.3,10.0)	32.2(19.0,49.0)
18	1.3%	4.2(3.6,4.9)	6.4(3.6,11.0)	34.5(20.3,52.1)
20	1.3%	4.3(3.6,5.0)	6.9(3.9,11.9)	36.6(21.6,54.9)
22	1.2%	4.3(3.7,5.1)	7.4(4.1,12.9)	38.6(22.8,57.3)
24	1.2%	4.4(3.7,5.2)	7.9(4.4,13.8)	40.5(23.9,59.6)
26	0.7%	4.4(3.7,5.2)	8.4(4.6,14.8)	42.2(25.0,61.6)
28	0.7%	4.4(3.7,5.3)	8.9(4.8,15.7)	43.8(26.0,63.5)
30	0.7%	4.4(3.7,5.4)	9.3(5.1,16.6)	45.4(26.9,65.2)
32	0.6%	4.5(3.7,5.4)	9.8(5.3,17.4)	46.8(27.9,66.7)
34	0.6%	4.5(3.7,5.5)	10.2(5.5,18.3)	48.1(28.7,68.1)
36	0.5%	4.5(3.6,5.6)	10.7(5.7,19.1)	49.4(29.6,69.4)
38	0.4%	4.5(3.6,5.6)	11.1(5.9,20.0)	50.6(30.4,70.6)
40	0.4%	4.5(3.6,5.7)	11.5(6.1,20.8)	51.8(31.2,71.8)

GM= Geometric Mean

[a] Based on the linear model for log PbB.

[b] Based on the logistic model for PbB ≥ 10μg/dL.

[c] Based on the logistic model for PbB ≥ 5μg/dL.

Figure Legends

Figure 1: Predicted PbB (µg/dL) based on Floor PbD (µg/ft2) by Dataset. Triangle = Evaluation, circle= NHANES, square = RA Study, asterisk = Rochester