A Randomized Trial of Education to Prevent Lead Burden in Children at High Risk for Lead Exposure: Efficacy as Measured by Blood Lead Monitoring

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In this article we report on the effectiveness of a community-based, culture-specific, controlled trial of intensive peer education aimed at preventing lead burden in children 0–36 months of age within a neighborhood with high risk for lead exposure. Mothers (n = 594) were randomly assigned to control or intervention groups. Offspring blood lead levels were assessed every 4 months. All participants received brochures on basic lead prevention strategies. Intervention participants were offered 20 bi-weekly educational sessions by same-ethnicity peer educators over the course of 1 year, and quarterly booster sessions for 2 years afterward. The intervention group's educational curriculum included information on lead sources (e.g., paint, dust, water, soil, and risks from home repairs and remodeling), health consequences of lead burden, and strategies to reduce lead exposure, including household cleaning, hygiene, safe use of water, and nutritional recommendations. Results indicated that of the 378 children contributing sufficient blood data for analysis, 23% had blood lead levels > 10 µg/dL before 3 years of age. Intervention participants were more likely to maintain blood lead levels < 10 µg/dL than were controls (81% vs. 73%; p = 0.08). Multivariate analyses demonstrated that the intervention reduced the risk of blood lead levels > 10 µg/dL by approximately 34%. We conclude that although intensive education resulted in a lower proportion of children with elevated lead levels, education alone cannot be relied upon to prevent lead burden. *Key words:* lead burden, lead poisoning, peer education, prevention, primary prevention. *Environ Health Perspect* 111:1947–1951 (2003). doi:10.1289/ehp.6352 available via *http://dx.doi.org/* [Online 2 September 2003]

Childhood lead burden is one of the most common and preventable environmental health problems. Rates vary depending on socioeconomic status and geographical location, but estimates for populations at risk are typically near 25% (Casey et al. 1996; CDC 2001; Javier et al. 1999; Nordin et al. 1998; Rifai et al. 1993; Singer et al. 1997). Although lead burden rates have declined dramatically since lead was removed from paint in 1978 and phased out of gasoline beginning in 1973 (Lanphear et al. 2003), many children are still poisoned, in part because these earlier practices still pose risks. Today, children living in homes built before 1978 are exposed to lead paint as it deteriorates, particularly on walls and windows damaged by moisture from leaks. Children play in bare soil contaminated by leaded gasoline emission deposits. Soil tracked into the house and deteriorating paint from interior walls and windows create lead in household dust. Children ingest dust as they crawl or play on the floor and put dusty hands in their mouths. In addition, water from lead pipes and copper pipes with lead solder continues to pose a risk in some communities (Lanphear et al. 1998, 2002). Children of certain ethnicities are also exposed through pottery glaze and traditional lead-laden medicinals (CDC 2002; Tait et al. 2002).

Low to moderate blood lead levels can lead to lowered IQ (Baghurst et al. 1992; Bellinger et al. 1991, 1992; Bergomi et al. 1989; Dietrich et al. 1993) and to deficits in attention (Walkowiak et al. 1998; Winneke and Kramer 1997), visuospatial and visuomotor skills (Bellinger et al. 1991; Dietrich et al. 1991; Winneke et al. 1994), language (Shaheen 1984), and reading (Fergusson et al. 1997), as well as generally poor academic achievement (Bellinger et al. 1992; Lanphear et al. 2000a; Wang et al. 2002) and hyperactivity, aggression, and emotional lability (Bellinger et al. 1994). Adolescents with prior lead burden commit more delinquent acts than do nonburdened adolescents (Dietrich et al. 2001; Needleman et al. 1996, 2002). Some of these developmental consequences may be permanent, leading to lost potential and unnecessary spending on special education and the justice system (Bellinger et al. 1992; Liu et al. 2002; Needleman et al. 1985, 1990; Tong et al. 1998). Although the current Centers for Disease Control and Prevention guidelines place the safe limit at 10 µg/dL (CDC 1991), there may be no threshold for the effects of lead (Schwartz 1994). The usual practice in most states is to respond environmentally and medically after an elevated blood lead level is detected, to prevent further exposure in the home and to hasten the elimination of lead from the body. Studies of parent education and household cleaning interventions to reduce elevated blood lead levels—the techniques most closely related to the prevention strategies used in the present study—have yielded mixed results depending on duration and intensity of the intervention, adequacy of controls, and other methodologic differences (Aschengrau et al. 1998; Charney et al. 1983; Haynes et al. 2002; Lanphear et al. 1996; Rhoads et al. 1999; U.S. EPA 1996). However, given that such interventions may occur too late to avoid long-term consequences to the child, it is most important to evaluate techniques that prevent lead burden in the first place. Limited data exist concerning the effectiveness of primary prevention techniques, and results appear to depend on the intensity and duration of education and cleaning strategies and on whether families or professionals are engaged in the preventive behavior (Lanphear et al. 1999, 2000b).

