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ScienceDirect

Environmental Research 102 (2006) 237–248

Environmental Research
www.elsevier.com/locate/envres

Evaluation of HUD-funded lead hazard control treatments at 6 years post-intervention☆

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Received 28 October 2005; received in revised form 17 March 2006; accepted 14 April 2006
Available online 5 June 2006

Summary

The Evaluation of the HUD Lead-Based Paint Hazard Control Grant Program (Evaluation) was a HUD-funded study of the effectiveness of lead hazard control (LHC) treatments conducted by 14 grantees in communities across the country. A stratified random sampling scheme was used to select treated units at four grantee sites for continued environmental assessment at 6 years post-intervention. The study compared the relative effectiveness after 6 years of the different classes of interventions used by the grantees, after controlling for such factors as housing conditions and characteristics and resident and neighborhood characteristics. Geometric mean dust-lead levels on floors and window sills were 11% and 23% lower, respectively, at 6 years post-intervention than at any preceding point following the intervention. Although geometric mean window trough dust-lead levels were slightly higher at 6 years post-intervention than at other post-intervention time periods, they were still over 75% lower than before intervention. Treatment at more-intensive levels was associated with lower window sill and window trough dust-lead levels; however, statistical modeling found no significant difference in floor dust-lead loadings over time between the levels of treatment; however, significant differences in window sill and window trough dust-lead levels between treatment levels were evident. Findings from the 6-Year Extension study indicate that across all grantees and treatment strategies the treatments applied were effective at significantly reducing environmental lead levels on floors, window sills, and window troughs at least 6 years following the intervention.

Keywords: Interior dust lead levels; Lead poisoning; HUD lead hazard control grant program; Lead-based paint

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1. Introduction

Since 1993, the US Department of Housing and Urban Development (HUD) has been providing Lead-Based Paint Hazard Control Grants to assist States and local governments with supporting comprehensive programs to identify and control lead-based paint hazards in low income, private homes. There have been 12 funding rounds, with 345 grants totaling approximately $1 billion awarded to date (US HUD, 2004a, b). In the interest of measuring the technical and cost effectiveness of the federally funded interventions undertaken to reduce lead hazards, HUD initiated an evaluation (the Evaluation) covering a range of

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☆This work was conducted by Battelle and the National Center for Healthy Housing under Contract No. C-OPC-21357 with the US Department of Housing and Urban Development's Office of Healthy Homes and Lead Hazard Control (HUD OHHLHC). The study followed the human subjects guidelines established by an independent institutional review board, registered with the US Department of Health and Human Services, convened at Battelle Memorial Institute and the conditions contained on the informed consent forms signed by participants.

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doi:10.1016/j.envres.2006.04.007

interventions designed and implemented by 14 state and local lead hazard control (LHC) grantees. Data collection for the study began in 1994 and was completed in late 1998. (Galke et al., 2001) A total of 2920 dwelling units were treated and eligible for inclusion in the Evaluation. Of these, 2682 had verification of final clearance with 2463 of those assessed at 12 months following clearance, 826 assessed at 24 months, and 695 assessed at 36 months. At 1, 2, and 3 years after treatment, environmental lead dust levels and children's blood lead levels were at significantly reduced levels from before the intervention (Dixon et al., 2005; National Center for Healthy Housing and University of Cincinnati Department of Environmental Health (NCHH and UC), 2004). This paper reports on environmental lead levels only in a subset of study units that were assessed 6 years following treatment. This study is the largest and longest assessment of modern lead hazard controls in housing so far reported.

Previous studies have examined the effectiveness of LHC interventions, but they have not examined effects beyond $3\frac{1}{2}$ years post-intervention (US EPA, 1998a). LHC interventions are generally categorized as either abatement or interim controls, with abatement defined as measures that permanently eliminate lead-based paint hazards (e.g., removal, enclosure) and interim controls considered measures that temporarily reduce lead-based paint hazards (e.g., specialized cleaning, stabilization of deteriorated paint) (US HUD, 1995). LHC programs often employ strategies that incorporate both abatement and interim control measures (e.g., window replacement and paint stabilization). Comprehensive abatement of lead-based paint, when followed by a thorough cleaning of all horizontal surfaces, has been shown to significantly reduce dust lead loadings up to three and a half years following treatment. (Farfel and Chisholm, 1990; Farfel et al., 1994) Comprehensive abatement as cited in the Farfel and Chisholm papers included fixing water leaks, treating all lead painted surfaces with replacement and enclosure methods, replacing windows, making floors smooth and cleanable, and thorough cleaning with wet washing and HEPA vacuuming.

Studies conducted more recently have generally focused on examining the effectiveness of strategies that incorporate interim control measures as part of the treatment approach. By definition, interim controls are expected to require some degree of ongoing maintenance to maintain their effectiveness. An early randomized trial of interim control measures in Boston observed slight reductions in floor dust lead loadings 6 months after intervention and greater reductions in window sill and trough dust lead loadings (Ashengrau et al., 1998). The sample size of the study was limited, however, and none of the changes were statistically significant. A study in Baltimore of three levels of LHC intervention, varying in intensity and cost, reported significant declines in dust lead loadings from pre-intervention through 2 years post-intervention, with the higher intensity interventions showing greater reductions on window surfaces (US EPA, 1998b). Similar findings were observed during the first 3 years of the Evaluation of the HUD Lead Based Paint Hazard Control Grant Program (National Center for Healthy Housing, 2004; Dixon et al., 2005).

Through the 6-Year Extension Study, HUD funded follow-up environmental sampling and assessment at a subset of the base Evaluation units at the 6-year anniversary of their LHC intervention. Four of the original grantees that participated in the Evaluation also participated in this 6-year follow-up study and included the State of Minnesota, the City of Milwaukee, the State of Vermont, and New York City, representing a mix of urban and rural housing. Base Evaluation grantees targeted homes with children under 6 years (72 months) old either diagnosed with lead poisoning or with elevated blood lead levels (EBLs ($\geqslant 10\,\mu g/dL$), homes that previously housed children who were lead poisoned or with EBLs, homes in high risk communities, or homes receiving other housing services. The principal objective of the 6-Year Extension was to determine if the benefits of the intervention strategies cease prior to 6 years post-intervention. The study also compared the relative effectiveness of the different classes of intervention strategies, after controlling for such factors as baseline environmental condition (BEC), exterior lead dust, soil-lead levels, and housing and resident characteristics. This article describes the effectiveness of the interior treatment strategies as determined by the levels of lead dust measured on floors, window sills, and window troughs.

