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EVALUATION OF THE EFFECTIVENESS OF THE MILWAUKEE LEAD HAZARD CONTROL ORDINANCE

Summary Report

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1.0 INTRODUCTION

The research project "Evaluation of the Effectiveness of the Milwaukee Lead Hazard Control Ordinance" was performed by Battelle, the Milwaukee Health Department (MHD), and the National Center for Healthy Housing (NCHH) under contract with the U.S. Department of Housing and Urban development (HUD). The research project was designed to evaluate the feasibility, costs and effectiveness of the Milwaukee Ordinance with respect to the primary prevention of lead poisoning in children. In 1999, the City of Milwaukee enacted an ordinance requiring owners of pre-1950 rental properties in two high-risk neighborhoods (North Treatment and South Treatment) to carry out specified essential maintenance practices and standard treatments, including window abatements, within a one-year period between May 1, 1999 and April 30, 2000. Both neighborhoods consist primarily of rental housing built before 1950, occupied by low-income families, predominantly African American in the North Treatment neighborhood and Hispanic in the South Treatment neighborhood. There were approximately 1,000 target housing units in the combined neighborhoods affected by the ordinance (pilot ordinance area) with an estimated 750 children under six years of age based on information from the 1990 U.S. Census. In 1997, 59 percent of the children aged 6-36 months in the North Treatment neighborhood and 29 percent of children in the South Treatment neighborhood had blood-lead levels above 10 micrograms per deciliter of blood, based on analyses of the City of Milwaukee Childhood Blood-Lead Surveillance Database.

Staff from the MHD made repeated contacts with owners of homes in the pilot ordinance area, offering technical assistance and grant funding to pay for approximately half of the lead hazard control (LHC) costs for residential units enrolled in the program. Nearly all owners complied with ordinance requirements. Since the completion of this Pilot Program, the Milwaukee Health Department (MHD) has applied similar LHC treatments to approximately 6,000 qualifying housing units throughout the City, at a rate of approximately 100 units per month. MHD's 2010 goal is to treat the estimated 24,000 remaining housing units within the City of Milwaukee that are still in need of LHC treatments, many housing families with young children.

The research project consisted of two different studies: a general screening study and a prospective longitudinal study. Both studies initially focused on children under the age of three years in four high-risk neighborhoods - two treatment neighborhoods (LAND, SSHC) and two control neighborhoods (North Control and South Control). However, the prospective study was expanded during implementation to include similarly treated housing units from other high-risk areas of the City of Milwaukee.

The following sections provide an overview of the study design, details on implementation, and a descriptive summary of the blood-lead (and environmental lead) levels, and key relationships for both studies.

2.0 GENERAL SCREENING STUDY

Background/Study Design

The general screening study was conducted to investigate the effect of the Milwaukee Lead Hazard Control Ordinance in reducing the neighborhood-wide prevalence of childhood lead poisoning. This objective was pursued by comparing children's blood lead levels before and after implementation of the ordinance in the two neighborhoods that were affected by the ordinance, and two carefully selected control neighborhoods that were not covered by the ordinance but had similar prevalence of elevated blood-lead concentration among screened children in 1997. Study personnel attempted to increase the screening penetration rate in the targeted treatment and control neighborhoods using door-to-door screening campaigns with trained outreach workers employed by MHD or the Sixteenth Street Community Health Center. The general screening study was implemented in two phases, with the first phase of the screening study taking place before the lead hazard control activities were completed in the treatment neighborhoods, and the second phase conducted approximately two years afterwards.

Initially, the general screening study was designed to characterize the distribution of children's blood-lead concentrations in Milwaukee in each of the four target neighborhoods and to draw inferences about the potential effects of lead poisoning prevention treatments in similar high-risk neighborhoods throughout the city. Based on the results of the power study performed on the data collected during the first phase of the general screening study, however, it was concluded that conducting the second phase of the general screening study in the South Treatment and South Control neighborhoods would have limited research value for this study. The power studies showed that it would be virtually impossible to detect statistically significant reductions in the prevalence of childhood lead poisoning in the South treatment neighborhood attributable to the Milwaukee LHC treatments because the pre-intervention prevalence of childhood lead poisoning was much lower than expected. As a result, door-to-door sampling to promote increased screening penetration during the second phase of the general screening study only took place in the North Treatment and Control Neighborhoods. Consequently, only data collected from the North side of the town during the general screening study are being used to draw formal inferences on the potential effects of lead poisoning prevention treatments in similar high-risk neighborhoods throughout the city. Since we had access to screening data and other study-related data for the South side of Milwaukee, this report does provide some limited presentation of data for the original South side treatment and control neighborhoods.

Although samples of blood lead from older children were collected during door-to-door site visits as part of the screening study, primary statistical data analyses were performed only for children aged 6 to 36 months. Children's blood-lead data for the general screening study were obtained from both door-to-door campaigns and the STELLAR database. During the door-to-door campaigns, capillary blood samples were drawn from study subjects at their residences by trained outreach workers experienced in drawing samples from newborns and infants. The results from door-to-door campaigns represented in this report were conducted both for the general screening study and, in some circumstances, for the prospective and scheduled screening studies as well. Results from the prospective study and the scheduled screening study were integrated into the general screening study analytical database when collected from children living in residential units located within one the four original study neighborhoods during windows of time comparable to those used for the general screening study (Table 2.1). Results from prospective study subjects screened during Phase I were excluded since their units were treated before the blood samples were taken.

Table 2-1. Dates of Blood Sample Collection in Phases I and II of General Screening Study

Source	Phase I	Phase II
Door-to-Door	March 25, 1999, to July 3, 2000	May 2, 2001, to September 12, 2001*
STELLAR	May 1999 to April 2000	May 2001 to April 2002

* Door-to-Door data collection in Phase II only occurred in the North Treatment and Control Neighborhoods

Additional subjects for the general screening study were identified through Milwaukee's STELLAR database and included children who were recently screened for lead poisoning independent from the research program (i.e., through physician visits or other Milwaukee outreach programs). Milwaukee law requires laboratories to report the results of all blood tests for lead screening performed on children under six years of age directly to the STELLAR database. The STELLAR database maintained at MHD contains the blood-lead screening information for all children screened throughout the City of Milwaukee, including blood-lead concentration, date of sampling, age, gender, name and address of the child, and the type of blood sample (capillary or venous). The STELLAR database reflects routine screening that has been conducted as part of normal physician practice, targeted screening and outreach activities conducted by the MHD and the Sixteenth Street Community Health Center, and screening/testing of children who have participated in various research studies being conducted throughout the city. Table 2-1 (above) provides the dates of blood samples considered at each phase of the general screening study.

A child had at most one blood-lead measurement from the door-to-door campaign, but could have had additional blood-lead measurements in the STELLAR database during each phase of the general screening study. Some children were tested at multiple residences within a single phase of the general screening study. For the purpose of the screening study, however, only one representative blood-lead testing result per child at each phase of the study was selected for the statistical analysis.

Due to the transient nature of families included in this study, our project team was concerned about wrongly attributing elevated blood-lead levels (EBLs) to a housing unit enrolled in the study, when there was clear evidence that the child had been exposed to lead in a different residence outside the study neighborhood immediately prior to the time that their representative blood-lead sample was collected. Several different exclusion criteria were developed and explored during the statistical analysis of data from this study, with the following two exclusion criteria being chosen for use in the main body of this report.

1. ***Elimination of children with prior lead exposure in a different residential unit or different neighborhood***: For each child represented in the study, a review of all prior blood-lead tests in the STELLAR database was conducted. If there was a record from a prior blood-lead test of 5 μg/dL or greater while living in a different housing unit outside of their current study neighborhood, the child was flagged for possible exclusion in the data analyses. The purpose of this exclusion criterion is to ensure, to

the extent possible, that all EBLs are attributable to living within the study neighborhood.

2. ***Elimination of children with short duration of residency:*** Again, to ensure that measured lead exposure in this study can be properly attributed to living in the subject's current residential unit (to the extent possible), we eliminated any children who had not been living at their current residence for at least six months. We based this determination on questionnaire data where available and through inspection of reported blood-test data in STELLAR for all other children, in which children were eliminated only if there was evidence within STELLAR that they had lived elsewhere within six months prior to the blood draw. Children who were missing both questionnaire data or repeated measure history were not eliminated – which has the potential to introduce some biases into the data analysis.

Results

A total of 1,557 children aged 2 to 84 months were screened during the general screening study. After eliminating (1) children with prior lead exposure obtained while living in a different neighborhood, (2) children with short duration of residency, and (3) children aged 0 to 6 months or more than 36 months, there were 752 children (297 and 455 in the North and South neighborhoods, respectively) from 579 housing units (239 and 340 from the North and South neighborhoods, respectively) in the study database. Twenty-eight of these children were screened at both phases, 336 children were screened at Phase I only, and the remaining 388 children were screened at Phase II only. The sample size achieved in the general screening study was lower than originally anticipated, based on 1990 US Census population projections in the study neighborhoods.