The purpose of this study was to assess the effectiveness of a culture-specific peer education program in preventing elevated blood lead levels in children during their peak period of risk for exposure. Although several outcome variables were measured, in this article we report the results of blood lead monitoring only. We hypothesized that more children of mothers in the intervention group would maintain lower blood lead levels than would children of mothers in the control group.

Materials and Methods

The Phillips Lead Project was a community-based, randomized controlled trial of the effectiveness of intensive, culture-specific peer education in maintaining low blood lead levels in children from birth to 3 years of age. The project was designed and conducted in collaboration with residents of the Phillips Neighborhood in Minneapolis, Minnesota. Mothers were randomized to a control or intervention group. Regardless of group assignment, all participants received state health department brochures about lead, in their own language. Blood was drawn regularly for all children. All home environments were

assessed for lead contamination. Results of blood lead testing and home inspections were communicated to caregivers in both groups. Knowledge of lead risks and prevention techniques was assessed periodically throughout the study for all participants. An intensive educational intervention was delivered to the intervention group only. Phillips Neighborhood residents from the largest ethnic groups (Caucasian, African American, Native American, Latino, Hmong, Cambodian, and Laotian) were hired and trained to fill the nine peer teacher positions. Peer teachers met individually with intervention group participants in their homes to improve their knowledge of lead exposure and to increase their capacity to reduce lead exposure of their offspring. The research protocol is summarized in Figure 1. In the procedures described below, additional details are given regarding blood lead levels, the outcome of interest in the present report.

Participants. Pregnant women and mothers of young infants (n = 594) were recruited from the Phillips Neighborhood. The neighborhood is a large, inner-city, economically disadvantaged (71% of the young children live in poverty), and ethnically diverse (78% persons of color) community. Participant characteristics are provided in Table 1. Participants were recruited via grassroots methods (door knocking, posters and flyers, information tables at community events) and via referral from cooperating obstetrics and pediatrics clinics serving the neighborhood. Mothers received a detailed description of the project, its risks and benefits, and their alternatives to participation and signed an informed consent form. Mother–infant dyads were randomized to either a control group (n = 301 mothers) or an intervention group (n = 293 mothers). A randomization design was used in which random numbers representing control or intervention group assignment were generated for each race within each pediatric clinic. This assured that possible differences in exposure to lead prevention information based on typical patient education practices within certain pediatric clinics or decreased access because of ethnic group or native language were balanced across groups. Assignment was modified when a close friend or sibling of a participant had already been assigned to a group or when relatives or friends lived together. This occurred in < 3% of the original 594 subjects recruited. Mothers of twins were eligible for randomization with both children contributing data to the assigned group. There were 13 sets of twins, approximately balanced between groups, making a total of 607 randomized children.

Procedures. According to the protocol, children's blood lead levels were to be tested every 4 months from 4 months of age through the third birthday. Initially, capillary sampling

was used; however, after the first birthday, venous sampling was used unless the parent objected, which occurred for 36 blood draws in 29 children, although five of these children were not included in the final analysis. Capillary samples indicating high blood lead levels were validated with a venous sample. At each encounter between peer teachers and participants, instances of information gained or shared outside the context of the study were assessed to document possible contamination between groups or an increase in awareness within the control group independent of the Phillips Lead Project. If lead poisoning information was passed from the intervention group to the control group, or the control group learned lead poisoning prevention techniques from sources outside the project, between-group differences in knowledge of prevention techniques and in blood lead levels could be reduced and the effectiveness of the intervention masked. All mothers received basic lead burden prevention information in the form of brochures in their native language. According to the protocol, mothers in the intervention group were to receive 20 bi-weekly, in-home education sessions delivered by a peer educator of her same ethnic background. Sessions lasted 0.5–1 hr. Quarterly follow-up educational sessions were to be conducted after this intensive period of education and were to continue through the final 2 years of the project. Most participants (> 90%) completed 19 or 20 sessions. Of those who missed two or more sessions, the average number of completed sessions was 10. Although most participants completed the educational intervention, most took 18 months, and some up to 36 months, to complete the 20-session curriculum.
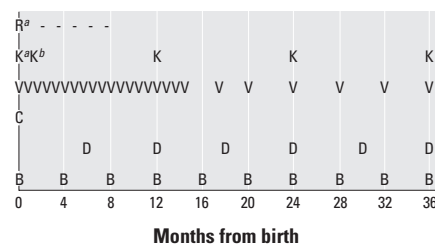