2. Materials and methods

2.1. Sampling design

The design of the base Evaluation assumed that, over time, the efficacy of the LHC interventions performed under the HUD grants may decline and that leaded dust could re-accumulate in the dwellings. The base Evaluation, the 3-year extension, and related analyses demonstrated significant differences in the performance of different interior treatment strategies; however, these results were likely affected by confounding between treatment and pre-intervention conditions. Because the base Evaluation was not a randomized control trial, no attempts were made to ensure that each different type of LHC treatment was applied across a sample of residential units with varying baseline environmental conditions. Each Grantee pursued LHC treatments based on the best judgment and expertise of its staff.

HUD sponsored a 6-year post-intervention follow-up study that would attempt to account for the effects of the confounding and determine the longer-term effectiveness of the interventions. The selection of treated dwellings from the base Evaluation for additional environmental assessment at 6 years post-intervention occurred via a stratified random sampling scheme. The primary sampling strata identified were treatment intensity level and BEC of the dwelling prior to treatment. The strata were initially constructed to provide adequate representation across two levels of interior treatment intensity (low and medium) and three BEC levels (low risk, medium risk, and high risk). Although some dwellings received a higher level of treatment, the higher treatment level was not incorporated into the primary sampling scheme because application of these treatments was not widespread. Table 1 summarizes the three levels of treatment intensity and Table 2 summarizes the criteria for the three BEC categories.

Table 1
Treatment intensity category definitions

Intensity	Treatments applied
Low	Cleaning, spot or complete paint stabilization; other possible treatments: caps on window sills/troughs, floor treatments
Medium	Cleaning, complete paint stabilization, floor treatments, window treatments and/or window replacement; other possible treatments: abatement of other selected components
High	All lead-based paint enclosed, encapsulated, or removed (meets public housing abatement standards)

Table 2
Baseline environmental condition category definitions

Geometric mean sill dust lead loading (μg/ft^2)	Geometric mean floor dust lead loading (μg/ft^2)		
	Floor $\leqslant 15$	$15 < \text{Floor} \leqslant 50$	$50 < \text{Floor}$
Sill $\leqslant 150$	Low	Low	Medium
$150 < \text{Sill} \leqslant 500$	Low	Medium	High
$500 < \text{Sill}$	Medium	High	High

Table 3
Numbers of targeted dwelling units in original sampling scheme for 6-year extension study

Treatment intensity	Baseline environmental condition			Total
	Low	Medium	High	
Low	110	60	30	200
Medium	110	60	30	200
Total	220	120	60	400

The investigators used information provided by the Grantees to categorize the treatments as low-, mid-, and high-level interventions. Paint film stabilization and specialized cleaning of dust typified low-level interventions. In some homes, window sills and troughs were capped with aluminum to reduce paint exposure and improve the cleanability of the surfaces. Partial or full window abatement plus abatement of selected surfaces with lead-based paint typified mid-level interventions. Partial window abatement refers to the use of abatement methods for some window components (e.g., stripping paint from sashes) and interim controls on other components. The high-level treatment units, all located in New York City, underwent full abatement. The "low" BEC rating corresponds to the lower mean floor and sill dust lead loadings, i.e., a relatively cleaner environment prior to LHC work. Conversely, the "high" BEC rating indicated higher dust-lead loadings on these components. Four hundred treated dwellings were selected for enrollment across the two primary treatment categories and the three BEC levels. Table 3 displays the distribution of the targeted 400 dwelling units across each combination of treatment intensity and BEC in the original study design. An additional 30 dwellings in New York City that received high-level treatments (representing removal, enclosure, or encapsulation of all lead-based paint) were also targeted for inclusion in the study. Data collectors successfully enrolled and conducted environmental data collection at 426 dwellings—400 in the primary sampling group and 26 of the high-level treatment units—at 242 separate buildings.

The data collection protocol established a ± 7 month window around the 6th year anniversary of the clearance date (i.e., the date the unit was cleared for reoccupancy) as the target time for environmental sampling. In 80% of the dwellings enrolled, environmental sampling was performed within 5 months of the targeted 6-year anniversary of the original clearance date. Two enrolled units whose data collection occurred significantly beyond the 7-month window were excluded from analyses. The relatively large window around the 6-year anniversary of clearance was used in order to expedite field data collection as treatments at each site were generally conducted over a 1.5–2-year period.

2.2. Available data

Three sets of data across seven data collection phases were used for the 6-Year Extension Study analysis—(1) the records of the base Evaluation (pre-intervention, immediately post-intervention, 6-months post-intervention, 12-months post-intervention), (2) the records from the 3-year Evaluation (24-months post-intervention and 36-months post-intervention), and (3) new (72-month post-intervention) data collected via the 6-Year Extension Study. The stratified sampling plan for dwellings in the study gave higher weight to housing units that had previously participated in the 3-year Evaluation. To ensure consistency of data collection, data collectors underwent standard training and auditors conducted multiple field quality control visits at each site. A limited description of Evaluation design and methods is presented in this paper but a more comprehensive description is available in other papers (Galke et al., 2001, 2005). Details about environmental sample collection in the 6-Year Extension are presented below.

To obtain interior dust lead loadings, which are the focus of this article, data collectors gathered wipe samples from floors, window sills, and window troughs following a standard protocol (HUD, 1995). Seven to nine dust samples were collected from each dwelling at each phase, from a consistent set of locations within each dwelling across phases. Floor dust samples were collected at the interior entry, child's playroom, kitchen, youngest child's bedroom (or smallest bedroom), and second youngest child's bedroom (if present). Floor samples were collected from a 1 ft^2 area just inside the door of the entryway to the room. When both bare and carpeted floor were available, the sample was obtained from the floor type sampled in previous phases. Sill dust samples were collected on interior window sills in the kitchen and youngest child's bedroom (or smallest bedroom). Trough dust samples were collected on window troughs in the child's playroom (or living room) and next youngest child's bedroom (if present). The window dust wipe samples were obtained from approximately 0.1 ft^2 areas (approximately 4 in × 4 in) of the same components that were sampled at the pre-intervention visit. Samples were taken from half of the windowsill and window trough with the half sampled alternating from phase to phase (e.g., left at pre-intervention, right at clearance, left at 6-months, right at 1-year, left at 2-years, right at 3-years). Similarly, floor samples were taken from alternate sides of the doorway with the side sampled alternating by phase. The type of surface that was wiped and its condition were also recorded. The same sampling scheme was implemented at all phases of data collection. Composite soil samples were collected from the perimeter of buildings with available soil. At each sampling location, surface cover and presence of paint chips was noted. Soil samples were not collected in New York City. Exterior dust wipe samples were collected from the step/sidewalk just outside the main building entry.