Among the 752 children aged 6 to 36 months without prior lead exposure and short duration residency as defined above, 94 were screened during the door-to-door campaigns, 33 were from the prospective study, 13 children were from the scheduled screening study, 608 children were identified from the STELLAR database, and the remaining 4 children were screened at both phases via multiple sources. [The results from door-to-door campaigns represented in this report contributed to the screening study, and in some circumstances the prospective and scheduled screening studies, as well.] Table 2-2 shows the number of children studied at each phase by neighborhood, study group, and data source. The data indicate that:

1. At each phase, more than 75 percent of the study subjects were identified from the STELLAR database.
2. At each phase, the number of children in the North control group was about the same as that in its associated treatment group, while the number of children in the South control group was double the number in its associated treatment group during Phase I.

Table 2-2. Number of Children Aged 6 to 36 Months Studied at Each Phase

Neighborhood	Group	Phase I			Phase II		
		Door-to-Door	STELLAR	Total	Door-to-Door	STELLAR	Total
North	Treatment	16 (4%)	54 (15%)	70 (19%)	20 (5%)	61 (15%)	81 (19%)
	Control	28 (8%)	53 (15%)	81 (22%)	13 (3%)	56 (13%)	69 (17%)
South	Treatment	22 (6%)	49 (13%)	71 (20%)	21 (5%)	93 (22%)	114 (27%)
	Control	20 (5%)	122 (34%)	142 (39%)	5 (1%)	147 (35%)	152 (37%)
Total		86 (24%)	278 (76%)	364	59 (14%)	357 (86%)	416

Tables 2-3 and 2-4 present the proportion of children with blood-lead levels of at least 10 µg/dL and 15 µg/dL, respectively, by phase, neighborhood, study group, and data source. The proportion of children with elevated blood-lead levels in the north neighborhoods was higher than that in the south neighborhoods. The proportion of children with elevated blood-lead levels in each combination of neighborhood and study group was reduced between 15 percent and 50 percent from Phase I to Phase II.

Table 2-3. Proportion of Children with Blood-Lead Levels at 10 µg/dL or Higher

Neighborhood	Group	Phase I			Phase II		
		Door-to-Door	STELLAR	Total	Door-to-Door	STELLAR	Total
North	Treatment	63%	46%	50%	45%	38%	40%
	Control	57%	53%	54%	38%	32%	33%
South	Treatment	18%	10%	13%	10%	10%	10%
	Control	15%	21%	20%	0%	18%	17%
Total		38%	30%	32%	27%	21%	22%

Table 2-4. Proportion of Children with Blood-Lead Levels at 15 µg/dL or Higher

Neighborhood	Group	Phase I			Phase II		
		Door-to-Door	STELLAR	Total	Door-to-Door	STELLAR	Total
North	Treatment	44%	24%	29%	15%	16%	16%
	Control	29%	23%	25%	15%	18%	17%
South	Treatment	5%	4%	4%	0%	2%	2%
	Control	10%	10%	10%	0%	7%	7%
Total		21%	14%	16%	8%	9%	9%

Table 2-5 presents descriptive statistics on children's blood-lead concentrations. Table 2-6 displays model-based unadjusted geometric means of blood-lead concentrations and proportion of children with elevated blood-lead levels. For those housing units with multiple children, these models account for the anticipated correlation between those children. Without adjusting for potential differences in sample recruitment between treatment and control neighborhoods and other potential explanatory covariates, the results indicate that:

In the North Neighborhoods:

- There are no statistically significant differences between the control neighborhood and its associated treatment neighborhood at Phase I, in terms of the geometric mean of children's blood-lead levels or proportion of children with elevated blood-lead levels.
- In the treatment neighborhood, although the geometric mean of children's blood-lead levels and the proportion of children with elevated blood-lead levels both decrease between Phase I and Phase II, these differences are not statistically significant.
- In the control neighborhood, the geometric mean of children's blood-lead levels and the proportion of children with elevated blood-lead levels (PbB∃10 μg/dL) at Phase II were significant lower than at Phase I.
- The effects of neighborhood-wide lead poisoning prevention treatments in reducing geometric means of children's blood-lead levels or the proportion of children with elevated blood-lead levels were not statistically significant.

In the South Neighborhoods:

- The control neighborhood had a significantly higher geometric mean blood-lead concentration than its associated treatment neighborhood at Phase I for children identified from the STELLAR database (p-value=0.01), as well as for the combined group (p-value=0.015).
- The effects of lead poisoning prevention treatments in reducing geometric means of children's blood-lead levels or proportion of children with elevated blood-lead levels were not statistically significant.

Table 2-5. Descriptive Summary of Children's Blood-lead Concentrations

Neighborhood	Phase	Source	Number of Children	Arithmetic Mean	Standard Deviation	95th Percentile	75th Percentile	Median	25th Percentile	5th Percentile
North Treatment	I	Door-to-Door	6	14.2	8.8	30	21	0.5	7	2
		STELLAR	54	10.5	6.5	22	14	9	6	3
		Combined	70	11.3	7.2	23	16	9.5	7	3
	II	Door-to-Door	20	9.3	5.7	20.5	13.5	7.5	4.5	2.5
		STELLAR	61	9.1	5.1	19	12	7	5	4
		Combined	81	9.1	5.2	19	12	7	5	4
North Control	I	Door-to-Door	28	11.3	5.4	21	15.5	11	7	3
		STELLAR	53	11.3	7.1	28	13	10	6	4
		Combined	81	11.3	6.6	21	14	10	7	4
	II	Door-to-Door	13	8.4	8.0	29	13	5	2	2
		STELLAR	56	8.5	5.0	20	10	7	5	3
		Combined	69	8.5	5.6	20	10	6	5	2
South Treatment	I	Door-to-Door	22	5.6	4.2	11	6	5	3	2
		STELLAR	49	5.8	4.1	14	6	5	5	1
		Combined	71	5.8	4.1	14	6	5	4	1
	II	Door-to-Door	21	4.0	3.1	10	5	4	1	1
		STELLAR	93	6.2	4.5	12	7	5	5	2
		Combined	114	5.8	4.4	11	7	5	4	1
South Control	I	Door-to-Door	20	5.9	4.3	17	6	5	4	1.5
		STELLAR	122	7.5	6.3	16	8	5	5	2
		Combined	142	7.3	6.1	16	8	5	5	2
	II	Door-to-Door	5	3.8	1.6	5	5	4	4	1
		STELLAR	147	7.0	4.4	16	8	5	5	3
		Combined	152	6.8	4.4	16	7.5	5	5	3

Table 2-6. Unadjusted Model-Based Geometric Means of Blood-lead Concentrations and Proportion of Children with Elevated Blood-lead Levels

Neighborhood	Phase	Source	N	Geometric Mean		% of Children with EBL			
						10 µg/dL or Higher		15 µg/dL or Higher	
				Estimate	G.S.D	Estimate	Std. Error*	Estimate	Std. Error*
North Treatment	I	Door-to-Door	16	10.9	1.2	58%	0.55	35%	0.61
		STELLAR	54	8.6	1.1	47%	0.27	23%	0.34
		Combined	70	8.9	1.1	48%	0.25	23%	0.32
	II	Door-to-Door	20	7.9	1.2	45%	0.46	17%	0.64
		STELLAR	61	7.8	1.1	36%	0.27	16%	0.36
		Combined	81	7.9	1.1	39%	0.23	18%	0.31
North Control	I	Door-to-Door	28	9.8	1.1	59%	0.39	31%	0.41
		STELLAR	53	9.4	1.1	52%	0.28	21%	0.33
		Combined	81	9.6	1.1	54%	0.23	25%	0.25
	II	Door-to-Door	13	5.9	1.2	41%	0.53	18%	0.57
		STELLAR	56	7.2	1.1	31%	0.28	16%	0.35
		Combined	69	6.9	1.1	32%	0.25	15%	0.33
South Treatment	I	Door-to-Door	22	4.7	1.2	.	.	.	.
		STELLAR	49	4.8	1.1	10%	0.46	4%	0.74
		Combined	71	4.8	1.1	13%	0.35	4%	0.61
	II	Door-to-Door	21	2.9	1.2	.	.	.	.
		STELLAR	93	5.4	1.1	10%	0.38	2%	0.72
		Combined	114	4.8	1.1	9%	0.34	2%	0.70
South Control	I	Door-to-Door	20	4.7	1.2	.	.	.	.
		STELLAR	122	6.1	1.1	22%	0.22	10%	0.30
		Combined	142	5.9	1.1	21%	0.21	10%	0.28
	II	Door-to-Door	5	3.3	1.4	.	.	.	.
		STELLAR	147	6.1	1.0	18%	0.22	7%	0.32
		Combined	152	6.0	1.1	17%	0.23	7%	0.32

3.0 PROSPECTIVE AND SCHEDULED SCREENING STUDIES

Background/Study Design

Since Milwaukee's Pilot Ordinance was one of only a few housing-based primary prevention efforts nationally, HUD funded an evaluation of the effectiveness of the efforts through a prospective longitudinal study tracking blood-lead levels (BLLs) of newborn children and corresponding dust-lead levels in homes that had either received the LHC treatments (treated) or were similar untreated housing units (control). The principal outcome of interest of this study was the rate of blood-lead accumulation over time, comparing children in treated housing units to those in control housing units. During the study design phase, power studies were conducted suggesting that 160 children living in treated housing units needed to be enrolled in the study (with the expectation that 120 children would complete the study protocol over an 18-month period of observation) to detect a 33 percent difference in the rate of blood-lead accumulation between treated and control housing units.