Figure 1. Research protocol. Abbreviations: B, blood lead tests every 4 months; C, comprehensive lead inspection for each home lived in during project; D, dust lead levels taken in home every 6 months after a comprehensive lead inspection; K, knowledge test given to primary caregiver five times; R, randomization to intensive or basic education group; V, intensive education visits by peer teacher (20 during the first year and then booster sessions to end of project).
[a]For enrollment during pregnancy, randomization and first assessment of knowledge occurred at birth; for enrollment after birth, they occurred at enrollment. [b]For those in the intervention group, knowledge was reassessed at first meeting with peer teacher, at the end of 20 education sessions, after 2 years, and at the end of the project; for those in the control group, knowledge was reassessed at the time of basic contact and after 1, 2, and 3 years (end of project).

Because of the duration of the recruitment period, the time necessary to complete the first 20 sessions, and the ending of the project, far fewer completed all six booster sessions (~50% completed the first year of booster sessions, but < 5% completed the second year of booster sessions).

The educational curriculum included information on sources of lead (e.g., dust, paint, soil, water, and risks from home repairs and remodeling), health sequelae of lead burden, and lead exposure reduction strategies, including household cleaning, safe use of water, hygiene, and nutritional guidelines (Table 2). One focus of the educational process was the development of a warm and supportive relationship between the participants and peer educators. All participants received incentives for participating in the project. The intervention group received $10 for each of the first 20 educational sessions, $15 for each follow-up session, and $15 for each blood draw, whereas the control group received $50 on four occasions during the first year, $25 twice a year thereafter, and $15 for each blood draw.

Statistical analysis. Group differences on baseline measures were analyzed by t-test for continuous measures and by chi-square test for categorical measures. Comparison of reported incidences of receipt of lead prevention information from external sources (contamination) used the chi-square statistic.

Missing data raised the concern that elevated lead levels might have been missed. If blood lead levels were not collected with sufficient frequency, blood lead elevations could have been missed because the level dropped below 10 µg/dL before the next blood lead test. Similarly, the child's highest lead level could have been missed if lead levels were collected infrequently. The rate of "true negatives" (children who never experienced a high lead level) could have differed between groups based on the effectiveness of the intervention. Including children whose true lead elevation status is unknown could have biased the results.

Table 1. Determinants of final sample available for blood lead analyses.

	Control	Intervention
Total children randomized[a]	308	299
Death of infant	−1	−1
Child moved away	−22	−27
Child entered foster care	−7	−7
Family withdrew child from study	−69	−68
Insufficient blood data[b]	−15	−12
Total available for blood analysis	194	184

[a]Because of the presence of 13 sets of twins, 13 more children were randomized compared with the number of mothers randomized. [b]For a child to have contributed sufficient blood lead data for analysis, three measurements < 10 µg/dL, with two having been done between 12 and 24 months of age, or one measurement ≥10 µg/dL at any time, were necessary.

Therefore, subjects who contributed to the major analysis were required to have one or more blood lead values > 10 µg/dL or, if no blood lead value was > 10 µg/dL, to have at least three blood lead measures, of which two were collected between 12 and 24 months of age. The second requirement was to ensure that if a subject was to be considered to have a normal blood lead level, there needed to be sufficient opportunities for an elevated blood lead value to be measured. The period from 12 to 24 months was considered one of enhanced vulnerability as the child became more independent (crawling/walking) but still lived "close to the floor" and was still likely to mouth fingers and objects at least occasionally.

Blood data were analyzed as categorical variables. Categorical analysis was conducted using chi-square with cut points at 10, 15, or 20 µg/dL. Based on these categories, prevalences of elevated blood lead were examined by experimental group. The child's highest lead level determined the child's category. These categories were also used in logistic regression analysis to investigate the differences between the experimental groups.

