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Validation of a Self-Administered Lead Exposure Questionnaire among Suburban Teenagers[1]

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Teenagers represent a unique population in which to evaluate lead exposure. A self-administered questionnaire was developed to evaluate the current and historic lead exposures of teenagers. This work evaluates the exposure questionnaire for both its ability to predict lead exposure and the accuracy of the teenage respondents. Subjects received the survey at school and were instructed to get assistance from their parents in questionnaire completion. Environmental samples (dust, soil, and water) were collected from 30 suburban Boston homes to evaluate the questionnaire's predictiveness. To evaluate the accuracy of subjects' responses, independent information about housing was obtained. The questionnaire was effective in identifying predictors of dust and soil lead levels, but not for water lead levels. Fine dust lead loading (<150 μm) varied significantly among the six housing age categories (pre-1940, 1940–1949, 1950–1959, 1960–1969, 1970–1979, and >1979) and traffic levels. Fine dust lead concentrations varied significantly with decade of housing construction. Mean soil lead levels varied significantly among housing age categories, traffic levels, and exterior construction materials. For the important predictors, there was excellent agreement between the teenagers' self-report and confirmatory information. For housing age categories, the observed agreement was 69%; for traffic level, the observed agreement was 88%. These results illustrate that questionnaires continue to be useful in evaluating home lead levels even in suburban homes and that teenagers are accurate respondents.

INTRODUCTION

Lead exposure continues to be an important public health problem in the United States and around the world. Although lead has been removed from gasoline, paint, and food cans in the United States, significant exposure to lead can still occur in the home environment through dust, food, water, and soil (ATSDR 1990). The patterns of lead exposure in the United States vary over time, region of the country, and housing stock as well as the age of the individual (NRC 1993; Brody *et al.*, 1994; Pirkle *et al.*, 1994). These characteristics make it difficult to assess all sources which may contribute to an individual's overall lead exposure.

While biological markers of lead exposure, such as blood lead, are useful at characterizing an individual's total lead dose, other exposure assessment methods are required to characterize the sources which contribute to lead exposure in order to minimize future exposure. Due to the large number and variety of lead sources, questionnaires provide an inexpensive means to evaluate exposure, to increase sample sizes, and to reduce participant burden. Questionnaires have been used extensively to evaluate potential lead exposure, primarily in the identification of the factors associated with biological markers of lead exposure: blood lead, tooth lead, and bone lead. Factors correlated with integrated measures of lead dose in children and adults include auto traffic, home renovation, working with lead, parental smoking, living in cities, age of housing, and exterior paint conditions (Chisholm *et al.*, 1985; Clark *et al.*, 1985; Rabinowitz *et al.*, 1985; Wilson *et*

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al., 1986; Lyngbye *et al.*, 1990; Shannon and Graef, 1992; Baghurst *et al.*, 1992; Fett *et al.*, 1992; Romieu *et al.*, 1992; Kosnett *et al.*, 1994). These factors have generally been measured by technicians rating these characteristics or by self-report of adults. Table 1 summarizes previous studies which have evaluated lead exposure factors associated with blood and bone lead levels.

Questionnaires have also been used to identify sources which may contribute to lead in dust, soil, and water. Factors associated with dust lead include traffic density, building age, exterior construction material, condition of housing, lead industry in the community, home renovation, and lead occupation (Archer and Barratt, 1976; Clark *et al.*, 1985; Fergusson and Schroeder, 1985; Schwar *et al.*, 1988; Schwar and Alexander, 1988; Hertzman *et al.*, 1991; Rinehart and Yanagisawa, 1993; Sutton *et al.*, 1995). Lead levels in soil have been associated with traffic levels, lead industries, and exterior lead-based paints (ATSDR, 1990; HUD, 1990). Water lead levels are associated with lead piping, the use of lead solder, and brass and bronze fixtures (USEPA, 1991a).

