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Source contributions of lead in residential floor dust and within-home variability of dust lead loading

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HIGHLIGHTS

- We estimated the contribution of lead sources to residential floor dust contamination.
- Dust lead from the landing of an apartment is the major contributor.
- Track-in of the exterior soil contaminates common area dust and interior dust.
- Exterior railings, smoking inside, demolitions, polluting sites are also contributors.
- Interior lead-based paint is no longer a contributor except for non-renovated homes.

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ABSTRACT

Evidence of the impact of exposure to low levels of lead on children's health is increasing. Residential floor dust is the assumed origin of lead exposure by young children. In this study, we estimate the contribution of different lead sources to household interior floor dust contamination. We also estimate the within-home variability of interior floor dust lead loadings. A multilevel model was developed based on data collected in a French survey in 2008–2009 (484 housing units, 1834 rooms). Missing data were handled by multiple imputation using chained equations. The intra-home correlation between interior floor Log dust lead loadings was approximately 0.6. Dust lead from the landing of an apartment, mostly originating outside the building, was the major contributor to interior floor dust lead. Secondary contributors included the lead-based paint on exterior railings, track-in of the exterior soil of the children's play area into the dwelling, smoking inside the home, demolition of nearby old buildings and sites of pollution in the vicinity. Interior lead-based paint contaminated interior floor dust only in old and non-renovated dwellings. To reduce interior floor dust lead levels in the general population of dwellings, common areas should be maintained, and track-in from the outside should be limited as much as possible.

1. Introduction

Policy measures have reduced lead exposure in industrialized countries. In France, for example, these measures include the phase-out of leaded gasoline in 2000, a ban on the use of lead-based paint (LBP) by professionals in 1926 and 1948, and the establishment of housing lead hazard reduction methods in 1999. Consequently, blood lead levels (BLLs) have sharply decreased, notably in France. In 1996, the prevalence of elevated BLLs (≥100 μg/L = 10 μg/dL) was estimated at 5% in adults and 2% in children in France (INSERM, 1999), decreasing to 1.7% in adults for the years 2006–2007 (Falq et al., 2011) and to 0.11% in children for the period 2008–2009 (Etchevers et al., 2010).

Meanwhile, scientific evidence of the effects of exposure to low levels of lead in children is increasing (Canfield et al., 2003; Lanphear et al., 2005), and exposures that were previously considered low are still of concern. The "level of concern" equal to 100 μg/L at which intervention was previously recommended in the United States

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was lowered to the “reference value” of 50 μg/L (5 μg/dL) in 2012 (ACCLPP, 2012; CDC, 2012). Similarly, in France, a reduction of the level of 100 μg/L to an as-yet undetermined threshold is underway. A further reduction of the lead levels in environmental media is an ongoing goal.

Dust is a major residential media of interest for lead exposure in children (Lanphear et al., 1998) and is the strongest predictor of BLL (Lanphear et al., 1996, 1998, 2002; Oulhote et al., 2013). Some authors have studied the contribution of different sources of lead to dust lead (DPb) levels. For instance, Sturges and Harrison (1985) studied the contribution from paint flakes to the lead content of household dust, Lanphear and Roghmann (1997) demonstrated that the contribution of LBP was greater than the contribution of lead-contaminated soil, and Dixon et al. (2005b) studied the migration of DPb from common areas in multiunit buildings into the associated dwelling. Other studies assessed the contamination of floor dust by lead sources in special contexts, such as around a lead mining unit (Sterling et al., 1998) or after LBP hazard control (Clark et al., 2004). To our knowledge, no study has assessed the joint contribution of numerous potential sources of lead to interior floor DPb levels. Moreover, previous results may be outdated because exposure reduction actions may have changed the relationships between the environmental media containing lead.

In addition, the number of wipes that must be used to sample house floor dust to ensure a representative sample of the level of lead in a home remains uncertain. According to the guidelines of the U.S. Department of Housing and Urban Development (HUD), either a minimum of 3 composite samples or at least 6 to 8 single-surface samples should be collected on floors, window sills, and window troughs (U.S. HUD, 1995). More precisely, 1 composite sample from 4 rooms or 4 rooms with 1 single-surface sample should be collected. According to the French Institute for Public Health Surveillance (InVS), a single floor dust sample is insufficient for assessing the lead contamination level of a housing unit. Three single-surface samples per dwelling are recommended (Bretin, 2006). However, these recommendations are not based on studies of the correlation between lead loadings in interior floor dust.

