Blood lead levels
and academic performance in a student population

by

Karen Ball Shaw

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CERTIFICATE OF APPROVAL

This is to certify that the Master thesis of

Karen Ball Shaw

has been approved

[redacted]
Professor in charge of thesis

[redacted]
Committee Member

[redacted]
Committee Member

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ABSTRACT

Problem: According to the Centers for Disease Control (CDC), childhood lead poisoning is one of the most common pediatric health problems in the US, today (CDC 1991). High blood lead concentrations are detrimental to neurological function, as measured by educational performance. Both behavioral disturbance and impaired cognitive skills are believed to result. Sub-clinical lead toxicity has been defined as a whole blood concentration greater than or equal to 10 micrograms per deciliter (ug/dl). Recent research has shown that an inverse relationship exists between blood lead levels and arithmetic and reading scores for children with blood lead concentrations lower than 5.0 ug/dl.

Research Design: This was an ecologic study. The specific aim of this study was to investigate the relationship between the percent of children with elevated blood lead levels measured in a subset of Medicaid eligible children aged 0-5 residing within the residential boundaries of Portland Public Elementary Schools and educational performance of those schools, as measured by academic achievement tests. Two variables were used to reflect blood lead levels in the population. The Percent Elevated Lead reflects the percent of children aged 0-5 who were tested for blood lead levels in each elementary school boundary with test results showing blood lead greater than or equal to 5 micrograms per deciliter. The Adjusted Lead Measure weights the Percent Elevated Lead to reflect the proportion of Medicaid eligible children within the school boundary.

Results: Analyses with four models vary from below the generally accepted (.05) level of significance to just above that level for measures of blood lead levels (Model 1: p=.059 for the Percent Elevated Lead variable; Model 2: p=.023 for the Adjusted Lead Measure; Model 3: p=.065 for Percent Elevated Lead; Model 4: p=.071 for Percent Elevated Lead). A dose-response relationship emerged between increasing levels of blood lead measured as an aggregate, prevalence of elevation measure, and decreasing academic performance measured at the level of the whole school. Elevated blood lead levels have a significant, detrimental impact on mathematics, but not reading performance. In addition, in the Portland area race has a greater predictive association with academic performance than does family income. Finally, the stability of the school population is clearly an important variable to include in any analysis seeking to predict school academic performance.

Conclusions: The results of this study support further investigation of the effects of elevated blood lead on the school population. To obtain answers to the population level questions that emerge from this study will require blood lead level measurements from a more representative sample of the school population. To obtain answers to the question of risk for poor academic performance possibly posed by elevated blood lead levels will require individual level data for both blood lead level and academic performance. The results of this study also support the importance of public health programs preventing lead poisoning in children. In addition, further consideration should be given to lowering the blood lead level identified as having a significant, negative impact on the health of the public.

INTRODUCTION

Lead as a Health Problem

The negative health impact of lead has been known for thousands of years. First century A.D. Roman naturalist and scholar Pliny warned of the deleterious effects of breathing lead vapor while his contemporary, Greek physician and writer, Dioscorides believed that lead "causes the mind to give way" (Needleman, 1983). Jumping two millennia ahead, a study published in 1943 showed that children who had been believed to be asymptomatic following an episode of acute lead intoxication were instead, profoundly impaired (Byers 1943). Over the past nearly half-century a substantial body of literature has developed, documenting the danger of lead contamination to humans - and particularly to children. As evidence of how lead exposure affects humans has grown, public health efforts to respond to the problem also have increased. In 1991 the Centers for Disease Control and Prevention (CDC) released an updated statement, saying,

> "Lead is ubiquitous in the human environment as a result of industrialization. It has no known physiologic value. Children are particularly susceptible to lead's toxic effects. Lead poisoning, for the most part, is silent: most poisoned children have no symptoms. The vast majority of cases, therefore, go undiagnosed and untreated. Lead poisoning is widespread. It is not solely a problem of inner city or minority children. No socioeconomic group, geographic area, or racial or ethnic population is spared. (CDC, 1991)"

Lead's poisonous effects can be seen in every system in the body, with particular impact on the developing brain and nervous system. As our understanding of lead's deleterious effect on the human body has heightened, the standard level for what constitutes lead toxicity has been repeatedly revised downward. For example, in the 1960's lead toxicity was identified as 60 micrograms per deciliter (ug/dl)(Chisolm, 1956). By 1978 it had been lowered to 30 ug/dl. In 1991 it fell even further when the CDC defined lead toxicity as 10 ug/dl (CDC, 1991). New data suggest that there is no "safe" blood lead level. Indeed, research by Lanphear et al. (2000) showed an inverse relationship between blood lead concentration and arithmetic and reading scores for children with blood lead levels lower than 5.0 ug/dl.

The problem of lead toxicity in children problem is neither small, nor localized to a specific part of the US. According to the CDC, childhood lead poisoning is one of the most common pediatric health problems in the US today (CDC 1991). Nordin, Rolnick and Griffin (1994) found 2.5percent of children enrolled in a large health maintenance organization to have blood lead levels $\geq$10 ug/dl. The HMO's urban clinics had pediatric patients with blood lead level rates 3 to 8 times those of its suburban clinics. Tejeda et al. (1994) studied a hospital-based general pediatric clinic population and children seen in local private practices in the San Francisco Bay area. Seven percent of those who completed the CDC screening questionnaire had blood lead levels $\geq$10 ug/dl. Binns (1999) found high blood lead levels in 12.1 percent of the children studied in Illinois, while Javier (1999) found high blood lead levels in 19percent of children studied in Texas. In 2001, Vivier et al. (2001) reported that 29percent of the Medicaid eligible children from Rhode Island in their study had a blood lead level of $\geq$10ug/dl.

Although exposure to lead is often tested by assessing blood lead levels, the major health impact happens when lead passes out of the circulatory system to rest in tissues. Severe lead exposure in children can cause coma, convulsions and death (CDC 1991). Lower exposure levels cause damage to the central nervous system, kidney tissue and the hematopoietic (blood forming) system. Blood lead levels as low as 5 ug/dl have been shown to have detrimental effects on intelligence and coordination (Lanphear 2000). The CDC 1991 report states that, "Although available evidence is not sufficient to conclude that lead-associated deficits are irreversible, a recent follow-up study (Needleman et al., 1990) reported that the educational success of a cohort of young adults was significantly inversely associated with the amount of lead in teeth they shed as first and second graders." This indicates that, although blood lead levels may fall as individuals mature, damage to tissues is longstanding, and impact from early lead exposure has a long lasting impact on educational performance.

Environmental Sources of Lead Exposure

A significant number of studies have explored the risk factors for high blood lead levels. The CDC lists the major sources of lead exposure as: lead-based paint, soil and dust, drinking water, parental occupations and hobbies, air, food, and for some children, ethnic medicines (CDC, 1991). Lead based paint, in wide use through the 1940s, is currently the major source of high-dose lead poisoning for preschool children in the US (CDC, 1991). The use and manufacture of interior lead-based paint declined during the 1950's, but was available until the mid-1970's (CDC, 1991). Currently occupied schools and homes built during that time period may be coated with lead-containing paint, continuing to expose generations of children to lead-containing paint chips and dust from degrading surfaces. There is some disagreement on the construction cut-off for date most indicative of risk for lead exposure to home occupants. Nordin et al. (1998) and Litaker et al. (2000) identified homes built before 1950 as being at higher risk for lead toxicity. Binns (1994) used 1960 as the cut-off date, but in a subsequent study published in 1999 found housing built before 1950 to be of the highest risk. Living in older housing, low socioeconomic status (SES), and urban dwelling have been shown to be the most powerful predictors of high blood lead levels in young children (MMWR, 2000).