The "prospective" study followed the BLLs of newborn children and dust-lead levels in treated housing units at 6-month intervals corresponding to the child's birthday (at 6, 12, 18, and 24 months). Children living in treated homes were identified both in housing units that had received LHC treatments through the pilot ordinance, as well as in other housing units that had received similar LHC treatments from the MHD in high-risk areas of the City. All housing units treated through the ordinance were rental properties; however, the remaining housing units enrolled in the prospective study included a mixture of rental and owner-occupied properties. At each phase of sampling, a blood-lead sample was collected from the enrolled child and environmental dust-wipe samples were collected from floors, window sills, and window troughs.

Each phase of data collection also included a questionnaire that was administered by the outreach worker to the primary care-giver present at the time of data collection. This questionnaire collected information on demographics and household characteristics, exposure-related behavior of the subject child, previous familial history with childhood lead-poisoning and prevention efforts, and length of residency. A Baseline Structural Assessment was conducted on the first visit to each property associated with the study to characterize housing characteristics and major structural problems. In addition, a visual inspection was conducted at each sampling visit to assess painted surfaces, the type and condition of floor and window surfaces, and housekeeping (cleanliness) within each room. There were additional variables used for investigational purposes, most of which were used to subset the population of study data to determine whether there are significant differences that need to be accounted for in the final models. These variables included side of town, race, whether or not neighborhood was covered by the ordinance, presence of dust-lead levels over the federal standards, and outreach worker.

The control housing were generally units in need of treatment (i.e. pre-1950 housing units with lead-based paint hazards and lead based paint on the window components), that had not been treated. Due to human subjects protection issues, it was not feasible to prospectively monitor children living in these potentially hazardous untreated units. Thus, the approach taken to study children in untreated units was to identify children aged 18-24 months who were screened for elevated BLLs one year previously and had lived in the same untreated housing unit for the entire intervening year. Children were identified for this "scheduled screening" study based on MHD blood-lead screening data. Study personnel collected a follow-up blood-lead sample, environmental samples, and questionnaire data approximately one year after an enrolled child's initial blood-test result. At the time of sampling, study personnel met with the family, identified hazards in the home, and provided education about risk reduction. Where hazards were identified, MHD staff HEPA-vacuumed windows, floors, and other potentially contaminated surfaces, and made referrals of hazardous homes to the LHC program. By linking the two blood-lead concentration measures on the same child (previously reported and the scheduled follow-up), the rate of blood-lead accumulation in a "control" population was constructed as a basis of comparison for the study.

This combined research design that utilized both a longitudinal prospective study of treated housing and a one-time scheduled screening study that took advantage of longitudinal blood-lead screening data provides most of the scientific advantages of a treatment versus control design, while eliminating many of the ethical concerns. Some advantages to the community afforded by this study included:

- Risk education, lead hazard control, and lead poisoning prevention services were provided to all control subjects as soon as they were enrolled in the study.
- Blood-lead, dust-lead, and visual inspection results were provided to all study subjects. Environmental inspection results, including dust wipe results, were also provided to property owners.
- Providing necessary interventions and services to the control group at the time of the single household visit did not interfere with scientific research goals.
- The study also provided necessary interventions, such as venous confirmation for all blood-lead levels above 10 µg/dL, and case management services for all confirmed blood-lead levels above 15 µg/dL regardless of whether the subject was enrolled in the prospective or scheduled screening study.

Cross-Sectional Summaries of Blood Lead Concentrations

The blood lead concentration of the subject child, as measured during the field visit, is the primary response variable for many of the statistical models that were to be investigated for this study. Blood-lead concentrations were collected in the field using capillary sampling methods by trained outreach workers, analyzed by the MHD Laboratory, and reported in units of micrograms per deciliter (µg/dL). The blood-lead data collected within the same phase were examined and found to follow a lognormal distribution, a distribution that is commonly attributed to this type of data. Statistical analysis was performed on the natural-log transformed blood-lead concentrations and the results were reported in terms of geometric means and geometric standard deviations. Before applying the log transformation, blood-lead measurements reported as lower than 1 µg/dL were replaced with 1 µg/dL.

Table 3-1 provides a descriptive summary of children's blood lead concentrations for each phase for both the prospective study and the scheduled screening study. Note that while the ages of children in the prospective study across the four phases were closely associated with the 6, 12, 18, and 24 month age groups, children in Phase I of the scheduled screening study ranged from 5 to 23 months old. Most of the scheduled screening study children were in the range of 5 to 17 months old at Phase I with a median of approximately 11 months. All children but one in Phase II of the scheduled screening study ranged from 17 to 29 months old with the median being 24 months.

Table 3-1. Descriptive Summary of Children's Blood-Lead Concentrations by Study and Phase

Study	Phase	Sample Size	Geometric Mean	Geometric Standard Deviation	Minimum	10th Percentile	25th Percentile	Median	75th Percentile	90th Percentile	Maximum	Exceedance Percentiles		
												>= 5 µg/dL	>= 10 µg/dL	>= 15 µg/dL
Prospective	I	185	2.49	2.10	1	1	1	2	4	7	24	25%	4%	1%
	II	126	4.67	1.93	1	2	3	5	7	11	42	55%	12%	4%
	III	102	5.87	1.94	0	3	4	5.5	10	14	28	70%	26%	7%
	IV	75	5.62	1.84	1	3	4	6	9	13	20	67%	13%	7%
Scheduled Screening	I	235	5.38	1.64	0	4	5	5	6	10	27	84%	12%	3%
	II	235	6.33	2.02	0	3	4	6	10	15	31	74%	27%	11%

Comparing geometric mean BLLs between the prospective and scheduled screening studies, Phase I of the scheduled screening study is 15 percent higher than the Phase II of the prospective study (5.38 vs. 4.67) and Phase II of the scheduled screening study is 13 percent higher than Phase IV of the prospective study. Comparing the percentage of children over certain blood-lead thresholds between the treated and control housing, a higher proportion of children had BLLs of five µg/dL or higher at Phase I of the scheduled screening compared to Phase II of the prospective study (84 percent vs. 55 percent). Similarly, a higher proportion of children had BLLs of 10 µg/dL and higher and 15 µg/dL and higher in Phase II of the scheduled screening study compared to Phase IV of the prospective study.

Considering the trend in prospective study children's BLLs over time, they do show an increase from six months of age to 18 and 24 months of age. All measures increased significantly from six months to 24 months – the geometric mean from 2.49 to 5.62 µg/dL, the median from 2 to 6 µg/dL, and percentage of children with tests of five µg/dL or higher from 25 to 67 percent. Thus, the children in the treated units do seem to be accumulating some levels of lead in their bodies.

Initial statistical modeling found a number of variables that have a statistically significant impact on children's BLLs. Some of these variables include:

- Side of Town – Children living in the North side of town tend to have higher geometric mean blood-lead levels and odds of observing BLLs over 5 µg/dL in all phases except Phase I of the prospective study.
- Ordinance Coverage of Neighborhood – Prospective study children living in neighborhoods covered by the ordinance show evidence of lower geometric mean BLLs at Phase IV, while scheduled screening study children living in neighborhoods covered by the ordinance show lower odds of achieving BLLs of 5 µg/dL and higher at Phase II.
- Race – Black children tend to have higher geometric mean blood lead levels and odds of observing BLLs over the thresholds of interest in all phases except Phase I of the prospective study (highly correlated with Side of Town).

- Interior Paint Condition – There is evidence that worse paint condition of ceilings, doors, walls, and trim is associated with increased odds of achieving BLLs over the thresholds of interest in both the prospective and scheduled screening studies.
- Housecleaning – There is evidence that less housecleaning is associated with higher geometric mean BLLs and achieving BLLs over the thresholds of interest in Phases I and II of the prospective study and in the scheduled screening study.

The prospective study suffered from a very high rate of attrition, as participants who moved out of their treated property were excluded from the study if they did not relocate into another unit that had been treated by the MHD. Of the 185 children enrolled for Phase I of the Prospective Study, only 75 maintained their participation for all four phases with the clear majority of drop-outs attributable to families moving out of the treated home and a minority of children de-enrolled because they achieved a confirmed elevated blood-lead level. This attrition may contribute to finding significance of certain relationships in the earlier phases of the prospective study but not in the later phases when fewer measurements are available.