A majority of the previous lead exposure studies have been conducted among young children in urban settings. Little information is available describing teenagers' lead exposure and the predictive factors for lead exposure in suburban environments. Teenagers represent a good measure of current and historic environmental exposure to lead, without concomitant occupational lead exposure; additionally most current United States teenagers have not been exposed to lead from automobile emissions. Suburban communities generally have lower traffic levels, a large majority of residents living in owner-occupied single family homes, and relatively well-maintained homes. As part of an ongoing study of lead exposure among suburban teenagers, we were interested in identifying which questions were predictive of suburban lead levels in the 1990s and in determining how well teenagers could respond to these questions. This current investigation allows for the evaluation of self-reported information from teenagers for factors ranging from family smoking habits to housing age.

TABLE 1

Environmental Factors Predictive of Blood and Bone Lead Concentrations in Previous Studies

Parameter Measure used	Assessed by	Reference
Auto Traffic		
Six-level scale	Technician	Rabinowitz *et al.*, 1985
Place of residence	Technician	Romieu *et al.*, 1992
Traffic department	Technician	Lyngbye *et al.*, 1990
Home Renovation		
Questionnaire in home	Parent	Rabinowitz *et al.*, 1985 Fett *et al.*, 1992
Questionnaire in clinic	Parent	Shannon and Graef, 1992
Housing Age		
Questionnaire	Parent	Fett *et al.*, 1992
Door-to-door survey	Technician	Chisholm *et al.*, 1985
Decade of construction	Adult participant	Kosnett *et al.*, 1994
Exterior paint		
Door-to-door survey	Technician	Wilson *et al.*, 1986
Drive-by evaluation	Technician	Clark *et al.*, 1985

MATERIALS AND METHODS

Questionnaire validation occurred as part of a lead exposure study conducted at a suburban Boston high school. Students in grades 9 through 12 were recruited in the spring of 1994 and 1995. In order to participate, students were asked to return a 12-page survey regarding their current and former houses. All study materials were approved by the Harvard School of Public Health's Human Subjects Committee.

To assess the questionnaire's ability to predict in-home lead levels, a field survey was conducted at the homes of volunteers recruited from the spring 1994 participants. Volunteers were solicited through mailings and phone calls.

To obtain confirmatory information for questionnaire responses relating to current housing, two methods, in addition to the field survey, were used. For building date information, the year of construction was obtained from the Town Assessor's office. To substantiate reports of exterior housing characteristics and traffic, a drive-by survey was conducted of participants' homes by a technician. All confirmatory information was collected by trained technicians in a standardized manner without knowledge of the subjects' questionnaire responses.

The initial questionnaire, the Home History Survey, was a 12-page survey designed to obtain information about demographic factors, current and former housing characteristics, vehicular traffic, and interior and exterior paint condition. It was designed to be completed by a teenage respondent with the assistance of her/his parents. Focus groups of minority teenagers were integral in the evaluation

How would you rate the traffic level on your street?

___ Light Traffic (primarily residential use)
___ Moderate Traffic
___ Heavy Traffic (major commuting route, stop and go traffic)

When was your current home originally built? Do not count remodeling, additions, or conversions.

___ 1939 or earlier
___ 1940 to 1949
___ 1950 to 1959
___ 1960 to 1969
___ 1970 to 1979
___ 1980 or later
___ Don't know

What is the general condition of the **interior wall paint** in the main activity rooms of your home? Rooms that we are interested in include kitchen, living room, dining room, bedrooms, and hallways.

___ Good, no flaking or peeling paint
___ Some flaking paint
___ Peeling paint
___ No paint (for example, paneling, wallpaper)

FIG. 1. Sample Home History Survey questions.

of both the questionnaire structure and the difficulty of the questions. Sample questions are included in Fig. 1.

The field survey was conducted in the summer of 1994 to collect environmental samples and to independently confirm information reported on the Home History Survey. At the time of scheduling, subjects were informed that environmental samples would be collected; subjects were not requested to change normal cleaning patterns prior to the home visit. At the appointment, one technician administered a questionnaire to an adult respondent, usually the mother, while another technician collected samples from dust, soil, water. The adult respondent provided additional information on family members, smoking in the home, frequency of cleaning and dusting, and home remodeling activities. The technician also recorded information on interior and exterior housing characteristics and paint conditions.