Lead Exposure Through Soil Contamination

Another source of lead exposure is soil contaminated by paint, gasoline or industrial by-products. Direct contact with contaminated soil, or contact with dust in a home or school has been implicated in elevated blood lead levels. Through the 1960's, gasoline-containing lead was the major source of airborne lead. Beginning in the next decade, the Environmental Protection Agency (EPA) ordered a significant reduction in gasoline lead content. By the mid 1990s lead was to be completely prohibited as a gasoline additive. Except around point sources like smelters and battery manufacturing plants, inhalation is no longer a significant route of lead exposure. However, during the time that lead was high in the atmosphere, a significant amount settled out in the soil. Because lead is an extremely stable substance, it persists in the soil until it is removed. Although we are no longer adding to the soil lead burden as we were with leaded fuel, we are still exposed to the lead that was deposited in past decades. The level of cleanliness maintained in the homes and schools may have significant impact on lead exposure for the students through this route. Lanphear et al. (1998) conducted a pooled analysis to estimate the contributions of lead-contaminated house dust and soil to children's blood lead levels. The results confirmed that "lead-contaminated house dust is the major source of lead exposure for children." Although this 1998 conclusion has yet to be corroborated by other sources, the impact of soil and dust as a source of lead exposure cannot be discounted.

Air in urban areas has a higher lead content than the air in suburban settings. Although the legal restriction on lead content in gasoline has significantly reduced the exposure from air, particularly during the time period between 1976 and 1980, lead absorbed from breathing contaminated air still contributes to the overall body burden, particularly as mentioned above, near industrial sources, or when winds mix particles of contaminated soil with inhaled air.

Lead Contamination Through Drinking Water

Lead contamination of drinking water may occur at five points: 1) lead connectors, 2) lead service lines or pipes, 3) lead-soldered joints in copper plumbing, 4) water fountains and coolers containing lead, and 5) brass faucets and other fixtures that contain lead (CDC, 1991). In 1986 Congress, through the Safe Drinking Water Act banned the use of lead-containing plumbing fixtures in public drinking water systems. The lead content of brass used for plumbing was limited to eight percent. Lead pipes are still found in residences built before the 1920s. Pipes made of copper and soldered with lead were common in the 1950s. Lead leaching from copper pipes with lead-soldered joints is considered a major source of water contamination in homes and public schools. Lead in drinking water is believed to be absorbed more completely than lead in food. The absorption rate for children is estimated to be greater than 60 percent (ATSDR). The Portland Public Schools (Portland, Oregon) have recently measured the lead content in the water from all school fixtures, resulting in the closure of one elementary school and in measures to protect students from unacceptably high lead levels in other school buildings.

Lead Exposure Through the Work Site

Children may also be exposed when adults bring lead home from the work site on their clothing, or when they bring scrap or waste material home from work. Professions that have been identified as sources of lead exposure include lead smelting (Ye XB, 1999), building construction, professional de-leading, house painting (Tumpowsky, 2000), traffic policing, (Mortada, 2002), printing, metal processing (Probst-Hensch 1993) wood refinishing (MMWR, 2001), plumbing, pipe fitting, lead mining, auto repair, glass manufacturing, shipbuilding, plastic manufacturing, steel welding or cutting, rubber product manufacturing, gas station work, battery manufacturing, bridge reconstruction work, and firing range instruction (CDC 1991).

Some hobbies also expose family members to lead. As noted above, furniture refinishing can be hazardous. Other activities that may cause exposure to lead include: making glazed pottery, target shooting at firing ranges, lead soldering for electronics or other purposes, painting, preparing lead shot or fishing sinkers, making stained glass, repairing cars or boats, or home remodeling.

Lead Contamination from Food

Food can also be a source of lead exposure. High airborne lead from gasoline over the course of several decades resulted in lead fall-out on crops and soil. This in turn caused elevated levels of lead in the food supply. Although recent legislation has reduced or eliminated the lead content in gasoline, much lead was deposited in our soil causing ongoing problems. In addition, pottery that is fired at low temperatures may contain lead, which can be leached from the glaze by acid-containing foods such as wine or tomato.

Predictors of Academic Performance

Academic performance is influenced by many variables. Some variables of importance have been known for many years. Others have only recently come to our attention. Spaulding and Papageorgiou (1972), found family income to be a significant predictor of reading and language achievement. Ma and Klinger (2000) used hierarchical linear modeling to show that gender, socioeconomic status (SES) and Native ethnicity were significant predictors of academic achievement, in a Canadian sixth grade school population. Patterson et al. (1990), found that income level and ethnicity were the best predictors of academic achievement in children in grades 2-4 in a small Southern city. Children from low-income homes and African American children scored lower on achievement tests. Williams (1972) further refined this area of study. She investigated the relative impact of race and poverty as predictors of school achievement, and found poverty to be 4 to 6 times more predictive than race.

More recently, Wassermann (2001) studied student mobility and its effect on school performance as measured by achievement tests. Students who changed schools more often had lower average scores in nearly direct proportion to the number of school changes. Wasserman devised a mobility index designed to examine the relationship of student mobility with school levels of students meeting standards on achievement tests. A similar mobility index is available for each elementary school in Portland. For the purposes of this manuscript, mobility will be identified as "stability" in the variables and their described relationships for this study.

Lead Contamination and Academic Performance

Although lead exposure is clearly identified as one of the most common pediatric health problems of our time (and one that has a clearly documented effect on academic performance) the literature has not included blood lead levels as a predictor of academic performance on the population level. Confusing matters more is the fact that the literature discussion of factors impacting blood lead levels for children is incomplete. No single study has included all the cited sources of exposure in a single analysis or determined the relative importance of those exposures for predicting blood lead levels. Furthermore, although recent studies have compared the effect of various factors influencing educational performance, no studies to date have investigated the full array of predictors of academic performance.

Study Objectives

1) To determine the association between blood lead levels in a subset of children living in each elementary school boundary and academic performance of 4th grade students from that school, and
2) To investigate the relationship between academic performance and predictive factors other than race/ethnicity and family income (stability index, varying blood lead levels, percent of housing built before an identified cut-off date, and number of students per FTE).
3) To determine the relative impact of blood lead levels versus other factors in accounting for differences in academic performance in the study population.

This study employs an ecologic design, which uses aggregate, or group data. While the limitations of an ecologic design prohibit inference of causality, it was an appropriate and cost-effective approach to ruling out or identifying avenues of study that may prove to be valuable. This study design allowed investigation of important questions using data that is currently available without compromising confidentiality for those providing the data. The study's findings will be useful to school officials, community leaders, public health officials and parents in broadening their understanding of potential outcomes to academic performance from lead exposure to students in the Portland Public Schools. It may also aid in planning interventions aimed at reducing blood lead levels among at-risk elementary school children.