Regarding the relationship between children's blood lead levels and the environmental lead levels measured in their housing units, our analyses identified statistically significant positive correlation between BLLs and floor dust lead levels across all phases in both the prospective and scheduled screening studies. Table 3-2 contains the correlation measures and associated p-values for the comparisons of BLLs to the three interior components. Although there was significant positive correlation between BLLs and both window components in the scheduled screening study, for prospective study children these relationships were only significant at Phases II and III for window sills and Phase I for window troughs.

Table 3-2. Pearson Correlation Coefficients between Natural Log-Transformed Blood-Lead Concentrations and Natural Log-Transformed Dust-Lead Concentrations by Study and Phase

Study	Phase	Blood vs. Floor	Blood vs. Sill	Blood vs. Trough
Prospective	I	0.221 (0.003)	0.105 (0.155)	0.145 (0.05)
	II	0.237 (0.008)	0.27 (0.002)	0.047 (0.605)
	III	0.433 (<0.001)	0.226 (0.022)	0.12 (0.229)
	IV	0.445 (<0.001)	0.214 (0.065)	0.043 (0.716)
Scheduled Screening Phase II		0.317 (<0.001)	0.348 (<0.001)	0.228 (0.001)

Note: p-values for testing whether the Pearson correlation coefficient is different from 0 are provided in the parentheses and p-values ≤ 0.05 are shaded in yellow.

Longitudinal Summary of Blood-Lead Concentrations

Longitudinal analysis was performed on children's blood-lead concentrations to characterize the primary prevention effectiveness of the Milwaukee lead hazard control treatment strategy. It combines information across phases to compare the rate of blood-lead accumulation between children living in treated (Prospective study) homes and untreated (Scheduled Screening study) homes. Due to the high rate of attrition experienced in the prospective study, longitudinal models were explored among three different subgroups of the study population, as described in Table 3-3. In addition, differences in the primary prevention effectiveness were assessed among a number of different subgroups of the study population, as described in Table 3-4.

Table 3-3. Number of Blood-Lead Measurements Used in the Longitudinal Analysis

<table>
<tr><th rowspan="2">Population Studied</th><th colspan="4">Prospective</th><th colspan="2">Scheduled Screening</th></tr>
<tr><th>Phase I</th><th>Phase II</th><th>Phase III</th><th>Phase IV</th><th>Phase I</th><th>Phase II</th></tr>
<tr><td>Prospective study children who completed two or more visits & All Scheduled Screening study children</td><td>128</td><td>128</td><td>102</td><td rowspan="3">75</td><td rowspan="3">235</td><td rowspan="3">235</td></tr>
<tr><td>Prospective study children who completed study protocol & All Scheduled Screening study children</td><td>75</td><td>75</td><td>75</td></tr>
<tr><td>Prospective study children who completed 18 months visit or 24 months visit & All Scheduled Screening study children</td><td>102</td><td>102</td><td>102</td></tr>
</table>

Figure 3-1 displays blood-lead levels over time for children who completed two or more visits in the Prospective and Scheduled Screening studies. It appears that children in the North neighborhoods had higher blood lead levels as opposed to the South. Also, somewhat surprisingly, when blood lead levels over time are compared between the treated and control groups, the Prospective study children had a significantly lower estimated geometric mean blood-lead concentration at birth and a higher rate of blood-lead accumulation.

The difference in estimated geometric mean blood-lead concentration at birth was not anticipated, and is discussed further in Section 4. Our initial plans for developing statistical models for the data from this study involved assuming a constant intercept among all children in the combined study (both prospective and scheduled screening), with separate slope estimates describing the rate of blood-lead accumulation as a function of age (in months) for children living in treated and untreated housing units. The difference in these slope estimates would then characterize the primary prevention effectiveness of the Milwaukee lead hazard control treatments in terms of the rate of blood-lead accumulation.

Table 3-4. Levels of Group Effects

Set	Group Effect
1	Prospective study children Scheduled Screening study children
2	North Prospective study children North Scheduled Screening study children South Prospective study children South Scheduled Screening study children
3	Prospective study children from the Original Neighborhoods Scheduled Screening study children from the Original Neighborhoods Prospective study children from the Expanded Neighborhoods Scheduled Screening study children from the Expanded Neighborhoods
4*	Prospective study children living in units with high floor dust–lead loadings (at least one visit at or above 20 $\mu g/ft^2$) Prospective study children living in units with low floor dust–lead loadings (all visits below 20 $\mu g/ft^2$) Scheduled Screening study children

* Note that this group effect was explored due to the strong relationship observed between blood-lead and floor-dust lead levels in the cross sectional analyses. The value of 20 $\mu g/ft^2$ was selected so that the prospective study population could be equitably split into two groups (low and high floor dust-lead levels)

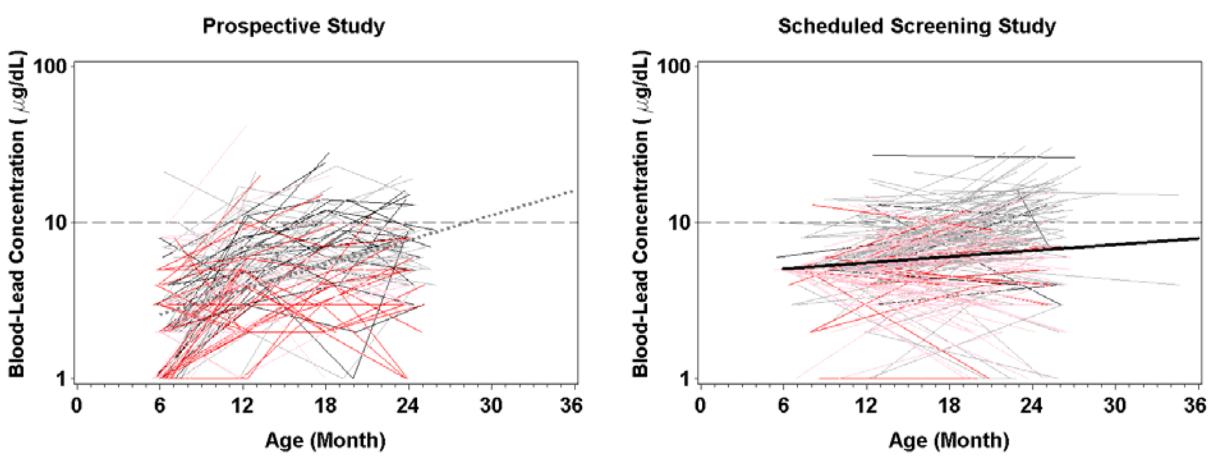

Figure 3-1. Blood-Lead Levels over Time in Prospective (Treatment) and Scheduled Screening (Control) Populations

The observation of statistically significant differences in estimated blood-lead levels between children living in treated and untreated housing units at birth required an assumption of separate intercepts for children in different study groups when modeling blood-lead concentrations. The base log-linear model developed for the longitudinal analysis of blood-lead concentrations assumes that the changes in blood-lead are constant (log-linear) over time (six months to 24 months of age) for children in the same study group. To account for the anticipated positive correlation among repeated measures on the same child, we used a mixed model that fits separate slopes and separate intercepts to each child as random effects, while estimating the blood-lead concentration at birth and the rate of change in blood-lead concentration as a function of age for each group as fixed effects. To adjust for covariates that may influence blood-lead concentrations, trends and relationships observed in the cross-sectional analysis were utilized. All strong predictors identified in the cross-sectional analysis were considered as potential covariates and added to the final base models. Final adjusted models were developed using a backward elimination approach to remove the non-significant terms.

The assumption of separate intercepts for prospective study and scheduled screening study children means that we can no longer simply compare the separate slope estimates between these two study populations to assess the primary prevention effectiveness of Milwaukee's Program. Rather, we must assess the differences between these two populations at different ages (e.g. at 6, 12, 18 and 24 months) based on a combination of the separate intercept and slope information. In general, we found that the Prospective study children had significantly lower geometric mean blood-lead concentrations at 6 months, 12 months and 18 months. At 24 months, there was no significant difference in the geometric mean blood-lead concentration between the treated and control groups. When exploring the data among different subpopulations (North vs South, Original vs Expanded Neighborhoods, Low vs High Floor-Dust Levels) we found a similar trend, with statistically significant differences generally observed only at 6, 12, and 18 months, as seen in Table 3-5, and Figure 3-2.

The proportion of children with an elevated blood-lead concentration (PbB≥10 μg/dL) was also studied as a function of time to address the health efficacy of Milwaukee's primary prevention activities using logistic regression models. These models were fit using Generalized Estimating Equations (GEE) to account for the anticipated positive correlation between multiple blood-lead concentrations observed on the same child. Data suggest that logistic regression models with a common intercept for children in different study groups is more suitable, most likely because the estimated proportion of children with blood-lead levels above 10 μg/dL at birth is close to zero for children in both study populations. Thus, an assessment of primary prevention effectiveness of the Milwaukee standardized lead hazard control treatments based on a comparison of the proportion of children with an elevated blood-lead concentration (PbB≥10 μg/dL) between treated and untreated groups reduces to a comparison of the two slopes (one corresponding to the treated group and the other corresponding to the untreated group). Table 3-6 summarizes the results of comparisons for all populations studied. For children living in dwellings with higher floor dust-lead levels, the prospective children who completed the study protocol had significantly lower odds of EBL, with or without controlling for other covariates.