In this study, we estimate the contributions of potential lead sources to household interior floor DPb levels. We also estimate the within-home variability of interior floor DPb loadings to ascertain whether one dust sample is sufficient to estimate the DPb contamination level in a housing unit.

2. Materials and methods

2.1. Surveys and study population

Data were collected in a survey called Plomb-Habitat (PHS) that was conducted in France, excluding overseas regions, between October 2008 and August 2009. PHS was a nested survey in the Saturn-Inf survey (SIS). SIS was a prevalence survey of childhood lead poisoning that was conducted in hospitals and in which 3831 children were enrolled (Etchevers et al., 2010). Data were collected from the housing of a subsample of 484 children to study the relationship between BLLs and environmental lead. Thus, 484 primary residences (as opposed to second homes) of the sample of children were investigated (139 multi-dwelling units and 349 single-detached dwellings). Parents agreed to participate. For inclusion, the child had to have lived in the dwelling for at least 6 months prior to enrollment. This home sample was representative of 3,581,991 French housing units in which at least one child aged 6 months to 6 years lived in 2008 (Lucas et al., 2012).

2.2. Sample collection

PHS consisted of a face-to-face questionnaire and measurements. The questionnaire included approximately 350 items and collected information about housing characteristics, the outdoor environment, the specific behavior of the child, and more general information related to lead sources.

In each housing unit, up to 5 rooms were investigated, including the child's bedroom, the living room, the main entrance, the kitchen, the bedroom of another child, and the playroom. For each investigated room, a single-surface sample of interior floor dust was collected by wipe sampling (μg/m^2) according to a standard protocol (ASTM, 2003). The different building elements of each room were measured with an X-ray fluorescence lead-based paint analyzer (mg/cm^2) in accordance with the French regulatory protocol (AFNOR, 2008c); a single brand was used (Niton). Paint chips were collected if the occupant agreed. Among the 484 housing units, 1834 rooms were investigated. If the child usually played outside of the home, the ground of his or her play area was sampled by wiping according to the same protocol as inside if its surface was a hard surface (μg/m^2) or by coring if it was soil (mg/kg). For soil, a composite sample (10 samples) was taken from the 0 to 2 cm layer and prepared according to a standard protocol (AFNOR, 2006).

Samples were analyzed by inductively coupled plasma mass spectrometry. The limits of quantification (LOQ) were 2 μg/m^2 for dust and 1.3 mg/kg for soil. Total and leachable lead concentrations or loadings were determined for each sample (Le Bot et al., 2011).

The details of the sample collection and data quality have been described extensively elsewhere (Lucas et al., 2012).

2.3. Statistical analysis

2.3.1. Modeling

We developed a model in which a set of covariates denoted X (in particular, the lead sources) explains a response variable denoted Y (the interior floor dust Log lead loadings). Classical linear regression is associated with single-level modeling. Because here we collected data about two different levels – rooms and dwellings – single-level linear regression was not an appropriate modeling method to take into account the non-independence between floor DPb loadings within a dwelling. Thus, we used a multilevel model (MLM), also known as a mixed model or hierarchical model. Related equations and assumptions are described in the Supplementary information. Rooms are called level-1 units and dwellings level-2 units.

The response variable was Log-transformed by natural logarithm ($\mathrm{Log} \equiv \log_e$) to allow us to approach the hypothesis of normality required for the errors in the model. Numerical covariates were also Log-transformed because such a transformation provides a good model to explain variability in the observations for lead exposure data (Jiang and Succop, 1996; Rust et al., 1997). When covariate X had null values, the Log-transformation was $\mathrm{Log}(X + 1)$, and it was $\mathrm{Log}(X)$ otherwise.

The within-home variability was represented by 1-ρ, where ρ is the intraclass correlation coefficient equal to $\sigma^2_L/(\sigma^2_L+\sigma^2)$ and a measure of reproducibility of replicate measures from the same subject (home).

Because the data were obtained from a survey, weights should be used in the statistical method for fitting an MLM, called the pseudo-maximum likelihood (Rabe-Hesketh and Skrondal, 2006). MLM on survey data is an active area of research in applied statistics. The existing literature focuses on appropriate choices for weights of level-1 units when these units are selected with unequal probabilities (Pfeffermann et al., 1998; Carle, 2009). Level-1 weights were not an issue in this study because rooms were not randomly selected. Rooms were automatically investigated if they belonged to the list indicated in Section 2.2. No scientific paper seems to have studied level-2 weights precisely. In a related simulation study of our data, we determined that it was better not to introduce level-2 weights and to ultimately fit an unweighted model (Lucas et al., 2013).