METHODS

Research Setting

The focus of this ecologic study was to analyze the potential relationship between blood lead levels measured in a sub-set of children living in the Portland, Oregon area and the academic performance at the elementary schools they attended. All data used in this study were aggregate, reflecting population characteristics. The unit of analysis was the elementary school. This study combined data from the State of Oregon's Department of Human Services Division of Environmental Occupational Epidemiology Lead Poisoning Prevention Program, the State of Oregon's Center for Population Research and the Portland Public Schools (PPS). The population of children receiving tests for blood lead levels is Medicaid eligible individuals 0-5 years of age. Although they are not the same individuals tested for academic performance or necessarily from the same families, they serve as a sample reflecting blood lead levels resulting from exposures present in their neighborhoods. The conditions governing exposure to lead in the Portland area have not changed appreciably in the past 5 years. In addition, the neurological damage from early lead exposure has been shown to persist long term, exerting potentially permanent effects on mental functions such as reading and mathematics (Byers, 1943).

Routes of Exposure to Lead

There are a number of exposure routes contributing to blood lead levels and a number of factors influencing academic performance. Blood lead measurements reflect the short-term combined effect of all routes of exposure to the individuals measured. Blood lead level measurements for this population were reported categorically. This analysis used linear regression modeling to evaluate the predictor variables for degree of association with the dependent variable (average academic performance) for each school. Regression modeling allowed investigation of significant associations between predictor variables and academic performance as well as to investigate the relative importance of blood lead level, compared with other factors in the model.

Data Sources

Before any data were requested from the three identified agencies, the Portland State University Human Subjects Review Committee approved the study data collection methods and sources on March 21st, 2002 by granting the study a designation of "review not required." Pertinent information about the data used for this study is given in Table 1.

Department of Human Services (DHS), Division of Environmental Occupational Epidemiology, Lead Poisoning Prevention Program

A series of phone conversations, e-mail exchanges and visits to the Lead Poisoning Prevention Program offices clarified what information was essential for this study. Once the study-specific information was identified, a specific request for data was transmitted to the Oregon Department of Human Services (DHS) Medical Assistance Program, in Salem, Oregon. DHS officials were concerned about any potential threats to confidentiality for participants in their health care program. Following a series of contacts, agreements were made to limit the data provided and to protect the confidentiality of program participants. All data provided from this source were collected and reported by zip code. The data set included the number of children eligible for the Oregon Medical Assistance Program (OMAP), the number of blood lead tests performed and the number of those tests in each of 3 blood lead level categories. Although all Medicaid eligible children are mandated to receive blood lead level testing, because of the voluntary aspect of the testing, zip code areas reported test completion as disparate as 12-19percent of children eligible for testing.

Center for Population Research

The Population Research Center (PRC) is the official source for all state of Oregon population information. PRC is responsible for producing the annual population estimates for Oregon's counties and cities. PRC also serves as the lead agency for the state's Data Center program providing US Census Bureau data to the citizens of Oregon. This agency is housed at Portland State University in the College of Urban and Public Affairs. Following a series of meetings and a number of phone calls and e-mail communications, the staff of PRC shared data and tables that had been created for other projects. Although much of their information is collected and reported by census tract, PCR has a wealth of data by school boundary. All data collected for this project is reported by school boundary. Information shared by this agency included demographic data on race/ethnicity, socioeconomic status and age of housing.

Portland Public Schools

PPS has created a public access web site offering a wide variety of information about the School District. Academic performance testing information for PPS can be found by accessing www.pps.k12.or.us and clicking on Directories, Management Information Services, and Elementary School Profiles. Results are reported by school boundary. Data included: academic performance for reading, academic performance for mathematics, the school's stability index, and the number of FTE per school.

Measures

Outcome

The primary outcome measure was average academic performance, computed from post-spring academic test scores for mathematics and reading comprehension for the years 1997-1998 for each elementary school for the 4^{th} grade (average age = 10). The tests used were the Portland Achievement Levels Tests (PALT). These tests were developed by the Research, Evaluation and Assessment Department of the Portland Public Schools, to match State and District content standards. A form of the test appropriate to each student's level of skill is administered. The various test levels produce scores on a common scale and are reported as Rash Unit (RIT) scores. RIT scores provide a measure of absolute (rather than relative) progress through the school district's basic skills curriculum.

Predictor Variables

The predictor variable of major interest for this project is blood lead level. Other predictor variables included in this analysis reflect race/ethnicity, family income, stability index, number of students per FTE, and percent of housing built before specified cutoff dates. Each of these variables is presented by school boundary.

Blood Lead Levels

The Lead Poisoning Prevention Program of the Oregon Department of Human Services provided blood lead level measurements with permission from the Oregon Department of Human Services Medical Assistance Program, in Salem, Oregon. Distribution of blood lead levels was reported in three categories: 1) included children with blood lead levels <5 micrograms per deciliter (ug/dl), 2) included children with blood lead levels of 5-9ug/dl, and 3) included children with blood lead levels ≥ 10 ug/dl. The percent of students tested with blood lead measurements in these three categories provide a profile of lead exposure per zip code. Data on blood lead levels in Medicaid eligible children by zip code presented two problems: 1) translating the data into school boundaries, and 2) representing the whole school population, rather than just the portion that was Medicaid eligible. In order to derive data by school boundary, the categorical data were used to derive a weighted percent reflecting the blood lead level profile for each school. The profile reflects the weighted percent of children with blood lead level measurements in each of three categories: percent< 5 ug/dl, percent 5-9 ug/dl, and percent ≥ 10 ug/dl. The formula (a x b): (a x c): (a x d), summed for each zip code contributing more than 10 students to the school was used, where a = the percent of students contributed to a school from a zip code, b = the percent of blood lead tests < 5 ug/dl for that zip code, c = the percent of blood lead tests 5-9 ug/dl for that zip code and d = the percent of blood lead tests ≥ 10 ug/dl for that zip code. The formula (a x b) reflects the category with percent < 5 ug/dl blood lead levels; the formula (a x c) reflects the category with percent 5-9 ug/dl blood lead levels; and (a x d) reflects the category with percent $\geq$ 10 ug/dl blood lead levels.

An additional variable was created, called, "Percent Elevated Lead". Current literature reflects negative impact on reading and mathematic skills with blood lead levels measured as low as 5 ug/dl. In addition, publicly available laboratory methods for testing blood lead levels do not allow discrimination for blood lead levels of less than 5 ug/dl. In essence, the cutoff for this categorical variable, divides measurement of blood lead levels into one category that reflects blood lead levels known to result in decreased educational performance in individuals (at or above 5ug/dl) and one category that cannot be discriminated from 0.0 ug/dl blood lead with available laboratory tests (below 5 ug/dl). The formula (a x b) summed for each zip code contributing more than 10 students to the school, was used, where a = the percent of students contributed to a school from a zip code and b = the percent of blood lead tests > 5 ug/dl for that zip code. All measurements contributing to this variable come from the Medicaid eligible population.

In order to create a blood lead level measurement reflective of the whole school's population, another variable was derived. Previous research has established that the Medicaid eligible population is at the highest risk of elevated blood lead (MMWR 2000). The percent of Medicaid eligible children per school boundary was derived by weighting the number of students contributed to the school by each zip code by the percent of Medicaid eligible children in those zip codes. If the assumption that non-Medicaid eligible children would measure below 5 ug/dl for blood lead is correct, then (percent

Medicaid eligible) X (percent ≥5ug/dl blood lead) may be considered a reasonable reflection of the blood lead levels for the entire population of the school.