Table 3-5. Differences in Geometric Mean Blood-Lead Concentrations between Untreated and Treated Housing Units (µg/dL)

Population Studied	Group Effect		Base Model 6 Months	Base Model 12 Months	Base Model 18 Months	Base Model 24 Months	Adjusted Model 6 Months	Adjusted Model 12 Months	Adjusted Model 18 Months	Adjusted Model 24 Months
PS study children who completed at least 2 visits & SS study children	Study	-	2.48**	1.82**	0.69*	-1.11	1.10**	0.82**	0.45*	-0.07
	Side of Town	North	2.25**	1.80**	0.90	-0.73	0.44	0.33	0.16	-0.12
		South	2.69**	1.81**	0.64	-0.91	0.94**	0.66**	0.33*	-0.06
	Ordinance Coverage	Expanded	2.24**	1.53**	0.33	-1.56*	1.20**	0.93**	0.55*	0.03
		Original	2.11**	1.43**	0.36	-1.26	1.09*	0.78*	0.35	-0.22
	Floor Dust-Lead	High	2.29**	1.40**	-0.14	-2.65**	1.25**	0.90*	0.41	-0.30
		Low	2.75**	2.45**	1.92**	1.08	1.30**	1.13**	0.91**	0.60
PS study children who completed study protocol & SS study children	Study	-	2.64**	2.19**	1.43**	0.23	0.91*	0.69*	0.40*	0.01
	Side of Town	North	2.39**	2.18**	1.67**	0.71	0.59	0.50	0.35	0.13
		South	3.07**	2.39**	1.51**	0.38	1.12**	0.76**	0.32	-0.21
	Ordinance Coverage	Expanded	2.22**	1.75**	0.99*	-0.15	0.93*	0.73*	0.46	0.10
		Original	2.43**	1.89**	1.03	-0.30	1.02*	0.75*	0.38	-0.12
	Floor Dust-Lead	High	2.57**	1.95**	0.91*	-0.77	0.96*	0.70*	0.34	-0.16
		Low	2.77**	2.59**	2.27**	1.76*	0.90*	0.76*	0.57*	0.35
PS study children who completed at least 3 visits & SS study children	Study	-	2.54**	1.91**	0.84*	-0.88	1.00**	0.75*	0.40	-0.06
	Side of Town	North	2.30**	1.89**	1.03*	-0.52	0.62*	0.47	0.25	-0.09
		South	2.84**	2.00**	0.88*	-0.63	1.25**	0.85**	0.36	-0.22
	Ordinance Coverage	Expanded	2.28**	1.62**	0.53	-1.20	1.08*	0.84*	0.50*	0.05
		Original	2.20**	1.54**	0.49	-1.13	1.00*	0.70	0.31	-0.23
	Floor Dust-Lead	High	2.40**	1.54**	0.07	-2.34**	1.15**	0.83*	0.37	-0.27
		Low	2.77**	2.49**	2.01**	1.26	1.20**	1.04**	0.83**	0.56

*Significant at 5% level.

**Significant at 1% level.

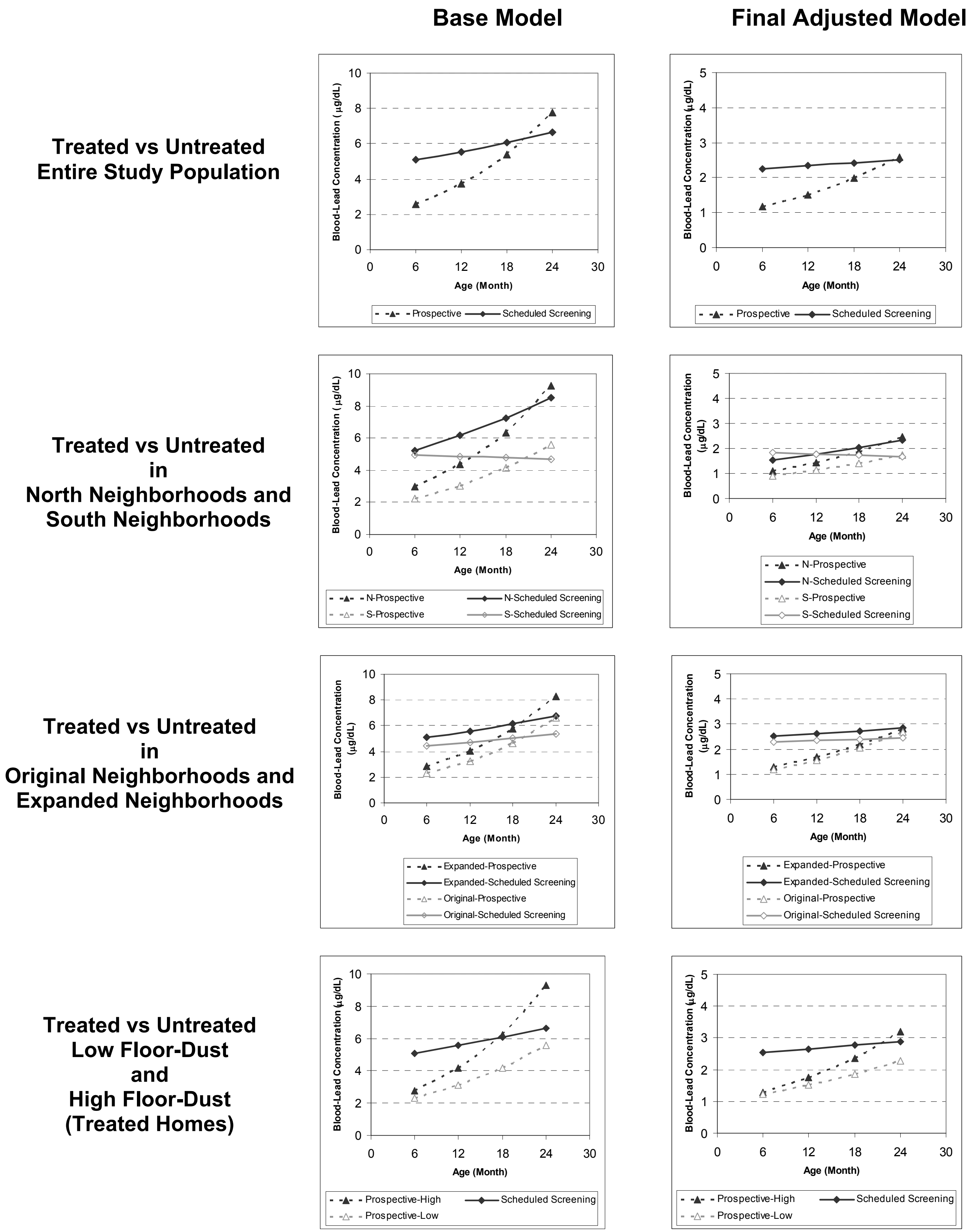

Figure 3-2. Change in Geometric Mean Blood-Lead Levels over Time

Table 3-6. Comparisons of Slopes (SS-PS) for Probability of Children with EBL

Population Studied	Levels of Group Effect		Base Model Estimate	Base Model Standard Error	Base Model p-value	Adjusted Model Estimate	Adjusted Model Standard Error	Adjusted Model p-value
PS study children who completed two or more visits & All SS study children	Study (PS & SS)	-	0.0166	0.0120	0.165	0.0140	0.0141	0.319
	Side of Town × Study	North	0.0255	0.0140	0.069	0.0214	0.0158	0.177
		South	0.0012	0.0245	0.961	-0.0097	0.0249	0.696
	Ordinance Coverage × Study	Expanded	0.0089	0.0151	0.556	0.0062	0.0176	0.723
		Original	0.0279	0.0289	0.335	0.0174	0.0332	0.600
	High Floor Dust Lead-PS, Low Floor Dust Lead PS & SS	High	0.0039	0.0138	0.778	0.0089	0.0160	0.578
		Low	0.0478	0.0194	0.014	0.0268	0.0206	0.194
PS study children who completed study protocol & All SS study children	Study (PS & SS)	-	0.0369	0.0147	<.001	0.0292	0.0162	0.071
	Side of Town × Study	North	0.0437	0.0162	0.007	0.0304	0.0175	0.083
		South	0.0522	0.0372	0.161	0.0157	0.0363	0.664
	Ordinance Coverage × Study	Expanded	0.0288	0.0188	0.125	0.0283	0.0206	0.169
		Original	0.0463	0.0328	0.159	0.0471	0.0382	0.218
	High Floor Dust Lead-PS, Low Floor Dust Lead PS & SS	High	0.0295	0.0175	0.092	0.0295	0.0201	0.143
		Low	0.0541	0.0223	0.015	0.0288	0.0206	0.162
PS study children who completed three or more visits & All SS study children	Study (PS & SS)	-	0.0192	0.0123	<.001	0.0166	0.0145	0.255
	Side of Town × Study	North	0.0270	0.0142	0.058	0.0229	0.0160	0.152
		South	0.0102	0.0266	0.701	-0.0049	0.0258	0.850
	Ordinance Coverage × Study	Expanded	0.0137	0.0159	0.388	0.0143	0.0185	0.440
		Original	0.0275	0.0290	0.343	0.0289	0.0344	0.401
	High Floor Dust Lead-PS, Low Floor Dust Lead PS & SS	High	0.0067	0.0142	0.636	0.0136	0.0168	0.416
		Low	0.0502	0.0202	0.013	0.0234	0.0201	0.244

Cross-Sectional Summaries of Interior Dust-Lead Loadings

Dust-lead loadings were collected using wipe samples from specified floor, window sill, and window trough locations in the previously treated housing unit at each of the four phases of the prospective study and at Phase II of the scheduled screening study. These samples were collected by certified risk assessors from the MHD following a standard protocol using baby-wipes as the collection vehicle. Templates were used for both floor and window components to ensure consistent areas being sampled. Additional information related to the surface was also recorded for each wipe sample. Samples were analyzed by the MHD Laboratory, with results reported in units of micrograms of lead per square foot of area sampled (µg/ft^2).