Environmental samples were collected from in-home dust, soil, and water. One composite dust sample was collected using a vacuum method developed by CS_3 (Bend, OR) similar to that specified in ASTM D-5438-93 (ASTM, 1993). The HVFS[3] is a vacuum collection method which utilizes a cyclone to collect dust with a mean aerodynamic diameter greater than 5 μm. This sampler was selected based on its ability to collect dust from both carpeted and hard surfaces. Each dust sample consisted of floor and windowsill dust from the kitchen, the main family activity room, and the subject's bedroom. One windowsill per room and approximately 1 m^2 from each floor were included in each sample. The sample was collected into a tared 250-ml high-density polyethylene (HDPE) catch bottle.

Two composite soil samples (foundation and yard) were collected per home depending on accessibility of bare soil. Foundation and yard soil were collected separately to represent different potential sources of lead exposure. All samples were collected from areas of bare soil; areas that were extensively landscaped or mulched were not sampled. The foundation soil sample was collected along the perimeter of the house within 10 cm of the foundation; at least two locations were sampled from each side of the foundation. The yard sample was collected along a grid of approximately 25 exposed soil locations from the entire yard area. Each soil sample was collected and mixed into a clean plastic bucket using a decontaminated metal trowel prior to placing the sample in a 1-liter HDPE container.

Two water samples were collected from each house: a flushed water sample and a first draw water sample. The flushed water sample, collected by the technician during the home visit, was taken from the cold water tap of the kitchen sink after the water had run for 1 min. The first draw sample was

[3] Abbreviations used: GF-AAS, graphite furnace–atomic absorption spectroscopy; GSD, geometric standard deviation; HVFS, high volume floor and surface sampler.

collected by the adult respondent from the kitchen tap at the beginning of the day prior to running any water in the home. Water samples were collected in 125-ml lead-free HDPE bottles; samples were acidified with 2 ml 50% nitric acid (HNO_3) prior to refrigeration. Water samples were refrigerated prior to analysis.

All environmental samples were analyzed using graphite furnace–atomic absorption spectroscopy (GF-AAS). Aliquots of the acidified water samples were analyzed directly by GF-AAS, while the soil and dust samples were acid extracted and the aqueous extracts analyzed by GF-AAS. Prior to extraction, dust and soil samples were sifted through 2-mm and 150-μm mesh sieves. All chemical analyses on dust and soil were performed using the fraction less than 150 μm. The extraction of the soil and dust samples was carried out using a modification of EPA Method 200.9 (USEPA, 1991b). For this method, each aliquot was extracted using 4 ml of 50% HNO_3 and 10 ml of 25% HCl heated on a hot plate for 30 min. The detection limit for the soil and dust analyses was 3 μg/g. The limit of detection for water analyses was 0.5 μg/liter.

To obtain confirmatory information on exterior housing characteristics and traffic level, a drive-by survey was conducted for the current homes of all subjects. The technician rated the street traffic level, measured the distance to heavy traffic, and evaluated the exterior housing material and its condition while stopped on the road in front of the subject's home. Distance to heavy traffic was designed to be a surrogate for atmospheric deposition of lead from vehicle exhaust; therefore, blocks to heavy traffic was determined based on actual "straight line" distance to heavy traffic rather than the driven route required to get to the heavily travelled streets. Heavy traffic was defined as a major commuting route or a street with "stop and go" traffic. Streets with heavy traffic were determined through prior consultation with several long-term town residents. All data were collected by one technician in a standardized manner without knowledge of the participant's response.

Data analysis consisted of descriptive analyses of environmental data and questionnaire responses, tests of association between environmental data and questionnaire data using ANOVA and two-sample t tests, and development of multiple regression models for the prediction of home lead concentrations. Agreement between subject's response and technician's observation was assessed using percentage of agreement, κ statistics, and Spearman correlation coefficients. κ statistics are a measure of chance-adjusted agreement, defined by Cohen (1960) as $\kappa = (p_o - p_e)/(1 - p_e)$, where p_o equals proportion of observed agreement and p_e equals proportion of expected agreement. All data analyses were performed using SAS Version 6.09 (1991).