All samples gathered in the 6-Year Extension study were analyzed by the University of Cincinnati's Hematology and Environmental Laboratories, which is accredited by the American Industrial Hygiene Association and participates in the Environmental Lead Proficiency Analytical Testing Program, using flame atomic absorption spectroscopy. One field spike and field blank sample was prepared and analyzed per dwelling. All data were double data entered from data collection forms. Data verification routines were performed upon entry and questionable data were checked with data collectors and corrected, where necessary. Multiple laboratories analyzed the samples gathered during the Evaluation through 3 years post-intervention using flame atomic absorption, graphite furnace, or inductively coupled plasma atomic emission spectrometry. Although the analyses were not centralized or standardized, participating laboratories were required to regularly analyze double-blind quality control samples to monitor accuracy of each laboratory's processes. Under-estimation of the actual lead content of samples, which was often due to inability of an analysis method to fully extract lead from the samples, was accounted for by applying an adjustment factor to all dust lead loadings in the period when the period and magnitude of under-reporting could be estimated. Two-percent of the field samples, which were from two laboratories, were adjusted.

For the 6-Year Extension, the UC lab provided the actual instrument values. The lab had a detection limit of 2 μg/sample. For the base and 3-year Evaluations, method detection limits of the laboratories used by the four grantees that participated in this study varied from 1 to 25 μg/sample; however, of the 8 participating laboratories, 4 had MDLs less than or equal to five while another 2 reported MDLs between 5 and 15 μg/sample. When possible, actual instrument values were obtained for samples with lead content below the reporting limits. Otherwise, dust lead values were substituted by the predicted value associated with the median percentile below each laboratory's MDL (Succop et al., 2004). Twelve percent of the floor samples and 7% of the window samples collected in dwellings included in the 6-year extension study were below the MDL. Actual machine values were used for approximately 80% of these measurements.

2.3. Statistical analyses

Both exploratory analysis and statistical modeling were performed on the data. An arithmetic mean dust lead loading was calculated for each component within each dwelling to represent unit-wide dust lead level and summary statistics were generated for each interior component across the grantees. Log-linear models that expressed the natural log-transformed dust lead loadings as a function of the explanatory variables (pre-intervention and clearance dust lead loading, exterior dust lead loading, soil lead, housing conditions, resident characteristics, and regional/neighborhood characteristics) were used to evaluate differences in treatment groups across time. The models were fitted using a variance components approach to account for the anticipated positive correlation between dust lead loadings in different dwellings within the same building. Time was represented by a categorical variable for Phase—6-months, 1-year, 2-years, 3-years, or 6-years after intervention.

Analyses compared dust-lead loadings to the current federal risk assessment standards, which are a dwelling average dust lead loading of 40 μg/ft^2 on floors and 250 μg/ft^2 on window sills. A similar comparison was not made for window troughs because of the lack of a comparable risk assessment standard for troughs. While the failure rates are presented using the current standards, the grantees actually cleared their units at their previous standards of 80 (Minnesota), 100 (New York City and Vermont), or 200 (Milwaukee) μg/ft^2 on floors and 500 μg/ft^2 on window sills. Logistic regression models were used to model the probability that the dwelling arithmetic average fails the applicable hazard standard. The logistic regression models express the probability of failing the standard as a function of the various explanatory variables.

Unit-wide dust lead levels (arithmetic mean values) less than one for floors were replaced with imputed random values from a Uniform distribution on (1,2) while arithmetic means less than 10 for window sills were replaced with random values from a Uniform distribution on (10,20). This replacement was made because differences between levels in these low ranges could be influential in the statistical modeling even though the differences are practically insubstantial.

3. Results

3.1. Housing characteristics

Four hundred and twenty-six dwellings in 242 separate buildings were enrolled. In NYC, 26 dwellings in 9 buildings had high-level treatment and 84 dwellings in 16 buildings had low- or medium-level treatments. Minnesota, Milwaukee and Vermont contributed low- and medium-level treatment dwellings: 75 dwellings in 63 buildings in Minnesota; 129 dwellings in 90 buildings in Milwaukee; and 112 dwellings in 64 buildings in Vermont.

Most of the buildings were constructed before 1910 (57%) or between 1910 and 1929 (39%). The remaining 4% were constructed between 1930 and 1949. The majority of the 242 buildings were single detached (33%) or two flats/duplexes (32%). Many buildings were either four-plexes (10%) or more than 4-unit buildings (range of 5–46 units) (17%). The remaining buildings were triplexes (7%) or rowhouses (1%). Building types varied across grantees. Buildings were primarily: single detached (57%) or two-flats/duplex (25%) in Minnesota; two-flats/duplex (54%) or single detached (31%) in Milwaukee; more than 4-unit (range of 6–46 units) (88%) in NYC; and single detached (25%), triplex (19%) or more than 4-unit (range of 5–9 units) (23%) in Vermont.

At 6-years post-intervention, 99% (416) of the dwellings were occupied and 79% of the dwellings were rentals (the remaining dwellings were owner-occupied).

3.2. Resident characteristics at 6-years post-intervention

Residents had lived in homes an average of 8 years with a range of 1 month to 52 years. On average there were 3.5 residents, including 1.6 children under 18, in the dwellings. Thirty-one percent of the dwellings had a child under 6.

Household income was reported for 90% of the dwellings. Twenty-eight percent of the residents had incomes less than \$9999 and an additional 26% had incomes between \$10,000 and 19,999. Approximately equal percentages of dwellings had incomes of \$20,000–29,999 (17%) and \$30,000–39,999 (16%). The remaining 3% reported incomes of \$50,000–74,999.

3.3. *Soil and exterior dust*

Perimeter soil lead samples were collected at 100% of the Minnesota buildings and 97% of the Milwaukee and Vermont buildings. Soil samples were not collected in New York City because the target buildings lacked soil. Geometric mean perimeter soil lead concentrations were 898 ppm (range 176–3812 ppm) in Minnesota, 1670 ppm (range 69–20,359 ppm) in Milwaukee and 807 ppm (range 43–6604 ppm) in Vermont.