Tables 3-7, 3-8, and 3-9 contain descriptive summaries of dust-lead loadings for each surface – floor, sill, and trough, respectively. Generally, geometric mean dust lead loadings for floors, window sills, and window troughs were a bit higher at Phase I of the prospective study than at the later phases. Comparing the dust lead measures from prospective study units to those from scheduled screening units, there are very significant differences for the window components but not for the floors. For floors, the results obtained at treated units during Phase I of the prospective study are quite similar to those found at the untreated units in the scheduled screening study. Geometric mean, median, and the percentage of dwellings over certain thresholds are nearly identical. Dwellings with the highest floor dust lead levels appear to be those that dropped out from the prospective study as the 90th percentile declined from 70 µg/ft^2 at Phase I to 33 at Phase IV while the median stayed fairly constant across the four phases, dropping from 13 µg/ft^2 in Phase I to 12 µg/ft^2 in Phase IV.

Table 3-7. Descriptive Summary of Floor Dust-Lead Loadings by Study and Phase

Study	Phase	Sample Size	Geometric Mean	Geometric Standard Deviation	Minimum	10th Percentile	25th Percentile	Median	75th Percentile	90th Percentile	Maximum	Exceedance Percentiles			
												>= 10 µg/ft^2	>= 20 µg/ft^2	>= 40 µg/ft^2	>= 100 µg/ft^2
Prospective	I	180	14.4	3.2	0	4	6	13	32	70	2052	58%	36%	21%	4%
	II	122	12.9	2.8	1	5	7	13	21	43	2879	60%	27%	12%	3%
	III	98	12.0	2.6	2	4	6	11	22	39	211	55%	29%	8%	3%
	IV	72	12.7	2.3	2	5	7	12	24	33	78	64%	33%	7%	0%
Sch. Scr. Phase II		232	14.4	3.2	1	4	6	13	30	78	1074	59%	34%	19%	6%

Note: The current federal standard for floor dust-lead loading is 40 µg/ft^2. At the time the study was initiated, the federal standard for floor dust-lead loading was 100 µg/ft^2.

On the other hand, window sill and trough dust lead levels in the Prospective study's treated dwellings are much lower than those found in the Scheduled Screening study's untreated dwellings. Prospective study geometric mean sill dust lead levels are 71 to 78 percent lower than the Scheduled Screening study. Whereas 66 percent of Scheduled Screening study units exceeded the current sill risk assessment threshold of 250 µg/ft^2, only 25 to 38 percent of Prospective study units exceeded this threshold. An even larger difference is apparent for window troughs. Prospective study geometric mean and median trough dust lead levels are 95 to 97 percent lower across the four phases than the Scheduled Screening study. However, 60 to 64 percent of Prospective study dwellings' trough lead levels in each phase exceed the current clearance standard of 400 μg/ft^2 and 40 to 49 percent exceed the prior clearance standard of 800μg/ft^2, which may still represent a cause for concern.

Although the cross sectional results are indicative of dust-lead levels decreasing over time on all three surface types (floors, sills, and troughs), we need to confirm that these results represent steady decline within the same housing units over time using the longitudinal models, as opposed to observing units with the highest dust-lead levels being lost due to attrition or de-enrollment.

Table 3-8. Descriptive Summary of Sill Dust-Lead Loadings by Study and Phase

Study	Phase	Sample Size	Geometric Mean	Geometric Standard Deviation	Minimum	10th Percentile	25th Percentile	Median	75th Percentile	90th Percentile	Maximum	Exceedance Percentiles	
												>= 250 μg/ft^2	>= 500 μg/ft^2
Prospective	I	180	162.5	4.1	0	29	58	162	395	1028	8139	38%	21%
	II	122	146.8	3.4	5	35	67	136	306	761	3232	33%	16%
	III	98	161.2	3.7	5	31	60	159	387	770	3818	38%	19%
	IV	72	120.5	3.3	19	29	49	96	273	564	2550	25%	13%
Sch. Scr. Phase II		232	557.7	5.1	16	75	185	499	1530	4080	124420	66%	50%

Table 3-9. Descriptive Summary of Trough Dust-Lead Loadings by Study and Phase

Study	Phase	Sample Size	Geometric Mean	Geometric Standard Deviation	Minimum	10th Percentile	25th Percentile	Median	75th Percentile	90th Percentile	Maximum	Exceedance Percentiles	
												>= 400 μg/ft^2	>= 800 μg/ft^2
Prospective	I	179	738.3	6.0	0	74	260	750	2400	7500	72300	64%	47%
	II	121	591.4	5.6	0	73	230	640	1600	4700	27000	61%	45%
	III	98	571.5	5.6	2	52	190	760	2000	5700	10000	62%	49%
	IV	72	671.0	6.0	34	86	180	580	1800	7900	67000	60%	40%
Sch. Scr. Phase II		225	14859.5	10.3	0	770	3910	17800	67100	270000	3450000	93%	89%

As with children's blood lead levels, there are many variables identified that significantly impact the interior dust lead levels. Some of these significant variables include:

- <u>Side of Town</u> – Dwellings located on the North side of town are associated with higher floor dust-lead levels in all phases and higher sill dust lead levels in Phases I and II of the prospective study and the scheduled screening study.
- <u>Ordinance Coverage of Neighborhood</u> – Dwellings in neighborhoods not covered by the ordinance show evidence of higher floor dust lead levels at Phases I, II, and IV of the

prospective study; higher sill dust lead levels at Phase I of the prospective study and in the scheduled screening study; and higher odds of exceeding 800 μg/ft^2 at Phase I of the prospective study.

- De-enrollment Status – Dwellings with children who were de-enrolled from the study were associated with higher odds of having floor dust lead levels exceed 20 μg/ft^2 and 100 μg/ft^2 at Phase II and Phase III of the prospective study, respectively. This suggests that children who were de-enrolled (i.e. had a confirmed blood-lead level above 15 μg/dL) may have been exposed to significantly higher floor-dust lead levels than children who remained in the study.
- Interior Paint Condition – There is evidence that worse paint condition of interior ceilings, doors, walls, and trim is associated with increased odds of exceeding thresholds on floors at Phase III of the prospective study and in the scheduled screening study.
- Housecleaning – There is evidence that lower ratings of household cleanliness are associated with higher floor and sill dust lead levels.
- Exterior Deterioration – There is evidence that exterior building deterioration is associated with higher floor and sill dust lead levels at Phase I of the prospective study.
- Interior Deterioration – Dwellings found with interior deterioration are associated with higher dust lead levels on all three components at Phases I, II, and III of the prospective study and in the scheduled screening study.

Relationships between dust lead loadings on the three components were explored for this report using correlation analysis and scatterplots. Table 3-10 contains the Pearson correlation coefficients and associated p-values for each combination of component at each phase. The results indicate that both floor and sill dust lead levels and sill and trough dust lead levels are positively correlated at each phase of the prospective study and in the scheduled screening study. The only significant evidence of positive correlation between floor and trough dust lead levels is for the scheduled screening study units. The correlation coefficient of .222 is not as strong as those found for the other two scheduled screening study component comparisons: .33 for floors vs. sills and .39 for sills vs. troughs.

Table 3-10. Pearson Correlation Coefficients between Natural Log-Transformed Dust-Lead Loadings by Study and Phase

Study	Phase	Floor vs. Sill	Floor vs. Trough	Sill vs. Trough
Prospective	I	0.245 (0.001)	0.002 (0.982)	0.356 (<0.001)
	II	0.234 (0.009)	0.065 (0.477)	0.252 (0.005)
	III	0.265 (0.008)	0.175 (0.085)	0.3 (0.003)
	IV	0.344 (0.003)	0.05 (0.679)	0.322 (0.006)
Scheduled Screening Phase II		0.334 (<0.001)	0.222 (0.001)	0.387 (<0.001)

Note: p-values are provided in the parentheses.