To evaluate the accuracy of this assumption, an additional variable was constructed [(1- percent Medicaid eligible) (percent pre 1960)]. This represents the non-Medicaid eligible children who live in housing built before 1960. The research literature has clearly identified living in old housing as the highest risk factor for elevated blood lead for children. The assumption that non-Medicaid eligible children have blood lead less than 5 ug/dl may be wrong if many of these children live in old housing. Several Portland neighborhoods are characterized by economically advantaged families living in housing predominantly built before 1960. If this variable is not significantly related to academic performance when included in the linear regression model, (Sig. > .05, with no increase in R^2) it may be concluded that the above assumption is reasonable.

Race/ethnicity

The data on race/ethnicity was obtained from the Center for Population Research at Portland State University. Data is categorical and representative of the entire community, rather than just the school-aged population, and was collected by questionnaire or phone survey to residents in the specific school boundary area. Previous analyses have identified being African American (Black) as a significant predictor of blood lead levels (Javier 1999, Litaker 2000) as well as academic success (Patterson, 1990). A regression with a single predictor variable was performed to identify the most significant predictor of academic success for the demographic distribution found in Portland, including number White, number Black, number American Indian, number Asian, number

Hispanic, percent White, percent Black, percent American Indian, percent Asian, percent Hispanic, percent non-White, and percent non-White-non-Asian in each school boundary. The most significant predictor of academic success was included in the final multivariate model. Please note that this variable reflects the population within the school boundary rather than a percentage based on student count.

Family Income

Data on income by school boundary is an estimate, from 1999 data provided by the Center for Population Research. Data was provided by household income category (<$15,000, $15,000-$24,500, $25,000-$44,000, $45,000-$74,000, and >$75,000). The percent of households at each category was multiplied times the midpoint income amount for that category ($15,000, $19,500, $34,500, $59,500, and $75,000). These numbers were then added to create an average income for the households within each school boundary.

An additional variable was created, called Average Income/1000, since the beta coefficient reflecting the change in academic performance per $1.00 of the average family income is quite small. It makes more sense to talk about the change in academic performance per $1000 of family income.

Stability Index

The Stability Index was obtained directly from the PPS web site. It is a percentage of the students in the 1997-98 school year enrolled at the same school for the entire school year, divided by the October 1 enrollment. Since the focus of this study was on elementary schools, this number reflects family relocation rather than school dropouts.

Students per Full Time Equivalent (FTE)

Data on the number of students per FTE was also taken from the PPS web site. This number was calculated by dividing the number of students at each school by the number of school staff FTE. School staff FTE includes all job positions at the school: janitorial staff, teaching staff, office staff and management personnel. Analysis was also performed using the number of students per teaching FTE. The variable most predictive of academic performance was used in the model building process.

Percent of old housing

These variables have been calculated from data provided by the CPR by adding the numbers of households with construction dates before each of the cut-off dates from each reported category (multiple family residence, single family residence, rented, and single family residence, owned), and dividing by the total number of households identified. As described above, living in old housing is the most significant predictor of elevated blood lead levels. The current literature is divided over whether the most significant housing construction cut-off date for predicting blood lead levels in children is pre-1950 or pre-1960. Accordingly, this analysis of the association of blood lead levels with academic performance includes data on age of housing for both of these time periods. Regressions were performed to identify which cutoff date presented the strongest association with academic performance for housing in the Portland area.

Data management

All data were checked for accuracy and completeness by the agency that supplied it. Data entry was done twice, with confirmation of correctness performed for each item that did not match between the two data sets. Complete data was not available for Hollyrood Elementary School, because it does not enroll students above the third grade. Forest Park Elementary School was too new to have the number of consecutive years of testing required to be introduced to the academic achievement data set of the PPS. Neither Bridlemile nor Kelly elementary schools had any blood lead level test data. With the omission of these four schools, the data set is complete with no missing data and an n = 60.

Strategy for Data Analysis

The analytic approach selected for this project was multiple linear regression. Assumptions underlying the multiple linear regression model are that: 1) the predictor (X) variables are nonrandom, 2) the subpopulations of outcome (Y) values are normally distributed, 3) the variances of the subpopulations of Y are all equal and 4) the y values are independent. It is also assumed that ε values are normally and independently distributed. The assumption regarding ε is a consequence of the assumptions regarding the distributions of the y values. Unbiased estimates of the parameters of the model were obtained by the method of least squares. The Statistical Package for the Social Sciences (SPSS, versions 9 and 11.5) was used.

The first step in analysis was to examine the outcome and predictor variables (Table 2) to identify the nature of their distribution and characteristics, verifying that the assumptions underlying linear regression were not violated. Transformations were explored for any variables that did not meet the assumption of normal distribution of ε values. In addition, correlation and colinearity were evaluated to assess the validity of the assumption of independence.

The second step in analysis was to examine the relationship of each predictor variable and the dependent variable. Only those variables with an association significance level $\leq$ .25 were considered further (Table 3). In many cases, several of the potential explanatory variables in a single category were highly associated with the dependent variable. When this was the case, the single most strongly associated variable for each category was selected for inclusion in the initial multivariate model. Factors used in assessing the most highly associated predictor variable for each category were: the level of significance for each single-predictor regression, the r^2 value and the size of the standardized beta coefficient. The one exception to this rule is the Income predictor. As illustrated in Table 4, the most highly predictive variable in this category was percent > $75,000 for family income. However, this variable was highly skewed in distribution, and reflected only a small portion of the income data available. The Average Income/$1000 was selected as the Income variable to include in further analysis because it met the assumptions underlying linear regression for normal distribution and represented the full range of income information available.

The third step in analysis was to use model-building techniques appropriate to multiple linear regression. The initial model equation was $y = \beta_0 + \beta_1 l + \beta_2 r + \beta_3 ec + \beta_4 si + ... + \varepsilon$, where y is the average of the reading and math test scores for grade 4 post-spring tests; $\beta_1 l$ is the most significant predictor from the group reflecting blood lead measurement; $\beta_2 r$ is the most significant predictor for race/ethnicity; $\beta_3 ec$ is the most significant Income variable; $\beta_4 si$ is the stability index for the school; with a beta value for each additional variable proving to be a significant predictor in the multiple regression.

Since it is well known that race/ethnicity and income are powerful predictors of school performance, the fourth step in these analyses was designed to control for those variables. This gave a greater explanatory power to other potentially-involved variables. This analysis was constructed to clarify the relationship, if any, played by exposure to lead, in addition to other factors identified by previous studies. The 50^{th} percentile Race/ethnicity and Average Income/1000 were identified from a frequency distribution, and each was divided into a high and low category. These categories were combined into: 1) High percent White/High Average Income, 2) High percent White/ Low Average Income, 3) Low percent White/ High Average Income, and 4) Low percent White/ Low Average Income.

These four variables were included in the linear regression model, controlling for the impact of Race/ethnicity and Income, as well as reducing the degree of correlation present if these highly related variables were to be used independently. In addition, analyses were run for each stratum, individually.

Following the development of the main effects model, a variety of linear regression models were explored to investigate the most useful approach possible for reflecting the association of elevated blood lead with academic performance in this population, given the data available. In addition, further linear regression analyses stratified by race/income were also conducted to explore the relationship of the stability index to elevated blood lead. A sensitivity analysis was done to investigate the relative contributions of the variable percent Medicaid Eligible and Percent Elevated Lead.