All 242 buildings had exterior dust samples collected. Geometric mean exterior loadings were 27 $\mu g/ft^2$ (range 0–1366 $\mu g/ft^2$) in Minnesota, 109 $\mu g/ft^2$ (range 3–5028 $\mu g/ft^2$) in Milwaukee, 67 $\mu g/ft^2$ (range 5–820 $\mu g/ft^2$) in New York City and 31 $\mu g/ft^2$ (range <1–621 $\mu g/ft^2$) in Vermont.

3.4. *Lead-hazard control costs*

New York City paid for lead removal with lead grant funds and paid for replacement of the removed leaded components with non-lead (concurrent) funds. So the costs for units with high-level treatments only include the cost of lead removal while the other two levels include removal and replacement (mid-level) or interim controls (low-level). The average cost for the 24 dwellings with high-level treatments were \$9200 and 68,000 for lead-hazard control and concurrent work costs, respectively. The average interior lead-hazard control costs were \$5690 for 55 dwellings with medium-level interventions and \$2452 for 144 dwellings with low-level interventions. Interior cost data was not available for the remaining 103 dwellings.

Exterior work was implemented at 54% (129) of the 242 buildings, while site work was only done at 4% (9) of the building properties. Exterior work costs averaged \$4431 per building for the 58 buildings with exterior work costs available. Site work costs averaged \$362 per building property for the five buildings with site work costs available.

3.5. *Trends over time*

Figs. 1–3 present results for the trends in surface-specific dust lead loadings over time separately for units that received low- and medium-level treatments. Table 4 contains the distribution of interior dust lead loadings by component and phase. All results presented are raw results; however, statements regarding significance of differences between treatment groups are based on statistical modeling results. Note that only 41% and 37% of the dwellings in the 6-Year Extension Study had 2- and 3-year post-intervention data available, respectively, while over 95% had data for 6 months and 1-year post-intervention.

Across all grantees and treatment strategies, the LHC treatments effectively reduced environmental lead levels on floors, window sills, and window troughs from pre-intervention levels and maintained those lower levels over the following 6 years. Table 4 shows that the geometric mean dust lead levels of floors and window sills were not only greatly reduced from pre-intervention but were also lower at 6 years following intervention than they were at any point from 6 months to 3 years following intervention. Over the post-clearance period (Phases 3–7), geometric

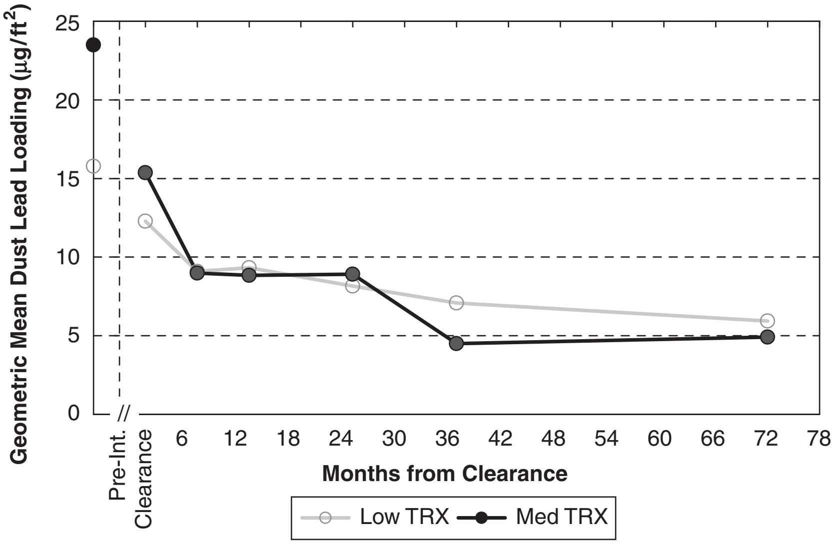

Fig. 1. Geometric mean floor dust lead levels from pre-intervention through 6 years post-clearance, by treatment level.

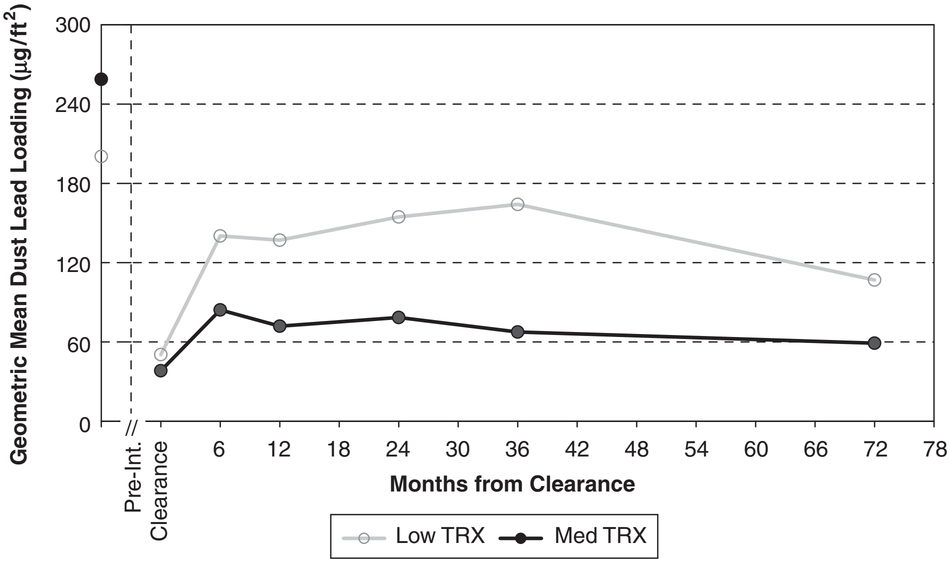

Fig. 2. Geometric mean window sill dust lead levels from pre-intervention through 6 years post-clearance, by treatment level.