RESULTS

The study was conducted at Randolph Junior–Senior High School in Randolph, Massachusetts, a suburban Boston community of 30,000 people where 70% of the housing units in the town are owner-occupied (United States Census, 1990). During the Spring of 1994 and 1995, approximately 500 students were approached about participating in the study. By March 1995, 209 subjects had agreed to participate. Drive-by verification of housing characteristics was obtained for all these subjects. Of these 209 individuals, 137 enrolled in 1994. Town Assessor's office information was gathered for 94 of the subjects enrolled in 1994. Ninety (90) homes were

TABLE 2

Demographic Characteristics of Study Participants at Randolph High School, Randolph, MA

Demographic variable	Sample size	Percentage	School statistics[a]
Population	209		895
Sex			
Female	109	52	45%
Male	100	48	55%
Race[b]			
Asian	32	15	13%
Black[c]	46[d]	22	25%
African-American	22	11	
Cape Verdean	7	3	
Haitian	13	6	
Hispanic	4	2	6%
Native American	3	1	1%
White	132	63	55%
Other Race	7	3	
Income			
Not reported	21	10	
<$15,000	5	2	
$15,000–$29,999	20	10	
$30,000–$49,999	43	21	
$50,000–$75,000	54	26	
>$75,000	28	13	
Don't know	37	17	

[a] *Source.* Randolph High School 1994–1995.

[b] Percentages will add up to more than 100% since participants could select more than one race.

[c] Black is classified by the school as African-American, Cape Verdean, Haitian, and Black Caribbean Islander.

[d] Includes four self-identified Caribbean Islanders from the other respondents.

eligible for participation in the field survey. Of these homes, 30 parents volunteered their homes for participation.

Participant recruitment was successful at obtaining a study population demographically similar to the school and the town from which the sample was drawn. Table 2 presents demographic characteristics of the study. The study population ranged in age from 14 to 19 years with an average age of 16.2 years. Family homeownership was greater for study participants than the town as a whole (84 vs 70%); however, this may be representative of the subpopulation of residents with high school children. For the 209 study participants, a total of 11 homes contain more than one participant. All analyses were limited to one subject per home.

Environmental Sampling

The field survey was conducted during the Summer of 1994. Volunteers for the field survey were recruited from the subjects who had enrolled in 1994. Of these 90 eligible homes, families that did not participate were not different from study participants for most demographic factors or for factors which may be associated with potential lead exposure at home.

Environmental samples were collected from the dust, soil, and water at each of the 30 homes. Composite dust samples were collected from floors and windowsills. The lead concentration in the fine fraction of dust (<150 μm) ranged from 34 to 4420 μg lead/g dust (ppm) with a geometric mean concentration of 226 μg/g (GSD = 3.36 μg/g). Dust lead loading, the mass of lead per unit area, ranged from 1.09 to 2439 $\mu g/m^2$, with a geometric mean of 51.4 $\mu g/m^2$ (GSD = 6.0 $\mu g/m^2$). Soil samples were collected from 28 of the 30 homes visited. Foundation soil samples were collected from 18 homes; yard soil samples were collected from 27 homes. Flushed water samples were collected in each of the 30 homes. The average lead concentration was 2.87 μg/liter with a standard deviation of 1.51 μg/liter. The concentration of lead in the 22 first draw water samples ranged from 2.2 to 17 μg/liter with an average concentration of 6.5 μg/liter. Environmental sample results are presented in Table 3. The natural logarithms of the environmental measurements for dust and soil were used for all analyses since the distributions were highly skewed.

Analysis of Lead Predictors

Specific questionnaire variables were significantly associated with environmental lead levels in dust and soil. Although water lead levels were also measured, no associations were observed with questionnaire responses, such as lead piping and housing age; however, only two subjects reported the presence of lead piping in their home. Table 4 presents the variables from the Home History Survey which were significantly associated with environmental lead levels as identified from ANOVA F tests and t tests. For both dust lead measures, mean lead values varied significantly by decade of housing construction. Street traffic level was significantly associated with dust lead loading ($P = 0.006$); homes on streets with heavy traffic had significantly greater dust lead loading than homes on streets with light or moderate residential traffic. Dust lead concentration and dust lead loading were not related to the number of people in the home, square footage, cleanliness, sweeping, vacuuming, home smoking, fireplace use, gardening, or exterior paint condition. Decade of housing construction, exterior construction material, and traffic level were all significantly associated with soil lead levels.