Finally, analyses were done using dependent variable = the reading achievement test score for each school and dependent variable = the math achievement test scores for each school. This allowed assessment of whether having a specific blood lead level could be associated with lower academic achievement in either reading or mathematics.

Ethical considerations:

Because there was no direct contact with the study cohort, just an analysis of aggregate data, there was minimal or no risk to human subjects. All data collected by the three agencies was done as a routine function of each institution. These data sets contain only aggregate data and do not include data that can be linked to individuals. As mentioned earlier, the Portland State University Human Subjects Research Review Committee granted the study the designation of "Review not required" on March 21st, 2002.

RESULTS

Descriptive Statistics

The frequency distribution, measures of central tendency, and measures of dispersion were examined for all variables (Table 3). On average 26 percent of the school population tested evidenced blood lead levels $\geq$ 5 ug/dl. More than 80 percent of the population within the Portland Public Schools elementary school boundaries identified themselves as "White". A glance at the histogram indicates that the non-White students are not distributed evenly across the District's schools. The average family income across all schools was $35,800, again not distributed evenly across all city regions. The stability index indicates that on average almost 86 percent of students in a school finish the year in the same school at which they registered in the fall. The variable, Percent Non-White, and its converse, Percent White were skewed beyond the degree consistent with the assumptions of linear regression, but when combined with the selected Income variable was within the acceptable range for skew. None of the variables skewed sufficiently to require transformation.

To view histograms of data for the variables of Average Academic Performance, Race (percent White), Income (AveInc/1000), Stability Index (StabInd), Students/FTE

(Stu/FTE), (Percent greater than or equal to 5 ug/dl blood lead), percent Medicaid Eligible and Adjusted Lead Measurement (percent ME*percent≥5), see appendix A.

Regression Results

Variable Selection

All results used for variable selection are from linear regression of average academic performance on single predictor variables. In the category of potential variables reflecting race, the Percent Non-White and its converse, Percent White were the strongest predictors (Table 4), with the difference being the direction of the effect. For every unit of change, Percent non-White reduced academic performance by .627, while for every unit of change Percent White increased academic performance increases by .627.

In the category of family income predictors, percent > $75,000 was the strongest predictor of academic performance, but the distribution was highly skewed, and reflected only a tiny portion of the data on income. The predictive power of Average Income was only slightly lower, the degree of skew was less and the representation of income data was broader. Therefore, Average Income was selected as the overall best Income predictor for this analysis. Average Income/1000 was used, because the size of the beta coefficient made more sense for discussion purposes.

Neither variable reflecting cut-off date of housing construction was significantly associated with academic performance at the school level. Neither was included in the initial model.

The number of students per teacher-FTE did not reach the cut-off level of significance for inclusion in the initial model, while the number of students per total school FTE did. This variable (Students/FTE) included school staff such as secretaries and janitors.

The blood lead level variable showing the strongest predictive capacity in this study was percent 5-9 ug/dl. However, since blood lead level has been shown to be dose dependent in its effect in individuals, the variable Percent Elevated Lead, reflecting percent blood lead $\geq$5 ug/dl was selected as the variable most representative of exposure for investigation in this analysis. Beta coefficients for each level of blood lead show a progressive impact on academic performance: +59.5 for percent $<$ 5ug/dl, -67.8 for percent 5-9 ug/dl, and –75.4 for percent >10 ug/dl.

Published literature on the relationship between lead exposure and academic performance predictions suggests that the variables identified to date are highly correlated. Indeed, a correlation analysis shows high correlations between several variables, notably percent White and AveInc/1000, Stability Index and AveInc/1000, and Percent Elevated Lead and percent White, AveInc/1000 and Stability Index (Table 5).

To limit the amount of correlation between variables and to control for the effect of Race/ethnicity and Income, these two variables were combined in subsequent analyses. In order to elucidate the less powerful predictors involved, the analyses were stratified on the combined Race/ethnicity/Income variable.

Single-variable regressions of average academic performance on various levels of measured blood lead result in the following (Table 6): Percent < 5 ug/dl, beta = 59.575; Percent 5-9 ug/dl, beta = -67.849; and Percent ≥ 10 ug/dl, beta = -75.397.

Exploration of models

A linear regression of academic performance at the school level was performed on percent White, Average Income/1000, Stability Index, Percent Elevated Lead and Students/FTE. Although much literature and the single-variable regression of academic performance on the number of students/FTE both indicate that this variable is significantly related to academic performance, when it was included in a multivariate analysis the predictive capacity was not strong enough to reach the .05 level of significance. Accordingly, it was removed from the model. Table 7 presents the results showing percent White to be a significant predictor at the p=.039 level, Average Income/1000 to be a non-significant predictor at the p=.487 level, Stability Index to be a very strong predictor at the p=.000 level, and Percent Elevated Lead to be a weak predictor at the p=.110 level. It is likely that the non-significant result for Average Income/1000 is due to high correlation with Percent White (r=.642).

A linear regression of academic performance at the school level was performed on Percent Elevated Lead, Stability Index, and four strata combining Race/ethnicity and Income (Hi/Hi, Hi/Low, Low/High, Low/Low). Results (Table 8) show that Stability Index is again a very strong predictor at the p=.000 level, Percent Elevated Lead is approaching the level of significance at p=.059, Hi/Low is not significantly different from the Hi/Hi reference group, with p=.116, and both of the strata with low percent White are significant predictors of academic performance as compared with the Hi/Hi group: Low/Hi with p=.029 and Low/Low with p=.003.

In response to the concern that all of the blood lead data came from the Medicaid eligible population, a variable was created that links the percent of Medicaid eligible students in each school to the total school population. When this variable, called Adjusted Lead Measure was included in the linear regression analysis, results (Table 8) are as follows: Stability Index p=.001, Adjusted Lead Measure p=.023, Hi/Low p=.088, Low/Hi p=.006, and Low/Low p=.005.

A variable was included in the previous model to evaluate the adequacy of the assumption that the majority of non-Medicaid eligible individuals have blood lead levels less than 5 ug/dl [(1-ME)(percentpre60)]. As can be seen in Table 9, the variable included to check the adequacy of the assumption is not significantly related to academic performance (p=.150), indicating that non-Medicaid eligible students living in housing built before 1960 are not significantly affecting academic performance as a result of elevated blood lead levels. The assumption underlying the Adjusted Lead Measure therefore appears to be a reasonable assumption in this population.

However, there is some question as to whether the predictive power of the Adjusted Lead Measure comes from the aspect of elevated blood lead or from the aspect of Medicaid eligibility. The Adjusted Lead Measure correlates r=.992 with Percent Medicaid Eligible. It is also true that the construction of the Adjusted Lead Measure is identical to that of an interaction term. Appropriate linear analysis including an interaction term must also include the main effects from which the term was derived. In order to address these concerns, four further analyses were conducted:

1. A linear regression of average academic performance on 4 strata of race/income, Stability Index, the Adjusted Lead measure and the main effects combined to create that measure (Percent Elevated Lead and Percent Medicaid Eligible) was performed. Results presented in Table 8 show: Stability Index p=.001, percent Medicaid Eligible p = .332, Percent Elevated Lead p=.065, Adjusted Lead Measure p=.472, Hi/Low p=.101, Low/Hi p=.016, and Low/Low p=.014.
2. A linear regression of average academic performance on 4 strata of race/income, Stability Index and percent Medicaid Eligible (Table 8) shows Stability Index p=.001, percent Medicaid Eligible p=.027, Hi/Low p=.068, Low/Hi p=.004, and Low/Low p=.003.
3. A model with 4 strata of race/income, Stability Index and Percent Elevated Lead was also run for comparison purposes. Data (Table 7) show Stability

Index p=.000, Percent Elevated Lead p=.059, Hi/Low p=.116, Low/Hi p=.029 and Low/Low p=.003.