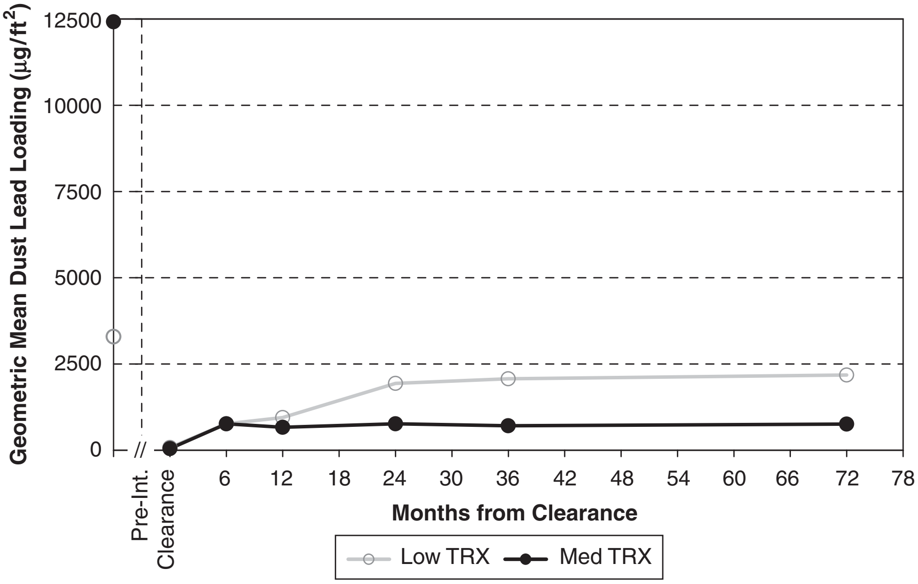

Fig. 3. Geometric mean window trough dust lead levels from pre-intervention through 6 years post-clearance, by treatment level.

mean floor dust lead levels fell from 9.2 µg/ft^2 at 6 months post-intervention to 4.8 µg/ft^2 at 6 years post-intervention. The declines in floor dust lead levels across all units from Phases 2–5 to Phase 7 are all statistically significant with p-values <0.001. Similarly, geometric mean window sill dust lead levels fell from 105 µg/ft^2 at 6 months post-intervention to 73 µg/ft^2 at 6 years post-intervention, a statistically significant decline with p-value <0.001. Conversely, geometric mean trough dust lead levels increased across the post-clearance period from 732 µg/ft^2 at 6 months post-intervention to 1266 µg/ft^2 at 6 years post-intervention. Note, however, that despite this 73% increase over the post-clearance period, window trough dust lead levels at 6 years post-intervention are still 79% lower than they were prior to interventions occurring.

As seen in the right-hand column in Table 4, the trends in change over time in percentage of dwellings failing risk assessment or clearance standards are similar to those seen in geometric mean dust lead levels. For floors, the percentage of units failing the current risk assessment standard for floors (40 µg/ft^2) declined from 14% at 6 months post-intervention to 7% at 6 years post-intervention. Similarly, the percentage of units failing the current risk assessment standard for window sills (250 µg/ft^2) declined from 32% at 6 months post-intervention to 25% at 6 years post-intervention.

Table 4
Dust lead loadings by component type and phase

Component type	Phase[a]	Number of units	Geometric mean (μg/ft^2)	Geometric standard deviation	Minimum	10th Percentile	25th Percentile	Median	75th Percentile	90th Percentile	Maximum	% Exceed the Federal Standard[b]
Floor	01	424	21.5	4.8	0.1	4.0	7.4	18.8	40.0	141.8	9407	25%
	02	423	14.0	2.5	1.3	4.0	7.4	14.3	28.7	45.1	100	14%
	03	407	9.2	4.4	0.3	1.6	3.3	8.9	20.3	56.0	7909	14%
	04	413	9.0	3.9	0.8	2.2	3.3	8.0	17.3	41.0	7688	10%
	05	176	8.6	3.7	1.1	2.3	3.4	7.2	15.2	47.3	2538	11%
	06	158	5.4	5.6	0.1	0.8	3.0	6.7	11.7	31.3	1981	8%
	07	424	4.8	5.5	0.0	0.8	1.8	5.1	14.0	31.9	2299	7%
Sill	01	424	239	5.7	3	32	81	197	643	2598	129,188	42%
	02	422	45	3.1	1	7	22	57	104	162	390	3%
	03	406	105	5.4	2	11	33	104	333	848	26,000	32%
	04	412	95	5.3	2	11	25	93	301	872	36,386	28%
	05	175	103	4.1	4	17	40	113	259	531	27,487	26%
	06	158	96	5.1	1	11	42	85	235	736	61,881	24%
	07	420	73	7.7	0	9	20	76	253	837	12,358	25%
Trough	01	424	5897	10.6	4	287	1036	6129	34,890	134,200	1,580,000	n/a
	02	412	65	3.7	2	9	26	81	177	329	778	n/a
	03	397	732	7.7	3	64	165	653	2995	8,940	362,000	n/a
	04	406	753	8.8	2	48	154	730	2862	12,200	378,000	n/a
	05	176	1108	8.5	3	75	225	1130	4396	24,389	172,000	n/a
	06	158	1082	8.5	11	79	230	961	3970	20,715	451,000	n/a
	07	405	1266	8.0	0	85	299	1315	4919	18,659	126,275	n/a

[a] Phases: 01 = pre-intervention, 02 = clearance, 03 = 6-months post-clearance, 04 = 12-months post-clearance, 05 = 24-months post-clearance, 06 = 36-months post-clearance, 07 = 72-months post-clearance.

[b] Floors: 40 μg/ft^2, sills: 250 μg/ft^2.

The results indicate that average floor and window sill dust lead levels declined or remained at relatively low levels across the 6 years following treatments. Conversely, average window trough dust lead levels increased quickly after treatments. Although average trough lead levels followed a different trend than the other two components, similar to other studies there was evidence of statistically significant positive correlation at a .05 level within individual dwellings between sills and troughs at all BEC levels for the low and medium treatment units as well as between floors and sills and floors and troughs at most combinations of BEC and treatment level.

3.6. Differences in long-term effectiveness between low- and medium-level treatments

Are these trends (decreasing floor and sill dust lead levels and increasing window trough dust lead levels) consistent between the two primary treatment levels evaluated in the 6-Year Extension Study? Statistical modeling of dust lead levels over the post-clearance period did not find any significant differences in floor dust lead levels over time between the two treatment levels, whereas there were significant treatment-level differences identified in sill and trough dust lead levels at various points in time. Figs. 1–3 plot the trends in geometric mean dust lead levels for floors, window sills, and window troughs, respectively, for the low and medium treatment categories. (Although pre-treatment and clearance dust lead levels served as independent variables in the statistical models, they are plotted in the figures to provide perspective regarding the size of the reductions achieved by the treatments.) Fig. 1 illustrates both treatment strategies resulting in low ($<10\,\mu g/ft^2$) floor dust lead loadings over the entire 6-year post-clearance period. Furthermore, in both the low- and medium-intensity treatment groups, the floor dust lead loadings stay level or decline from 6 months to 6 years post-intervention. Overall, both levels of interventions were generally effective at maintaining reduced post-clearance dust lead loadings on interior floors.