Longitudinal Summary of Interior Dust-Lead Loadings

Longitudinal analysis of Prospective study dust-lead results collected from 120 units is provided in this section. These units had dust-lead results from two or more visits. Of these units, 23 are from the North Original neighborhood, 46 are from the North Expanded neighborhood, 27 are from the South Original neighborhood and 24 are from the South Expanded neighborhood. Figure 3-3 displays dust-lead levels over time in the Prospective populations for floors, sills and troughs. It appears that units in the North neighborhoods had higher floor and sill dust-lead loadings as opposed to the South. There was a slight downward trend in the floor dust-lead loadings. The initial base models for dust-lead data do not account for any potentially significant covariates – such as race, side of town, or number of times recently moved. They simply model dust-lead levels by time since clearance. The models fit a separate slope and intercept for each unit.

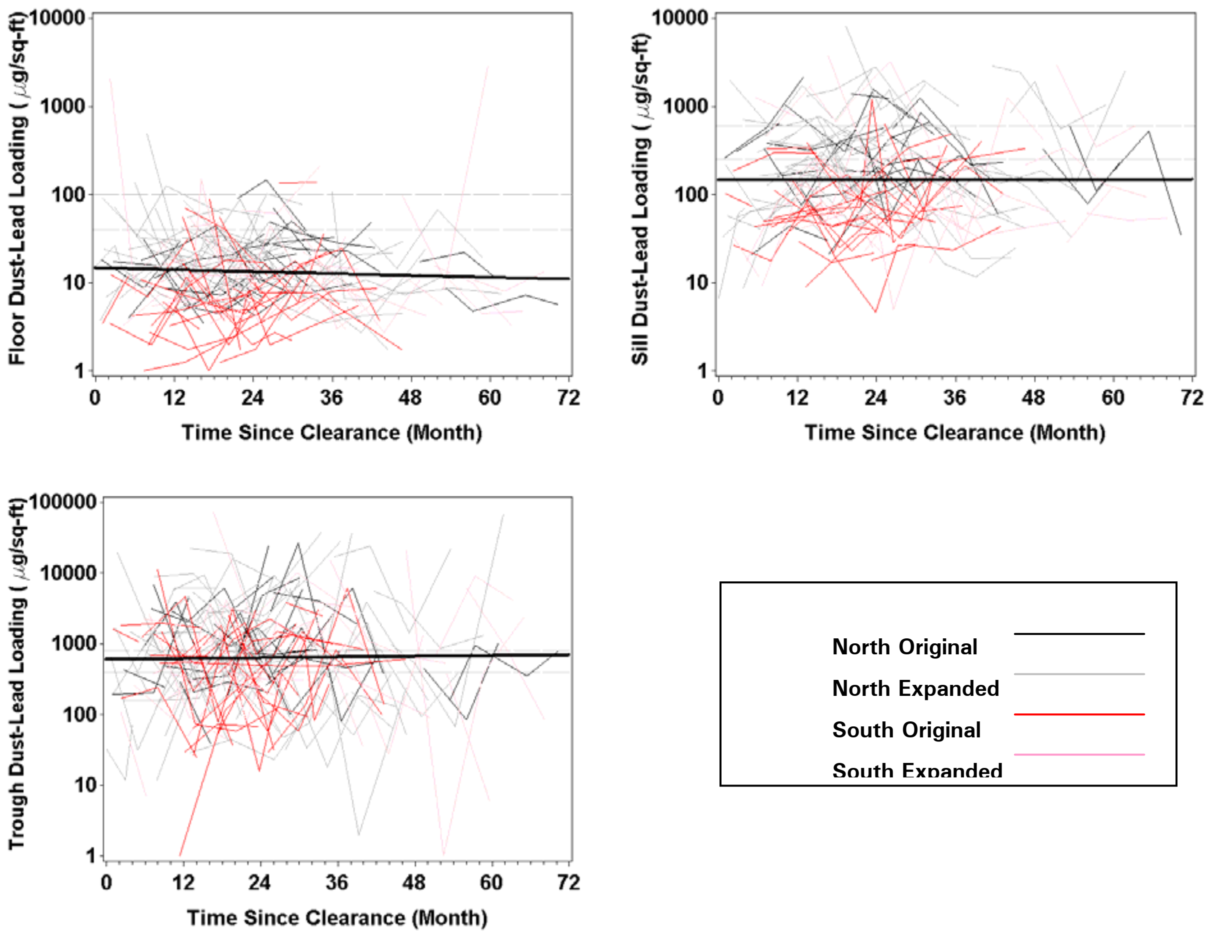

Figure 3-3. Dust-Lead Loadings over Time in Prospective Populations

Table 3-11 presents the rates of dust-lead re-accumulation for floors, sills and troughs, with or without accounting for other covariates. There were no significant trends in sill and trough dust-lead loadings. For treated dwellings in original neighborhoods, there was significant downward trend in floor dust-lead loadings, and a significant upward trend in the expanded neighborhoods as predicted by the base model.

Table 3-11. Rate of Dust-Lead Re-accumulation

Component	Levels of Group Effect		Base Model			Adjusted Model		
			Estimate	Standard Error	p-value	Estimate	Standard Error	p-value
Floor	None		-0.0042	0.0048	0.391	-0.0038	0.0059	0.522
	North vs. South	North	-0.0088	0.0064	0.174	-0.0043	0.0079	0.588
		South	0.0029	0.0072	0.690	-0.0064	0.0091	0.483
	Original vs. Expanded	Original	-0.0177	0.0057	0.002	-0.0148	0.0071	0.041
		Expanded	0.0195	0.0073	0.009	0.0158	0.0097	0.107
Sill	None		0.0003	0.0052	0.954	0.0056	0.0053	0.292
	North vs. South	North	-0.0034	0.0072	0.634	0.0058	0.0071	0.415
		South	0.0067	0.0080	0.402	0.0052	0.0077	0.502
	Original vs. Expanded	Original	-0.0058	0.0068	0.396	0.0036	0.0065	0.588
		Expanded	0.0098	0.0084	0.242	0.0104	0.0088	0.241
Trough	None		0.0023	0.0078	0.771	0.0038	0.0052	0.466
	North vs. South	North	0.0096	0.0088	0.275	0.0074	0.0056	0.186
		South	-0.0054	0.0091	0.550	-0.0008	0.0058	0.896
	Original vs. Expanded	Original	0.0053	0.0083	0.526	0.0051	0.0054	0.346
		Expanded	-0.0030	0.0092	0.749	0.0009	0.0060	0.887

Table 3-12 summarizes parameter estimates for the time trend in probability of failing the current federal dust-lead standards (40 µg/ft^2 for floors, 250 µg/ft^2 for sills and 400 µg/ft^2 for troughs) as well as the previous dust-lead standards (100 µg/ft^2 for floors, 500 µg/ft^2 for sills, and 800 µg/ft^2 for troughs). Treated dwellings in expanded neighborhoods had a significant downward trend in the probability of failing the current floor dust-lead loadings. Treated dwellings in North neighborhoods had a significant upward trend in the probability of failing the previous sill dust-lead loadings.

Table 3-12. GEE Parameter Estimates of Group×TSC

Response	Component	Levels of Group Effect		Base Model Estimate	Base Model Standard Error	Base Model p-value	Adjusted Model Estimate	Adjusted Model Standard Error	Adjusted Model p-value
Probability of Units Failing Current Dust-Lead Standards	Floor	None		-0.0171	0.0116	0.142	-0.0264	0.0138	0.055
		North vs. South	North	-0.0167	0.0127	0.188	-0.0347	0.0154	0.024
			South	-0.0175	0.0134	0.193	-0.0136	0.0156	0.384
		Original vs. Expanded	Original	0.0149	0.0201	0.459	0.0116	0.0226	0.607
			Expanded	-0.0306	0.0143	0.032	-0.0327	0.0164	0.046
	Sill	None		-0.0030	0.0076	0.687	0.0017	0.0110	0.875
		North vs. South	North	-0.0092	0.0096	0.341	-0.0002	0.0140	0.988
			South	0.0105	0.0128	0.410	0.0031	0.0172	0.855
		Original vs. Expanded	Original	-0.0137	0.0096	0.154	-0.0070	0.0135	0.604
			Expanded	0.0014	0.0079	0.856	0.0058	0.0116	0.615
	Trough	None		0.0008	0.0075	0.913	-0.0082	0.0100	0.411
		North vs. South	North	0.0062	0.0083	0.459	-0.0047	0.0108	0.664
			South	-0.0052	0.0084	0.534	-0.0130	0.0116	0.262
		Original vs. Expanded	Original	0.0003	0.0090	0.973	-0.0019	0.0119	0.875
			Expanded	0.0011	0.0079	0.893	-0.0117	0.0107	0.273
Probability of Units Failing Previous Dust-Lead Standards	Floor	None		-0.0045	0.0212	0.831	-0.0055	0.0221	0.805
		North vs. South	North	-0.0187	0.0270	0.488	-0.0125	0.0271	0.646
			South	0.0041	0.0216	0.848	-0.0008	0.0234	0.973
		Original vs. Expanded	Original	0.0603	0.0317	0.057	0.0628	0.0332	0.058
			Expanded	-0.0440	0.0308	0.153	-0.0456	0.0316	0.149
	Sill	None		0.0082	0.0094	0.381	0.0274	0.0113	0.016
		North vs. South	North	0.0198	0.0098	0.044	0.0304	0.0121	0.012
			South	-0.0226	0.0144	0.118	0.0185	0.0172	0.284
		Original vs. Expanded	Original	-0.0068	0.0127	0.593	0.0147	0.0136	0.279
			Expanded	0.0131	0.0095	0.168	0.0352	0.0119	0.003
	Trough	None		0.0038	0.0072	0.597	0.0038	0.0072	0.597
		North vs. South	North	0.0066	0.0079	0.408	0.0066	0.0079	0.408
			South	0.0005	0.0083	0.951	0.0005	0.0083	0.951
		Original vs. Expanded	Original	-0.0057	0.0089	0.519	-0.0057	0.0089	0.519
			Expanded	0.0084	0.0077	0.271	0.0084	0.0077	0.271