4. A sensitivity analysis was conducted to investigate the relative predictive power of Percent Elevated Lead vs. percent Medicaid Eligible for each race/income stratum (data not shown). The impact of varying values was not different across strata. The variation in predicted value for academic performance from a minimum value to a maximum value for Percent Elevated Lead was .043. This compares to variation of 2.072 for percent Medicaid Eligible.

Further analyses

Previous studies have identified race and family income as the major predictors of academic performance. Analyses were run to investigate the impact of these two factors in this data set (Table 10). A linear regression of average academic performance was run on 4 strata of race/income. Results show Hi/Low p=.001 coefficient = -6.057, Low/Hi p=.000 coefficient = -9.039 and Low/Low p= .000 coefficient = -9.584. An additional regression used percent White and Average Income/1000 as predictive variables for the same outcome variable. Results from this analysis show Percent White p=.005, with a large coefficient effect of 14.634 and Average Income/1000 p=.001, coefficient = .390.

Secondary outcomes

None of the three models employed to evaluate the effect of elevated blood lead on the school reading performance measure resulted in identification of a significant association

(Table 11). All three models employed to evaluate the association of elevated blood lead with mathematic performance at the school level indicated a statistically significant result (Table 12).

DISCUSSION

Context

Blood lead levels measured in young children today reflect a new steady state of exposure since lead content has been restricted in gasoline and in paint. Even though exposure to lead has decreased, significant numbers of children still exhibit blood lead levels that are known to negatively impact academic performance. Public health officials must discriminate those exposures that pose significant risks to populations. In addition, they must isolate those factors amenable to change through public health measures. This study was designed to investigate the relationship of factors other than race/ethnicity and income that influence academic performance at the population (school) level, particularly that of elevated blood lead.

Information from single-variable regression

There has been a great deal of attention focused on how the number of students per classroom impacts academic performance. It has occasionally become an election issue as candidates for school board or school superintendent positions try to find changes that can be expected to improve academic performance. It was interesting that, although the number of students per FTE was a significant predictor of academic performance at the single variable level of analysis in this population, the number of students per classroom teacher was clearly not. There may be a number of explanations for this. It may be that, without adequate school staff teachers are not able to effectively provide instruction to students. It may also be that student relationships with ancillary staff members are supportive, allowing a wider range of students to perform well academically. Further studies may tease out the elements that contribute to the importance of including all staff FTE when predicting school academic performance.

Also of interest was the fact that, while the number of students per FTE was significantly associated with academic performance in single variable analysis, it did not possess the predictive power to remain below the .05 level of significance in a multivariate analysis. It is of note that both stability and elevated blood lead levels had a greater association with academic performance at the school level, and therefore warrant more attention from officials concerned with education than the number of students per FTE in the school.

It is notable that these aggregate data show a dose-response pattern as the level of blood lead increases. The coefficients from a series of three regressions indicate that blood lead levels below 5 ug/dl positively impact school performance, while increasing levels of blood level have a progressively more negative impact on school performance. This could indicate a causal relationship between blood lead levels and academic performance, should it be corroborated by further studies. Such a biologic gradient is reassuring since this pattern has been clearly established for individual response to lead exposure.

Examination of alternative models

There is a divergence of thought as to the best analysis approach to investigate the association of lead with academic performance at the school level, given the limitations of this set of data. Analyses were performed with the five models presented in Table 7. Each embodies strengths and weaknesses as a tool for understanding the relationships between the variables under study.

An epidemiological approach would support selection of the adjusted lead measure as a variable that reasonably represents elevated blood lead levels for the whole school population. From this perspective, the linear regression model regressing average academic performance on Stability Index, the Adjusted Lead Measure and four strata of race/income (model number2) would be the model of choice.

The results of this model show a significant association between Adjusted Lead Measure and academic performance at the p=.023 level. The direction of impact on academic performance for an increasing blood lead level is negative, as shown by the standardized beta coefficient. In addition, the stability index is significantly associated with academic performance, showing a positive impact as the stability index increases. The High Percent White/High Average Income group was the reference group for the regression. Being in one of the other three groups has a negative impact relative to the High Percent White/High Average Income group on academic performance. It is clear from the standardized beta coefficients that, in terms of academic performance, it is more advantageous to be White, with low income than to be non-White with high income. Not surprisingly, the group that is non-White with low income has the largest negative standardized beta coefficient. Interestingly, comparison of standardized beta coefficient size indicates that the stability index of the school is a more powerful predictor of academic performance than any of the combined Race/Income group variables. This model explains nearly 70 percent of the total variation in average academic performance.

A more statistically based orientation to the problem would treat the adjusted lead measure as an interaction term, thus requiring the inclusion of Percent Medicaid Eligible and Percent Elevated Lead in the regression model. Analysis using model number 3 (including Stability Index, percent Medicaid Eligible, Percent Elevated Lead, Adjusted Lead Measure and 4 strata of race/income) results in $p=.065$ for Percent Elevated Lead, narrowly missing the .05 level of significance. There is high correlation between the Adjusted Lead Measure and both main effects (Percent Elevated Lead $r=.422$, Percent Medicaid Eligible $r=.992$), presenting problems for a linear regression as a result of challenging the assumption of independence between predictor variables. The Main Effects model (number 4) suffers from the same difficulty, i.e. that all of the information contained in Percent Elevated Lead is also contained in percent Medicaid Eligible, along with additional factors, some of which may have a bearing on academic performance. It is therefore problematic interpreting the results of the Main Effects analysis.

Analysis with model number5, regressing average academic performance on Stability Index and Percent Medicaid Eligible plus four strata for race/income, fits the data as well as a model that replaces Percent Medicaid Eligible with the Adjusted Lead Measure (number1). Results suggest that something other than race or income that is reflected in Percent Medicaid Eligible significantly predicts academic performance at the school level. It is not possible from this analysis to rule out that the effect of elevated blood lead may be part of the reason that this variable is such a strong predictor.

A sensitivity analysis was performed to shed further light on the strengths and weaknesses of the various models. It was clear that the variation in predicted values for academic performance was less for different values of Percent Elevated Lead than for different values of Percent Medicaid Eligible. This suggests that Percent Medicaid Eligible is contributing more to the predictive power of the Adjusted Lead Measure than is Percent Elevated Lead. This fact would support the selection of model number1, which uses a variable with potentially less "noise" for the purpose of evaluating the impact specific to lead. The level of significance for Percent Elevated Lead in this analysis was $p=.059$. It may be that a larger data set would result in a level of significance below the generally accepted cut-off point of .05.

While reasonable people may differ on choice of an analytical approach, they would likely agree that the data presented in this manuscript as a whole do not rule out a significant relationship between elevated blood lead and academic performance at the school level. In order to answer the question of whether an association exists between elevated blood lead levels and academic performance at the school level, a data set more representative of the population at large is required. This question cannot be definitively answered given the data currently available.

The results of these analyses corroborate findings by Wasserman that the stability of the school population is significant for predicting academic performance at the school level. In fact, the stability index was more strongly associated with average academic performance across all of these analyses than were measures of race/ethnicity or income. It is clear that models seeking to predict school academic performance must include stability as a predictive variable.