Multiple regression models were developed to identify the extent of variation for environmental lead levels that could be predicted by questionnaire

TABLE 3
Environmental Sample Results for 30 Suburban MA Homes in Summer 1994

Environmental measure	Units	N	Mean	SD	(Range)
Dust[a]					
Lead concentration	(μg/g)	30	538	934	(34.3, 4420)
Lead loading	($\mu g/m^2$)	30	248	534	(1.1, 2439)
Soil[a]					
Foundation lead concentration	(μg/g)	18	755	1513	(30.2, 6261)
Yard lead concentration	(μg/g)	27	218	315	(26.2, 1043)
Water					
Flushed water concentration	(μg/liter)	30	2.87	1.5	(1.06, 7.47)
First draw concentration	(μg/liter)	22	6.56	4.1	(2.22, 16.9)

[a] Dust and soil analyses performed on fraction smaller than 150 μm.

TABLE 4

Questionnaire Variables Associated with In-Home Lead Levels (Based on Univariate Analyses)

Dust lead concentration	(n = 30)
Housing age	P = 0.013
Street traffic level	P = 0.076
Dust lead loading	(n = 30)
Air conditioning[a]	P = 0.08
Housing age	P = 0.03
Street traffic level	P = 0.006
Wood-frame houses	P = 0.052
Foundation soil lead concentration	(n = 17)
Housing age	P = 0.0011
Street traffic level	P = 0.01
Exterior siding[a]	P = 0.09
Wood-frame houses	P = 0.09
Yard soil lead concentration	(n = 27)
Housing age	P = 0.0002
Street traffic level	P = 0.10
Exterior siding[a]	P = 0.026
Wood-frame houses	P = 0.01
Water lead	
None identified	

[a] Inverse association with environmental lead parameter.

responses used as categorical variables. For fine dust lead concentration, housing age category alone described 48% of the variance in the 30 samples (P = 0.013). A model with both housing age category and traffic level explained over 60% of the variance in dust lead concentration (P = 0.002). Dust lead loading was modeled as a function of the six-level housing age category and high traffic level (R^2 = 0.58, P = 0.0013). When use of air conditioning was included in the model, the R^2 improved to 0.61 (P = 0.0002). For foundation soil lead level, a multiple variable regression model using both the reduced four-level housing age category (pre-1940, 1940–1949, 1950–1959, >1959) and traffic level (low and moderate versus heavy) as categorical variables explained 77% of the variability (R^2 = 0.77, P = 0.0004). For yard soil lead levels, a linear regression model using the reduced four-level housing age category had an R^2 of 0.64 (P = 0.0001). Due to the small sample sizes in each category, these analyses should be regarded as exploratory. However, these results indicate that these factors continue to be significant predictors of environmental lead levels, even in a suburban environment, and that questionnaires can be used for ranking relative lead exposure.

Accuracy

Three sources of data were available in order to evaluate the accuracy of the teenage subjects' responses regarding current housing on the Home History Survey: the field survey, the Town Assessor's office records, and the drive-by assessment. For the field survey data, agreement was evaluated both for general family characteristics, such as home ownership, pets, smoking, and family size, and for lead predictive factors. Table 5 presents the agreement for all variables. The observed agreement in the field survey between the teenagers' self-report and technician observations was good to excellent for most questions, ranging from an observed agreement of 67% for exterior paint condition to 100% for home-ownership. The agreement for distance to heavy traffic was poor (37%) between technician and self-reported values. Since some subjects reported more than one exterior housing material, each house was assessed for all types of housing materials present

TABLE 5

Observed Agreement for Home History Survey Variables (One Subject per Home)

Parameter	N	Observed agreement	κ	Spearman correlation
A. Field survey data				
Home ownership	30	1.0	1.0	1.0
Pets	30	0.93	0.86	0.86
Total family size (five categories)	30	0.87	0.82	0.85
Number of rooms (three categories)	30	0.80	0.40	0.43
Smoking in home	29	0.93	0.83	0.84
Outer material[a,b]				
Siding	28	0.96	0.93	0.93
Wood	28	0.82	0.64	0.64
Exterior paint condition (three categories)	17	0.67	0.29	0.53
B. Assessor's office and drive-by data				
Decade of construction (six categories)	78	0.69	0.64	0.93
Outer material[b,c]				
Brick	193	0.92	0.48	0.56
Siding	193	0.83	0.64	0.68
Wood	193	0.76	0.52	0.56
Building type (five categories)	192	0.91	0.75	[d]
Exterior paint condition (three categories)	90	0.63	0.21	0.39
Traffic level (three categories)	185	0.88	0.65	0.70
Distance to traffic (six categories)	184	0.37	0.22	0.52

[a] Assessed at house.
[b] Individual types of construction material evaluated separately.
[c] Assessed from street.
[d] Nominal categories for building type; no Spearman coefficient calculated.

and agreement was evaluated for each category (wood frame, siding, brick) individually.