4.0 DISCUSSION

The goal of this study was to determine the effectiveness of the Milwaukee Pilot Ordinance, which sought to reduce children's exposure to lead dust and debris through a set of treatments at each home. By funding the abatement of lead based paint on windows in a home, requiring the owner of the property to make all paint intact, and testing the units after work to assure that the levels of dust lead in the home were below the Federal/local standards, it was anticipated that children's blood level levels would be lower than children living in similar, untreated homes. It was also anticipated that dust-lead levels and the proportion of painted surfaces that were deteriorating would be lower in treated homes than in untreated homes. The study monitored blood lead levels of a child born into the treated homes and compared them to the blood lead levels of children in untreated homes who were screened by pediatricians or clinicians and then later tested for the study. The expectation was that at young ages, children in both groups would have similar blood lead levels because a child under six months of age is less likely to be mobile (i.e., rolling and crawling) and less likely to be exposed to household lead dust and debris. Over time, as children became mobile and began mouthing their hands and toys that were exposed to lead dust, children in the treated units (the Prospective Study group) were expected to have lower blood lead levels than children in the untreated units (the Scheduled Screening group). Specifically, it was expected that children in the Prospective Study group would be significantly less likely than children in the other group to have a blood lead level that exceeded 10 µg/dl, the Federal level of concern.

Effectiveness in Achieving Lower Dust Lead Loadings

Comparisons between the Prospective Study group dwellings and the Scheduled Screening dwellings demonstrated that the Pilot Ordinance was effective in decreasing dust lead loadings on window sills and troughs. On both sills and troughs, geometric mean dust lead loadings and the percentage of dwellings with dust lead exceeding the Federal dust lead standards in the Prospective Study group were significantly below the loadings in the Scheduled Screening group. On window sills no more than 38 percent of the treated dwellings in any one phase of the study exceeded the current Federal standard of 250 $\mu g/ft^2$ as compared with 66 percent of the untreated dwellings. Furthermore, there were no significant changes in sill and trough dust lead loadings in the Prospective Study units during the 18 months that they were monitored.

On floors, the results are more ambiguous. Geometric mean floor dust lead loadings and the percentage of dwellings over certain thresholds (10, 20, 40, and 100 $\mu g/ft^2$) were nearly identical between the two groups. Like the window surfaces, there were no significant changes in the geometric mean dust lead loadings in the Prospective Study units during the 18 months study period. Reductions were observed at the higher percentiles, but this was attributed to an increased likelihood that the worst units would drop out of the study. Although the treatments, which were intended to reduce floor dust lead levels below the previous floor standard of 100 $\mu g/ft^2$, did not have a differential effect as compared to the untreated units if measured against the current Federal floor standard (40 $\mu g/ft^2$), all units could be considered to have relatively low dust-lead levels. One-fifth or less of the homes in either study group exceeded the current standard.

Effectiveness in Achieving Lower Blood Lead Levels

Although the treatments conducted under the Milwaukee Pilot Ordinance were relatively effective in bringing window dust lead loadings below those in comparable untreated units, the effects on children's blood lead levels did not meet original expectations. The study compared the probability of having an elevated blood-lead level (i.e., blood lead concentrations at or above 10 µg/dL) by age between the Scheduled Screening study children and Prospective Study children, and found no significant differences, with or without accounting for other factors of interest. Twenty-six percent of children age 18 months in the Prospective study group had elevated blood-lead levels, while 27 percent of children in Phase II (median age 24 months) of the Scheduled Screening group had elevated levels.

To better understand why the treatments did not result in the anticipated improvements in children's health, a number of potential confounding factors were explored. The study had earlier found that children living in the North side of Milwaukee tended to have higher blood lead levels than children in the South side of the city, so it was hypothesized that neighborhood factors may have influenced the probability of elevated blood lead levels. The study also looked at whether the time when the Ordinance went into effect in a community had an impact on the blood lead levels. Although both the neighborhood and the time when the Ordinance went into effect influenced the blood lead levels, after controlling for these factors, there were still no significant differences in the likelihood of having an elevated blood-lead level between the two study groups and no differences between the geometric mean blood lead levels in the two groups.

One factor that appears to have had an effect on the blood lead levels between the Prospective Study group and the Scheduled Screening group was the floor dust lead loading. Children in the Prospective Study were divided into two groups: those living in homes where all visits had floor dust lead levels less than 20 $\mu g/ft^2$ and those living in homes with at least one higher dust lead result. Prospective Study children living in a home with the lower floor dust lead loadings had proportionally fewer elevated blood lead levels as they got older compared to all children in the Scheduled Screening group (regardless of floor dust-lead levels) when other factors were not considered, as seen in Table 3-5. In addition, children living in treated dwellings with lower floor lead levels had significantly lower blood lead levels than children in the untreated dwellings, at 6, 12, and 18 months of age; at 24 months, the blood lead levels were marginally lower (p-value=0.059).

These findings suggest that had the treatments been able to result in lower floor dust lead levels than in the Scheduled Screening homes, then the impact on the blood lead levels may have been greater. This observation is further supported by the findings that after controlling for age and seasonal effects, floor dust lead levels were significantly related (p-value=0.006) to the blood lead concentration of children in the Prospective Study, while window sill and trough levels were only marginally related (p-value=0.058 and 0.069, respectively). Of all the factors that influenced floor dust lead loadings (season, inspector, rental vs. owner-occupied, interior deterioration), interior deterioration is one factor that is both a possible cause and could be influenced by treatment.

Potential Limitation of the Study

The observed trends in blood lead levels for the two groups were also unexpected. Previous studies have demonstrated that children's blood lead levels tend to rise from birth until early in the second year and then decline. It would have been anticipated that children in the Scheduled Screening group would have exhibited this positive rate of increase in blood lead levels from age 6 months to 24 months, while children in the Prospective study would have had a lower rate of increase or ideally no significant increase. Instead, there was there was no significant change in blood lead levels for the Scheduled Screening group after controlling for other factors, while there was a significant upward trend for the Prospective Study group. It raises the question of why children in the untreated dwellings would not experience the same upward trend of blood lead levels that is observed with children in other studies and whether there are any limitations of using this population as a quasi-control population.

At age 6 months, the predicted blood lead level for children in the Scheduled Screening group was almost twice the level seen in children in the Prospective Study group. As noted earlier, because household exposure sources would be expected to be less of an influence on younger less mobile children, the magnitude in this difference was not anticipated. If our assumption is wrong about household exposure at a young age, then this suggests that the treated homes may have a dramatic effect on children at a young age, but the effect disappears by age two. However, if the original assumption about household exposures is correct, the finding may further suggest that children in the Scheduled Screening group had different non-housing lead exposure levels before 6 months (and possibly before birth) than children in the Prospective Study. The finding could also mean that the scheduled screening study represents a biased sample of children. For example, despite the fact that the Milwaukee Standard of Care includes the proactive screening of children for elevated blood-lead levels at 12 months of age, the population of children that actually receive this screening may be biased towards higher levels of lead exposure.

Conclusions

Whether the Scheduled Screening group served as an optimal control group or not, the fact that children in the treated dwellings had a significant increase in blood lead levels from age 6 months to 24 months and that over a quarter of these children had elevated blood lead levels suggests that improvements to the Milwaukee Pilot Ordinance should be considered. The program was very successful in reducing window dust lead loadings, an exposure source that proved be marginally related to the children's blood lead levels. However, it was not successful in reducing floor dust lead levels, which was strongly influential as an exposure source. The strong relationship observed between interior deterioration and dust lead levels suggests the importance of correcting interior deterioration and maintaining properties over time. Adding components to the city's program that can be proven to reduce floor lead loadings, possibly to levels below the current Federal standards, and to keep floor dust lead loadings low, would be recommended to improve the benefits of the program.