Conversely, level of treatment was found to be a significant determinant of post-clearance window sill dust lead loadings. Fig. 2 displays the lower window sill dust lead levels in homes receiving the medium-level treatments (i.e., jamb liners, window replacement, etc.) compared to the homes receiving the low-level treatments (i.e., paint stabilization, cleaning, etc.) In homes receiving the medium-level treatments, geometric mean window sill dust lead loadings decreased from 84 to 59 $\mu g/ft^2$ from 6 months to 6 years post-intervention. In the low-level treatment dwellings, geometric mean window sill dust lead loadings declined from 140 to 107 $\mu g/ft^2$ from 6 months to 6 years post-intervention, although they temporarily increased to 164 $\mu g/ft^2$ at 3 years post-intervention. Similarly, homes treated with medium-level treatments were found to have significantly lower window trough dust lead levels than homes treated with low-level treatments. In Fig. 3, geometric mean window trough dust lead levels remain slightly below 800 $\mu g/ft^2$ over the post-clearance period for the medium treatment group while in the low-level treatment group they increase across the 6-year post-clearance period from 768 $\mu g/ft^2$ at 6 months post-intervention to 2181 $\mu g/ft^2$ at 6 years post-intervention. Much of the increase occurred within the first 2 years after treatment as the modeled geometric mean window trough dust lead loading for the low-level treatment group at 2 years post-intervention was 1939 $\mu g/ft^2$.

Differences in the effectiveness of the treatment strategies on floors and window sills were also measured by the percentage of units failing risk assessment standards over the post-clearance period. There was no statistical difference in the percent failure for floors; however, there was some evidence of differences in the failure rates for window sills. Fig. 4 displays the floor failure rates for the low- and

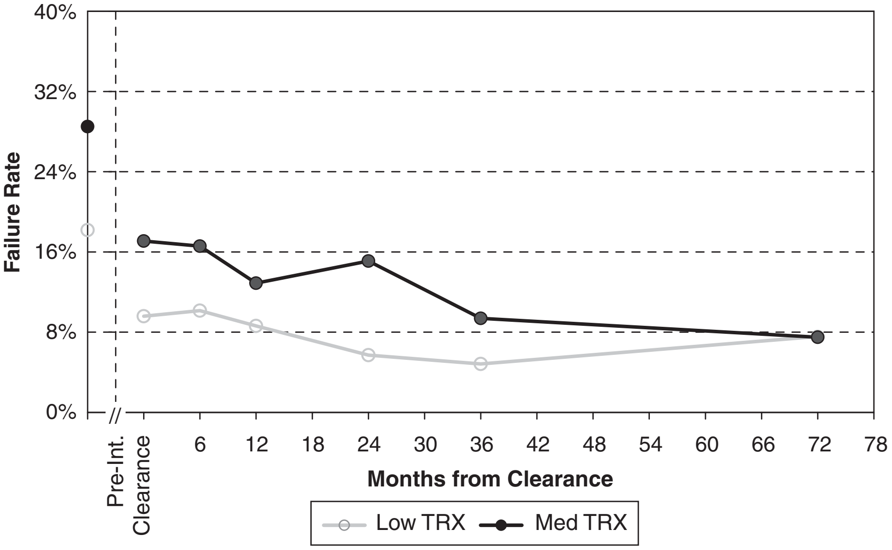

Fig. 4. Floor failure rates (at $40\,\mu g/ft^2$) from pre-intervention through 6 years post-clearance, by treatment level.

medium-level treatment groups. Both floor treatment groups report failure rates of 8% at 6 years post-intervention. For window sills, there was no statistically significant difference in probability of failing the current risk assessment standards between the two groups. As seen in Fig. 5, however, there was evidence of higher window sill failure rates in the low-level treatment group across the post-clearance period—narrowing from a difference of 10% at 6 months post-intervention (37% vs. 27%) to a difference of 5% at 6 years post-intervention (29% vs. 24%).

Note that analyses that evaluated differences between two finer levels of treatment within the low-level treatment group (cleaning/spot painting vs. complete paint stabilization) did not observe any statistically significant differences between the two treatment types for floors or window sills. For window troughs, mere cleaning/spot painting was associated with higher lead loadings at 6 months post-intervention, while lead dust loadings took longer to increase in units receiving complete paint stabilization.

The interior dust-lead trends for the relatively small sample of high-level treatment dwellings (i.e., employing only complete abatement measures), in which lead-based paint hazards were completely abated (i.e., removal, enclosure, or encapsulation of all lead-based paint and window replacement) provide a useful comparison to the units receiving the low- and medium-level treatments. For floors and sills, dust lead levels declined across the post-clearance period to geometric means at 6 years post-intervention of 1 $\mu g/ft^2$ on floors and 19 $\mu g/ft^2$ on window sills, which are lower than the geometric means of 5 and 59 $\mu g/ft^2$, respectively, found across the approximately 200 medium-level dwellings (statistically significant difference at a .05 level). The failure rates of 0% and 4% on floors and sills for the high-level treatment dwellings are also lower than the medium-level treatment units (statistically significant for sills but not floors as the test could not be performed for floors because all measurements in the high-level treatment units were below the federal standard). Conversely, geometric mean window trough dust lead levels increased across the post-clearance period to a high of 986 $\mu g/ft^2$ at 6 years post-intervention, noticeably higher than the 761 $\mu g/ft^2$ found in the medium-level dwellings at the same time period, although this difference was not statistically significant.

Exterior entry dust-lead and soil lead concentration at 6 years post-intervention were found to be significant determinants of interior floor dust lead levels, indicating the contribution of exterior lead sources to interior floor dust-lead loadings. This conclusion is based in part on a previously reported finding that the baseline floor dust lead loadings at the unit entry were approximately 50% higher than loadings on other interior floors (Galke et al., 2001). In this analysis, all interior floor samples were averaged together. Floor dust lead loadings at clearance were also a significant determinant of 6-year post-intervention floor dust lead levels. Higher clearance dust lead levels on window sills were also found to be associated with higher 6-year post-intervention window sill dust lead levels. These findings emphasize the importance of proper cleaning after treatment. A number of other factors were also identified as being significantly associated with dust lead loadings on floors and window surfaces. These factors include floor condition, presence of perimeter soil, and interviewers' assessment of cleanliness for floor dust lead levels, and pre-intervention window paint lead loading and window component condition at the 6-year post-intervention visit for both window components. Table 5 contains parameter estimates, standard errors, and *p*-values for these various factors from the floor, sill, and trough models for post-clearance dust lead levels.