Data were collected in the DBiv database (ACI/ACI US 1994) and transferred onto Excel (Microsoft 1995) spreadsheets. The data were then analyzed by the Statistical Analysis System (SAS, release 6.12; SAS Institute 1997).

Results

Participant status. Sixty-two percent of the 607 children entering the project provided data sufficient for analysis. Insufficient blood data to allow a confident declaration that the child either had an elevated lead level or had blood lead levels < 10 µg/dL throughout the study were provided by 27 children (15 control, 12 intervention). Other children moved away, entered foster care, or were withdrawn from

the project by their parent. Hence, the final analyses of blood lead levels were on 378 children (194 control, 184 intervention; Table 1).

Baseline group comparison. Extensive comparisons were made between the control and intervention groups to ensure that the groups were comparable at baseline. The baseline blood lead levels were taken at 4, 8, or 12 months of age depending on the age of the child when the caregiver was recruited. The results of this initial blood draw were comparable between groups, and all participants had blood lead values < 10 µg/dL before the intervention. Randomization was judged to have been successful in balancing ethnic groups (which was a deliberate design feature) and all other baseline characteristics. There was no evidence for a missing data pattern that differed by randomization group. The level of maternal education was thought to be a possible confounder, but it was closely balanced at baseline in the randomized cohort of 594 mothers ($p = 0.55$) and, more important, it was comparable ($p = 0.83$) between the two groups for the mothers whose children had sufficient data to be entered in the final analysis.

Contamination. Within the control group, 198 contamination surveys were completed; 233 were completed in the intervention group. Within the controls, 22.2% reported receiving information from sources outside the research project; 18.8% of the intervention group reported receiving such information. These rates did not differ ($p = 0.093$).

Blood lead outcome results. In accordance with the hypothesis, a greater percentage of the children in the intervention group maintained blood lead levels < 10 µg/dL (81% of children) compared with the control group (73% of children), although the effect was of borderline significance ($p = 0.08$ for two-sided test). Fifteen percent of the intervention group

and 24% of the control group had blood lead levels of 10–19.99 µg/dL. However, 4% of the intervention group and 2% of the control group had blood lead levels ≥ 20 µg/dL (Table 3). Neither of the last two differences was statistically significant. Results were similar if the blood lead levels were dichotomized (< 10 µg/dL or ≥ 10 µg/dL) rather than trichotomized ($p = 0.09$ for a two-sided test, $p = 0.04$ for a one-sided test). To assess whether the use of inclusion criteria based on available blood data influenced the results, the analysis was also conducted without invoking these criteria. The results were the same, with the chi-square significance level dropping to $p = 0.07$ from $p = 0.08$.

Conclusions were confirmed with logistic regressions, whether adjusted for mother's educational level (Table 4 for odds ratios) or not (data not shown). No interaction was found to be present between the mother's educational level and assignment group. Higher educational level of the mother promoted lower blood lead levels in the child for levels below 20 µg/dL ($p = 0.03$). However, used as a covariate, the mother's educational level was not significant in adjusting the estimate of the intervention effect using the study criterion (lead burden exists if blood lead is ≥ 10 µg/dL). The odds ratio is about 0.7 for 4 years' difference in educational level [e.g., between finishing only grade 8 and finishing high school (12 years), or between finishing high school and finishing college (16 years)].

In summary, the models show that intervention tended to keep blood levels < 10 µg/dL on average; intervention reduced the risk of a blood lead ≥ 10 µg/dL by approximately 34%.

Discussion

Peer education, emphasizing dust control through household cleaning, hygiene such as hand washing, nutrition, and behavior changes such as removing shoes at the door and letting the water run were partially effective in maintaining lower lead levels. The intervention reduced the risk of an elevated blood lead level by 34%, although the effect was of borderline significance.

This study has a number of unique and positive features, including the ethnic diversity of the participants; use of education as a primary rather than secondary prevention approach; implementation of an ethnically matched peer teacher model; intensive education with frequent follow-up; repeated blood lead monitoring; measurements of housing lead contamination, knowledge of participants, and blood lead levels in a single study; and a firm grounding in a community-based collaborative research model that ensured benefit to the community and therefore increased trust in research within a community that traditionally mistrusted the university.