κ statistics were used to estimate chance-adjusted agreement between observers. All κ estimates were statistically significant. Landis and Koch (1977) developed a scale for interpretation of κ statistics: almost perfect agreement (81–100%), substantial agreement (61–80%), moderate agreement (41–60%), fair agreement (21–40%), slight agreement (0–20%), and poor agreement (<0%). Substantial to complete agreement was observed for homeownership, pets, family size, smoking, outer housing material, and traffic level. Spearman correlation coefficients were calculated for all ordinal categorical variables as a method to include agreement that was close but not perfect, since unweighted κ statistics measure only perfect agreement. The Spearman correlation coefficients were similar to the κ values suggesting that most of the agreement was perfect.

Town Assessor's office information was used to confirm students' responses for home age. Approximately 26% of the subjects in the study did not provide information on building date; they either responded that they did not know housing age or left the question blank. Of the 94 homes on which Assessor's office information was obtained, 78 students provided a usable response for housing age (i.e., not missing or Don't Know). The exact agreement between students and assessor's office information for the six housing age categories was 0.69 with a κ value of 0.64 and a Spearman correlation coefficient of 0.93, suggesting that if the responses did not exactly agree they were within one category of the true value.

Drive-by results indicate excellent agreement for exterior material, building type, exterior paint condition, and traffic level for all subjects, whether they participated in the field survey or were only evaluated in the drive-by survey, suggesting that the field survey participants were representative of the study population as a whole. The drive-by survey collected data on all homes, regardless of participation in the field survey.

DISCUSSION

The demographics of this study population of suburban teenagers were representative of the school's population as a whole. Overall recruitment in the study was moderately successful, approximately 40% of the individuals who received recruitment information enrolled in the study. These participants are demographically similar to the nonparticipants, based on demographic data for the high school. Participation in the field survey was poor; as only a third of those already recruited for the study opted to participate. While there was no apparent difference in the demographic characteristics between the field survey participants and nonparticipants, perhaps the burden of a 2-hr home visit or concern about the economic impact of lead in the home reduced interest in study participation. Level of agreement for environmental lead predictors, such as housing age, was similar for both field survey participants and the study population as a whole, suggesting that participants in the field survey were not better (or worse) responders than other participants. Since the houses sampled were similar to those in the community as a whole, these results should be generalizable to all study participants, especially those who live in family-owned homes.

The modeling results suggest that this questionnaire is appropriate to evaluate in-home lead exposure in this suburban community, due to the large amount of variability explained by a few categorical variables. These observations are consistent with those seen in previous investigations in urban settings (NRC, 1993; Chisholm *et al.*, 1985; Clark *et al.*, 1985; Rabinowitz *et al.*, 1985; Romieu *et al.*, 1992; Bornshein *et al.*, 1985; CDC, 1991). However, given the small sample size and the narrow range of these predictors, the strength of the associations is surprising. For example, traffic level in this community is much lower than that of a city and yet both technician and subject reports were excellent predictors of both soil lead concentration and dust lead loading.

One key finding of this study was the ability to explain the variability in dust lead loading. This is an important result since dust lead loading has been demonstrated to be a better predictor of blood lead levels in young children in New York than dust lead concentration (Lanphear *et al.*, 1995). In a previous investigation of dust lead loading in California, age of housing, interior and exterior paint levels, and soil lead levels had little ability to explain dust lead levels (Sutton *et al.*, 1995). However, the Sutton *et al.* study used a different dust collection technique than this study or the one by Lanphear *et al.* (1995) study. Since dust lead appears to be the primary route of lead exposure in the home environment (Bornschein *et al.*, 1985; CDC, 1991; Lanphear *et al.*, 1995), further work should investigate the ability to predict dust lead concentration and loading. It is of interest that while dust lead loading was not a function of frequency of house cleaning or of overall house cleanliness, the use of air conditioning did reduce the amount of dust lead loading. This is not surprising since frequency of cleaning would remove dust but not lead sources; however, air conditioning may reduce the flow of lead into the home.