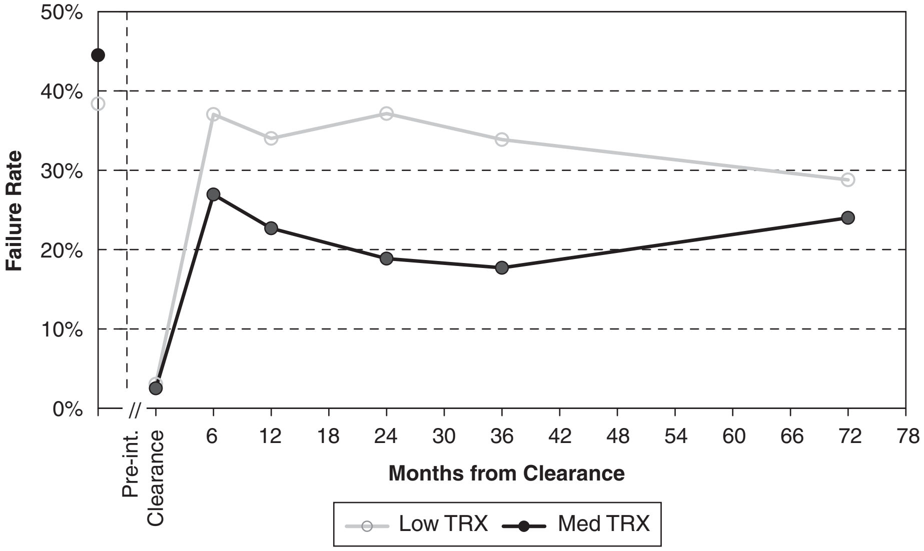

Fig. 5. Window sill failure rates (at 250 $\mu g/ft^2$) from pre-intervention through 6 years post-clearance, by treatment level.

Table 5
Other parameters included in final models of post-clearance dust lead loadings

Parameter	Floors			Window sills			Window troughs		
	Est.	Std. error	*p*-value	Est.	Std. error	*p*-value	Est.	Std. error	*p*-value
Pre-intervention dust lead	0.095	0.036	0.009				0.161	0.035	<0.001
Clearance dust lead	0.161	0.049	0.001	0.224	0.056	<0.001			
Exterior entry dust lead	0.064	0.025	0.010						
Weighted wiped component condition	1.145	0.129	<0.001	0.215	0.073	0.003	0.621	0.153	<0.001
Entry height (in # of stories from entrance)	−0.194	0.046	<0.001						
6-yr other interior components paint condition	0.491	0.116	<0.001	0.095	0.177	0.592			
Presence of perimeter soil	−0.886	0.429	0.039						
Perimeter soil-lead concentration	0.222	0.054	<0.001						
Interviewer assessment of cleanliness	0.321	0.061	<0.001						
Frequency of cleaning window sills							−0.156	0.055	0.005
6-yr Presence of painted windows				0.396	0.434	0.361	−1.002	0.726	0.168
6-yr Percent of windows painted							1.241	0.388	<0.001
Pre-intervention window paint lead loading				0.407	0.051	<0.001	0.484	0.089	<0.001
Constructed 1920–1949	−.362	0.117	0.002						
Precipitation for the previous week				0.151	0.047	0.001			

4. Discussion

When the Evaluation of the HUD Lead-Based Paint Grant Program was initiated in 1993, the concept of low-level temporary lead hazard controls or *interim controls*, as defined by Congress, was relatively new in the field of lead hazard control, and questions were raised about their long-term effectiveness. This study is the first known to these authors to look at the efficacy of lower level lead hazard control over a period of 5 or more years and the first to have those results published. The results demonstrate that 6 years after treatments were applied, average dust lead loadings remained significantly below their pre-intervention levels on floors, window sills, and window troughs. The percentage of homes at 6 years post-intervention that exceeded the current Federal risk assessment standards on either floors or window sills were comparable regardless of the intensity of treatment. The use of low-level treatments to reduce dust lead loadings on window sills and troughs, however, was not as effective as interventions that partially or fully abated the windows.

Previous studies have reported mixed effects on longer term post-intervention dust lead loadings when only professional dust control (specialized cleaning) was used. (Rhoads et al., 1999; Farfel et al., 2000; Ettinger et al., 2002; Tohn et al., 2003) When cleaning was combined with paint film stabilization, reductions in dust lead loadings are observed as long as 2 years post-intervention (Ashengrau et al., 1998; US EPA, 1998b). It has been demonstrated, however, that professional cleaning and minor repairs alone is not an adequate treatment strategy in homes that were initially assessed as needing more intensive treatments (Farfel et al., 2000). In this study, the period of observed effectiveness on floors and window sills was tripled and suggests that interim controls (in the form of specialized cleaning, spot or complete paint stabilization, and other limited treatments) can be more than just a short-term fix for lead-based paint hazards.

Floor and window sill dust lead loadings significantly decline from immediate post-intervention to 6 years post-intervention. These declines may reflect the finding that the lead hazard control treatments tended to remain effective for the period of study. As a result, the amount of dust lead generated from deteriorating lead-based paint may have been smaller than the amount of dust lead removed through routine housecleaning. The results may also reflect reductions in exterior sources of lead over time and the subsequent reduction of in dust lead entering the home.

One limitation of this study is the inability to describe the type or frequency of maintenance that was required to maintain the reduced dust lead levels. The investigators initially considered interviewing the property owner about the maintenance history of the properties; however, this component of the study was not pursued because of concerns about poor response rates, poor recall of maintenance activities, and possible changes in ownership over the period.