Table 2. Intensive education session topics.

Session no.	Session topic
1	Introduction to the project
2	Sources of lead in home environments
3	Identification of lead sources in participant home—review of lead test results
4	Relationship of child's blood lead level to health risks
5	Reducing lead contamination through cleaning
6	Reducing exposure to peeling paint
7	Reducing exposure to lead in the water
8	Reducing exposure by keeping children's hands, pacifiers, and toys clean
9	Reducing exposure to lead from foods
10	Reducing exposure to lead in the soil
11	Reducing exposure to lead from pets
12	Other lead hazards
13	The role of nutrition in decreasing lead absorption
14	Developmental stages from birth to 6 years of age that place children at risk
15	Removal of lead paint vs. covering old paint
16	Medical procedures for addressing lead poisoning
17	Individual and family rights in legal procedures involving lead
18	Assessing other environments of children for exposure to lead
19	Review results of follow-up testing of blood lead levels
20	Summary and evaluation

This peer education project is unique in some ways but also shares features with other projects conducted in other parts of the country. Rhoads et al. (1999) conducted maternal education and provided household cleanings for families as a secondary intervention to reduce elevated lead levels. Although their intent (to decrease lead levels) was different from ours (to prevent initial lead level elevation), the intensity and duration of their intervention more closely parallel those of the present study than do those of other lead burden projects. In their intervention (Rhoads et al. 1999), children in homes cleaned 20 or more times by trained lay cleaners within the year-long study achieved a 34% decline in blood lead level. In the present study, peer educators met 20 times with participants over 12–36 months to teach a range of concepts, but also to encourage appropriate housecleaning methods and cleaning frequency. In the Rochester, New York (USA), primary prevention study by Lanphear et al. (1999, 2000b), a maximum of eight visits by a dust control advisor were conducted during 18 months, but household cleaning was performed by families, not trained outsiders. The authors concluded that the intervention was not effective in preventing lead burden as performed by families. The present study is similar to the Rochester project in that families were responsible for their own cleaning. However, the present study represents a more intensive effort in terms of the number of educational visits, duration of maternal education, focus on preventive techniques beyond household cleaning, including nutrition, hand washing, leaving shoes at the door, outside hazards, and the like, and is unique in its culture-specific approach and its focus on building a relationship between the peer teacher and the participant. It is not known at this point which of these differences between the Rochester study and the present study may account for the more positive results obtained in the present study.

Although this study has many strengths, it also has limitations. Quality and reliability of the blood lead data as well as of the delivery of the educational intervention need to be considered. The possibility of blood collection error and laboratory analysis error was not evaluated beyond reliance on the laboratories' own stringent standards and checks on reliability. However, because the sample was randomized and randomization was stratified by clinic, it is

highly unlikely that laboratory error would have differentially affected the groups. The probably unavoidable variability in education delivery presented a greater concern. Although the protocol required 20 visits over the course of the first year followed by quarterly booster sessions for the next 2 years, there was variability in the number of educational sessions delivered and the time span over which the education occurred. Based on information provided by staff to their supervisors, the reasons for this might relate to difficulties scheduling and keeping appointments due to stressors in the lives of the participants and the peer teachers, who were from the same neighborhood and facing similar socioeconomic and environmental hardships. These inconsistencies in adherence to the protocol may have weakened the efficacy of the intervention because some families did not receive the intervention with its intended intensity and duration.

If the control group received unintended lead burden prevention information, group differences would become nonsignificant. Although the amount of information consciously received and reported by the control group did not differ from that of the intervention group, collection of cross-contamination data could have been compromised by poor recall of all such incidents. In addition, the fact that control families were in a lead study and were receiving feedback on their child's blood lead results and their home lead inspection results may have increased their awareness and led to behavior changes that kept lead levels lower than expected in the control group. There were increasing public awareness efforts nationally, at the local health department level, and at the pediatrics clinic level during the study period, "contaminating" the control group by increasing their knowledge through avenues other than the research. Awareness may also have been increased in the intervention group, although the information presented through such public awareness activities did not likely provide much new information over and above that which was provided through this study.