The pattern of standardized beta coefficients for stratified groups runs counter to the paper presented by Williams (1972), in which she reported that the poverty variable is 4 to 6 times more predictive of academic performance than the race/ethnicity variable. These data reflect a somewhat different picture, with the 2 groups including a high percent of White individuals showing better academic performance than groups with a low percent of White individuals in either the high or low economic strata. It may be that the Portland area has greater divergence in income for non-White vs. White workers than other parts of the country, enhancing the correlation between the race/ethnic variable and the income variable, and emphasizing the impact of race/ethnicity in this locality.

Although race/ethnicity and income are powerful predictors incorporating many aspects involved with academic performance they do not provide a complete picture of the important influences. Previous investigation has shown gender, income, household composition and race/ethnicity to account for 25percent of the variance in predicting academic achievement (Patterson, 1990). This indicates that factors other than these four explain nearly three times as much of the variance. Analysis of this data set shows that the race and income information alone explains about 50percent of the variance in average academic performance (Table 9). Four of the five models examined here account for nearly 70percent of the total variance in academic performance, significantly broadening our understanding of important influences and enhancing the capacity to predict.

The variables predicting academic performance are complex and interconnected, presenting a challenge for public school officials, public health policy makers and society as a whole. When the powerful influences of race/ethnicity and income are controlled, other factors emerge to deepen our understanding of important influences affecting childhood academic performance. Of these, elevated blood lead level is the most amenable to interventions in the public health arena.

There is a currently debate in Oregon over whether to lower the level of blood lead for public health concern from 10 ug/dl to 5 ug/dl. It is interesting that analysis using 10 ug/dl as the cut-off level did not result in a significant association with academic performance, while analysis with blood lead levels 5 ug/dl and above did. It may be that the numbers of those with blood lead above 10 ug/dl in this area are simply not large enough to show the detrimental effect of elevated blood lead at the population level in this type of analysis.

Analyses for the secondary outcome measures of reading and mathematics performance are very interesting. There was no support across models for a significant association between elevated blood lead and reading performance at the school level. There was consistent support across models for a significant association between elevated blood lead levels and mathematics performance at the school level. This may possibly reflect differential impact of elevated blood lead on various areas of the brain.

Limitations

In addition to the usual limitations for individual-level analysis (imprecise measurements, inadequate study size, inappropriate study design, selection bias, and information bias, ecological study designs have limitations associated with aggregate, or group-level data. Although the ecological design made good use of data currently available under constrictions protecting the confidentiality of subjects, ecological fallacy precludes any inference about effects on individuals. The results of this study are intended for hypothesis generation and to guide public health decisions related to collection of data on blood lead levels in children and the appropriate blood lead level for public health concern. They are not intended to answer questions about risk. All the tests used in this study are subject to the usual limitations of validity, variability of adherence to the test protocol, and errors of reporting. Data for the PPS does not identify the proportion of students actually tested for academic performance vs. those eligible to be tested.

It was assumed that lead exposure for Medicaid eligible children who received blood tests was representative of the lead exposure for Medicaid eligible children who did not receive blood tests. Although blood lead level testing is federally mandated for the entire Medicaid eligible population, there is a voluntary aspect to it, which may mean that some eligible children are not tested. In this study, the percentage of eligible children actually tested for blood lead levels in specific Zip codes varied between 12-19 percent.

It was assumed that the non-Medicaid eligible students at any of the schools investigated were not at risk for elevated blood lead levels. Previous research indicates that the Medicaid eligible population is the "at risk" population for elevated blood lead level. The results of inclusion of a predictor variable to check the accuracy of this assumption in the regression model indicated that, given the study population, this assumption was reasonable.

It has been well established that early exposure (before age 2) to lead has a negative impact on later school performance (Needleman 1983). It was assumed that the exposure in the 0-5 year old population was representative of the lead exposure experienced at that age by students in the 4th grade during the 1997-1998 school year. Instability in the school population would challenge this assumption. This may be the reason that elevated blood lead levels did not show an association at or below the .05 level of significance in the Low Percent White/ Low Average Income Group stratified analysis. This group has less residential stability compared to other groups.

Previous investigations of academic performance have used explanatory variables such as race/ethnicity or income that are broadly inclusive. This strategy creates strong predictive power, but obscures the more subtle interactions between less broad, less powerful variables. Race and income, even in combination with household composition and gender explain little of the variance in academic performance. It is clear that a broader and deeper understanding of the influences associated with academic performance is needed. Since race and income are clear predictors of academic performance, they must be included in the analysis, but in a way that allows the other variables to manifest themselves more clearly.

There are multiple high correlations between the explanatory variables known to affect academic performance. Many of these variables are also highly correlated with elevated blood lead levels. This makes it more difficult to establish the relationships between factors and challenges the assumption that predictor variables are independent.

A further limitation of this study is the divergence of opinion on the regression model that is most appropriate to analyze the data. While something is lost in clarity by presenting divergent approaches, something is also gained in depth and breadth of understanding.

Directions for Future Study

In spite of various unavoidable limitations, this study contributes valuable new information to the literature and poses some interesting directions for future research.

The fact that single variable analysis showed the number of students per FTE to be a significant predictor of academic performance while the number of students per classroom teacher was not opens a number of questions about what factors contribute to that result. Perhaps the amount of support that teachers have (i.e. Secretarial support, help from aides, functional facilities, access to librarians, music specialists, physical education specialists, etc.) is more important to student learning than the number of students in the classroom. It may be that these ancillary staff have a greater impact on students than has been recognized. Further research could illuminate this puzzle and provide guidance for officials responsible for enhancing educational performance in Portland.

Another interesting result worthy of follow-up research was the relative importance of the Race/ethnicity variable compared to the Income variable in Portland. Further research might identify local factors such as number of minorities with significant numbers, specific minorities that have differential effects on educational performance, or disparities in hiring practices that influence Income for different minority groups that tip the balance in predictive power between these two variables. An alternative hypothesis that may bear further investigation is whether teacher expectations in the Portland area are responsible for the fact that well-to-do non-White students do not achieve the same level of academic performance as less well-to-do White students. Another approach to understanding this finding might be to investigate what elements of culture may be different in various locations around the US, resulting in race/ethnicity being a more powerful predictor of academic performance than Income in one locality, but less powerful as a predictor in another.

Further research is also needed to understand whether the differential impact of elevated blood lead seen here for mathematics and reading is consistent across studies, or was a phenomenon of this data set. Do other locations find elevated blood lead to have a more detrimental effect on mathematics than on reading?

The results of this study also encourage further research with individual level data that can address the question of causality for blood lead above 5 ug/dl and impaired academic performance at the population level. Many of the limitations endemic to this study design could be eliminated using other design models. These studies could be important in informing decision-makers in the current debates over how to improve academic performance as well as what level of blood lead should be considered a public health hazard worthy of response by health care agencies.

SUMMARY AND CONCLUSIONS

Taken as a whole, the results of this study support further investigation of the effects of elevated blood lead on the school population. A dose-response relationship between increasing blood lead levels and decreasing academic performance was shown. A differential effect emerged, showing a significant, detrimental effect from elevated blood lead levels on mathematics in the absence of a significant effect on reading performance. Additionally, contrary to published studies from other US localities, in the Portland area race has a greater predictive association with academic performance than does family income. Furthermore, the stability of the school population is clearly an important variable to include in any analysis seeking to predict school academic performance.