This study did not include a control population to prove with certainty that the reductions in dust lead levels were the result of the interventions. The investigators recognize that in a previous study of dust lead controls, the control population, which received only educational materials, displayed short term declines in dust lead loadings that were similar to that study's intervention population. (Lanphear et al., 1996) It is of note, however, that the period in this study where the dust lead loadings declined the most for all intervention levels was between pre-intervention and immediate post-intervention, which suggests a treatment effect. The observed differences between the window dust lead loadings in units treated with the low and medium interventions also suggest an intervention-related effect. In dwellings where the lead-based paint on the windows was fully abated or the paint on at least the friction surfaces of the window was abated, the geometric mean dust lead loadings for window surfaces six years after treatment were significantly lower than in units where the treatment was restricted to paint stabilization (59 vs. 107 $\mu g/ft^2$ on sills; 761 vs. 2181 $\mu g/ft^2$ on troughs).

The results of the high-level interventions provide some evidence of how low dust lead loadings can be for 6 years post-intervention in a fully abated dwelling. Yet only New York City conducted a large number of these treatments, so the data collection was limited to this site and the data were not stratified by baseline condition. Additional studies are needed to demonstrate that these results would be replicable in other communities with different types and conditions of housing.

Somewhat surprisingly, the low-level interventions performed just as well on floor dust lead loadings as medium-level interventions over the full 6-year post-intervention period. This was true even when the baseline environmental condition of the dwelling and all other housing factors were considered in the models. Because the intervention levels were largely defined by the intensity of the treatments to the windows, this may suggest that higher intensity window treatments do not by themselves produce lower dust lead levels on floors. This observation is further supported by the fact that overall increases in window trough dust lead loadings did not seem to correspond to concurrent or subsequent increases in sill or floor dust lead loadings.

The finding that lead in exterior dust and soil were significant determinants of interior floor dust-lead loadings at 6 years post-clearance supports the findings of Clark et al. (2004) who conducted pathway analysis on the post-intervention exterior dust and soil lead samples from the Evaluation data and reported a direct pathway from exterior entry dust lead loading to floor, interior entry, and windowsill dust lead loading and an influence of soil treatments on the exterior entry dust lead loading. The findings also support the need to address exterior lead hazards as part of routine lead hazard control activities.

If there was one area where the low-level treatments did not appear to perform well over the study period, it was on window troughs. Low-level treatments stopped having comparable effects to mid-level treatments on window trough dust lead in homes with poor baseline condition sometime between 6 months and 1-year post-intervention and in homes with fair baseline condition sometime between 2 and 3 years post-intervention. By 6 years post-intervention, the level of treatment had a significant effect on trough dust lead loadings at all baseline condition levels. This suggests that when interim controls are applied, special attention must be paid to treatments around troughs in an effort to prevent the occurrence of the very high trough dust leads found in many more of the lower-level treatment units than in the medium-level treatment units. At the same time, it is interesting that even after many of the medium-level dwellings received more thorough window treatments, over half-achieved mean trough dust lead levels over 800 $\mu g/ft^2$, which was the clearance standard at the time the treatments were conducted. It is also noteworthy that the geometric mean window trough dust lead levels in the 24 fully abated dwellings with 6-year post-intervention window trough measurements available was higher than the mean for troughs in the medium-level dwellings (986 vs. 761 $\mu g/ft^2$). Window troughs are likely to be more influenced by the settling of exterior, lead-contaminated dust than sills, and are likely cleaned less frequently than sills. These results are also consistent with the findings of a recent study in New York City that documented significant atmospheric deposition of lead on settling plates (Caravanos et al., 2006).

Although this study offers some important evidence supporting the long-term effectiveness of lower level interventions on dust lead levels, it did not examine the effect of the intervention on blood-lead levels of children residing in study units. The 3-year Evaluation provides some evidence of positive effects of all levels of interventions on children's blood lead levels through 2 years post-intervention (NCHH, 2004). Even as early as 2 years post-intervention, many of the children originally enrolled in the Evaluation had moved or chose to no longer participate in blood lead testing. Because blood lead sampling at 6 years would not have provided a sufficient sample of children with both pre-intervention and 6-year data for analysis, the investigators decided not to include blood lead sampling in the design; however, dust lead loadings and children's blood-lead level are known to be highly correlated. Future long-term studies of interim control measures should be designed to collect sufficient blood lead data for analysis. Other limitations of this study include (1) categorizing dwellings into baseline condition groups based only on dust lead levels, which could potentially have resulted in some misclassification, and (2) a lack of control units that could provide evidence of dust lead level trends in similar dwellings that did not receive HUD-funded lead hazard control treatments.

Given the findings of this study and some of the other referenced studies supporting the effectiveness of lower-level treatments for certain aspects of lead hazard control, local housing and health departments coordinating LHC programs may want to review their current set of treatment strategies to determine if more extensive use of lower-level treatments is warranted. In making this decision; however, it is important that programs consider local factors such as the general condition of target housing, as well as factors that might influence the maintenance of housing following treatment (e.g., property values, the degree to which housing codes or other ordinances requiring regular treatment of rental housing are enforced). Also, it should be kept in mind that this study did not use a controlled design—the lower-level treatments were applied to units based on their condition at the time. Units in worse condition tended to receive more extensive treatment. Still, local communities may be able to significantly expand the number of units they are treating by applying the low-cost treatments to units with more limited hazards. HUD's continued support of a range of treatment strategies through the available guidelines, HUD's requirements for lead evaluation and hazard control in most pre-1978 HUD-assisted housing and federally owned housing being disposed of by the Government, and requirements for obtaining LHC program grants can encourage use of these treatments and contribute to reducing lead hazards in a larger number of housing units.

5. Conclusions

This study showed that both lower and higher intensity interim control measures were effective at maintaining lower dust lead loadings on floors and window sills in both rural and urban housing. Both floor and window sill dust lead loadings were lower at 6 years following intervention than any other point during the follow-up period. Similar trends were observed for the percentage of dwellings failing the current federal risk assessment standards for lead loading on floors and window sills. Window trough dust lead loading showed a gradual increase over the 6-year follow-up period, but on average were 79% lower than they were prior to intervention. The level of treatment had little effect on floor dust lead loadings, however, dwellings receiving the higher level treatments had significantly lower dust lead loadings on window sills and troughs after controlling for other factors, such as housing condition, that could affect dust lead levels.

Acknowledgments

The authors acknowledge the contributions of the participating grantees from the Milwaukee Health Department, the New York City Department of Health, the St. Paul Health Department, and the Vermont Department of Health. The authors also acknowledge the contributions of Rona Boehm, Basil Coutant, Jyothi Nagaraja, Elizabeth Slone, Kristen Swinton, and Darlene Wells from Battelle, and Shara Godiwalla previously with the NCHH.

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