Although 626 participants were recruited into the project over 3.5 years, recruiting such a large sample proved to be difficult for several reasons. Many epidemiologic studies involving newborns have recruited mothers by telephone, using a county or city data set of new births. However, Hennepin County (in which the

Phillips Neighborhood is located) does not make such data available to the public when the parents of the newborn are not married or are younger than 21 years. This policy, combined with the fact that many residents did not have telephone service, made such a recruitment design impossible. In addition, a primary recruitment strategy involved local health clinic staff presenting information about the project to their pregnant and new mothers. Because of the new demands of health practice in the context of managed care, clinics were not as capable of assisting our recruitment efforts as they had initially anticipated. These factors slowed the rate of recruitment.

This project experienced a 40% attrition rate and also experienced missing data. Project staff's ability to maintain connections with enrollees over the course of 3.5 years was compromised because of frequent participant moves and unstable phone service. For a project of this nature, there needs to be a staff person responsible for establishment of a network of contacts to minimize the number of participants "lost to contact."

The Welfare-to-Work program was initiated about the time the research project was implemented and led to participants' being at work during the day. Despite the addition of evening and weekend appointments, it was still difficult to accommodate participant schedules. In addition, because of the myriad of complexities related to life with children and life stresses experienced by economically disadvantaged people, participation in research-related activities often becomes a low priority. These factors compromised complete data collection on blood lead measurements and made it difficult to maintain a consistent education schedule for the intervention group.

As a result of these recruitment, retention, and missing data challenges, it was important to assess the possibility of bias. The results indicate that despite the challenges, bias is unlikely and threats to validity are minimized. Therefore, changes in blood lead outcome data can be attributed to the effects of the prevention education. However, factors related to attrition and missing data may have reduced the power to detect group differences.

Table 4. Odds ratios (ORs) and 95% confidence intervals (CIs) for elevated blood lead any time during the intervention, comparing intervention and control groups, as estimated by logistic regression.

Elevated blood level[a]	OR for assignment (95% CI)[b]	p-Value
≥ 20 µg/dL	2.23 (0.69–8.5)	0.20
≥ 15 µg/dL	0.85 (0.42–1.69)	0.63
≥ 10 µg/dL	0.66 (0.40–1.08)	0.10

[a]Nonelevated levels require both blood lead measures never to be > 10 µg/dL, and at least three measures total, two of which fall in the window from month 12 to month 24. [b]Odds ratios are adjusted for mothers' education (0–20 years) as a linear covariate.

Table 3. Blood lead level ranges [count (%)] in study children.

	< 10 µg/dL ("safe" level)	≥ 10 µg/dL, < 15 µg/dL	≥ 15 µg/dL, < 20 µg/dL	≥ 20 µg/dL
Intervention (n = 184)	150 (81)	18 (10)	9 (5)	7 (4)
Control (n = 194)	143 (74)	32 (16)	115 (8)	4 (2)

This comparison includes all of the children whose blood lead was ever ≥ 10 µg/dL and the children whose blood lead was always < 10 µg/dL but had at least three blood tests done, including two between the first and second birthdays. Chi-square p-value = 0.08.

For all of the limitations mentioned above, the effect of the limiting variable would decrease the likelihood of detecting a true difference between groups, rather than increasing the likelihood of making a "false positive" error. Therefore, we are confident that the direction of the effect discovered is real. However, our ability to assess the strength of this effect may have been compromised by the factors noted above.

Conclusion

Policy decisions may be informed by the results of the present study in the context of the other intervention studies discussed above. Although our study's findings of modest statistical significance suggest that education as primary prevention may be efficacious, it appears that an educational approach alone is not sufficient to prevent lead burden in high-risk, low-income populations. The fact that seven children in the intervention group had blood lead levels ≥ 20 μg/dL indicates that the intervention was not 100% effective in preventing high blood lead levels. It does appear that certain factors can make an educational approach more effective. Intensity and duration of the educational process, a focus on a range of prevention strategies beyond housecleaning, tailoring the educational curriculum and delivery approach to specific ethnicities, and facilitating a rapport between a consistent and dedicated peer teacher and the participant may be important factors. Professional cleaning can help reduce lead levels, although we do not yet know the effectiveness and feasibility of this method as a long-term primary prevention strategy. It is likely that a multipronged and flexible approach will be needed, with homes most contaminated by lead receiving more comprehensive environmental interventions such as abatement as well as education, and individuals at somewhat less risk receiving intensive, sustained, tailored training on the range of preventive strategies. In some cases in which compliance or ability may be an issue, provision of outside assistance with housecleaning tasks may be needed.

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