The study was limited by the small sample size for the field survey. Unfortunately many exposure assessment investigations have been similarly limited as a result of low response rates (Akland *et al.*, 1985; Wallace *et al.*, 1987; Ryan *et al.*, 1988). Since none of the subjects in the study were lead poisoned, parents may not have felt an onus to participate as opposed to participation in studies of lead-poisoned children. For questionnaire prediction and agreement analyses, the sample size was reduced as a result of "Don't Know" or missing responses on the Home History Survey, leading to a loss in power to detect significant differences. For some factors of potential interest, such as smoking, the sample size was too small to evaluate their role in predicting in-home lead levels.

The excellent agreement between student-reported and technician-rated data for current homes increases the confidence in self-reported information about former houses as estimates of past exposure. While we cannot be certain that the teenagers filled out the questionnaire alone, we are confident that by following the directions given they were able to provide accurate information. The extent of parental involvement in questionnaire completion was not determined, yet most of the questionnaires were completed by the students. Since family size and pet ownership may have changed in the 6 months between when the first questionnaire was received and when the field survey was conducted, it is not surprising that the agreement for these measures was good but not perfect. Poor agreement for some variables such as distance to heavy traffic and window paint condition may indicate poorly defined questions or improper timing of technician observation. For example, student responses for distance to heavy traffic are speculated to have considered the driven route to get to the street rather than the actual distance to the street. Additionally, these suburban teens were unfamiliar with the term "block" as a measure of street distance; while focus groups with city dwelling teens were knowledgeable of this term.

A major strength of this investigation is the ability to obtain objective measures to use as "gold standards" to confirm the teenagers' reports. Questionnaires are frequently used to obtain various types of information from teenagers and only rarely is there an objective measure to which to compare the subjects' response. The use of Town Assessor's office information and technician measurements during the field and drive-by surveys were able to demonstrate that teenagers were accurate respondents about those variables that can be measured, ranging from house age to smoking in the home. These objective measures also gave insight into those questions that were poorly created, such as the one regarding distance to heavy traffic.

The participants in the study represent a diverse population of teenagers. The population was racially diverse, represented a wide range of income levels, and had differing levels of academic attainment and success. While the participants in this study are generally characteristic of high school students in the United States, this investigation probably benefitted by conducting a school-based study which may result in a teenage population with greater motivation and literacy than teenagers overall.

To evaluate exact agreement, κ statistics were used. κ statistics were developed by Cohen (1960) as a means to adjust interrater agreement for agreement primarily due to chance. As discussed by Maclure and Willett (1987), values for κ statistics vary based on the number of categories and therefore comparison of κ statistics from different sized tables may not be appropriate. However given the high percentage of agreement and the relatively high κ statistics in our study, we can be confident that the overall agreement is good between reviewers. The use of Spearman correlation coefficients for all ordinal categorical variables allowed for the evaluation of close as well as perfect agreement. However, since correlation does not necessarily require matching of identical responses, Spearman correlation coefficients were used only in conjunction with other agreement measures.

The study results can be used to develop focused sampling strategies that minimize participant burden and the cost of data collection. Since teenagers' responses were demonstrated to be accurate, questionnaires can be used to collect information on predictors of dust and soil lead. Since questionnaires can predict greater than 50% of the variability in environmental lead concentrations in dust and soil, this surrogate information may be sufficient to estimate approximate levels of lead exposure, especially in studies where the exposure of interest is long-term lead exposure. For use with lead biological markers, a questionnaire which correctly predicts body lead burden may not require the ability to predict environmental lead levels; for example, a question that is predictive of lead dose may not be highly correlated with measured lead levels but may be more associated with behaviors that contribute to lead exposure (e.g., smoking). In order to improve understanding of lead exposure, standardized questionnaires which can identify both predictors of environmental lead levels and predictors of lead dose are critical.

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