Public health officials and government policy makers are charged with the responsibility of protecting the public health. Lead exposure is clearly detrimental for individuals. This study contributes to our growing understanding of the impact of lead exposure on the health and well being of the public. These data support continuation of the conversation around lowering the blood lead level identified as "toxic" to 5 ug/dl. It is clear from these analyses that, in order to answer the questions that remain before us around this issue, future studies will require a more representative data set than is currently available.

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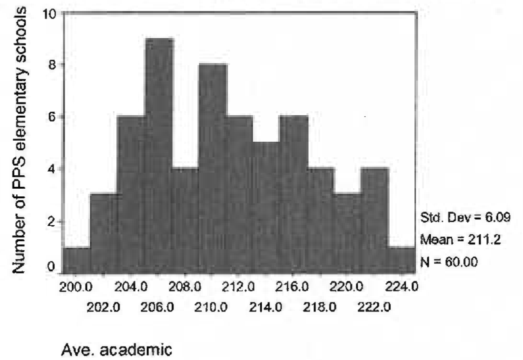
Appendix A:

Histograms

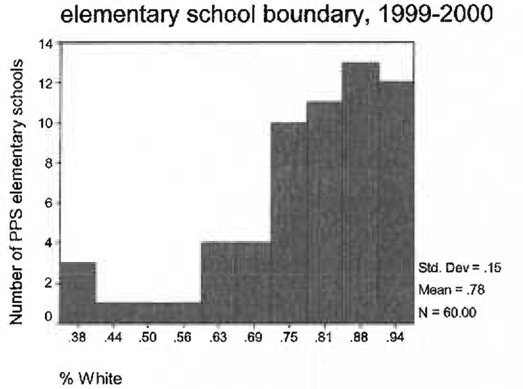
Distribution of academic performance for

60 PPS elementary schools 1997-1998

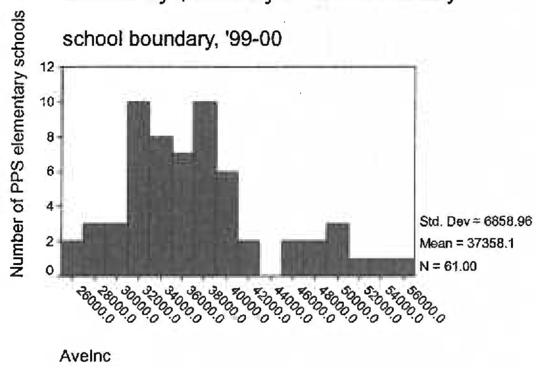


Distribution of % White population by PPS

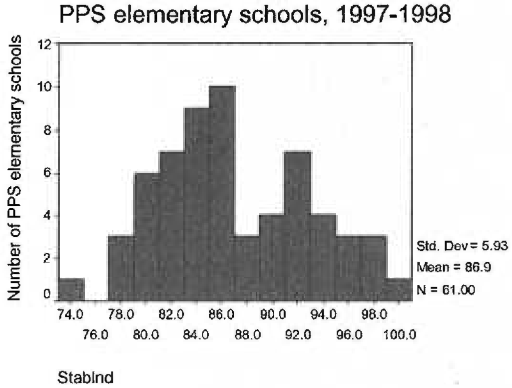
elementary school boundary, 1999-2000



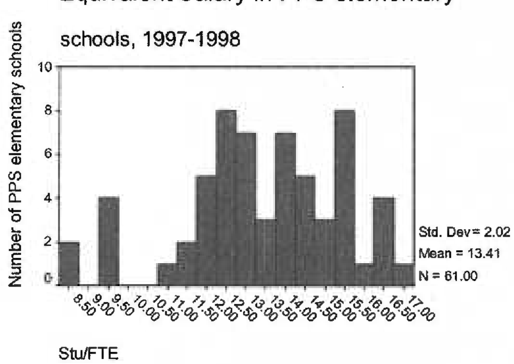
Distribution of average family income divided by $1000 by PPS elementary school boundary, '99-00



Distribution of the stability index for PPS elementary schools, 1997-1998



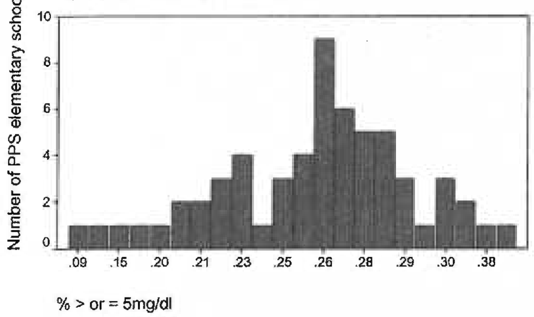
Distribution of students per Full-Time Equivalent Salary in PPS elementary schools, 1997-1998



Distribution of the % of children aged 0-5

with blood lead levels 5 ug/dl or greater

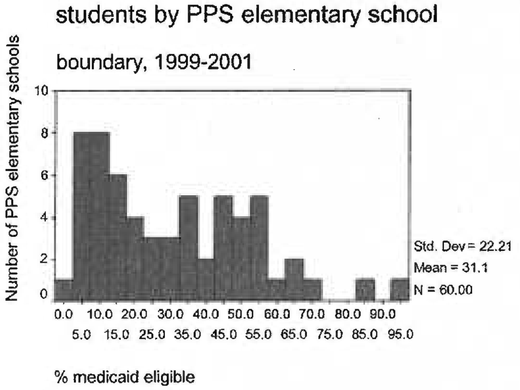
by PPS school boundary, '99-01



Distribution of the % of medicaid eligible

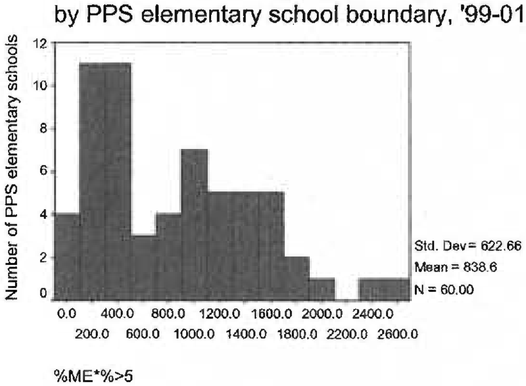
students by PPS elementary school

boundary, 1999-2001



Distribution of Adjusted Lead Measure

by PPS elementary school boundary, '99-01



TABLES

Table 1. Data Sources for a study of blood lead levels and academic performance in the Portland Public elementary schools, 2002.

Source	Lead Poisoning Prevention Program	Center for Population Research	Portland Public Schools
Population	Medicaid eligible children aged 0-5yrs by zip code	Population based per school boundary	School-based
Data	Blood Lead Levels # Medicaid eligible # Tested for blood lead level	Demographic Data Race/ethnicity Income ($/household) Housing construction dates # students per school	Standardized Test Scores – 4th grade Stability Index* # Students # FTE* Year of School construction
Year of data collection	1999 - 2001	1999-2000	1997-1998

*FTE = Full Time Equivalent, or Full-time salaries
*Stability Index: A percentage derived by dividing the number of students who completed the entire school year by the number of students enrolled on Oct. 1st.

Table 2: Variables evaluated for a study of blood lead levels and academic performance in the Portland Public elementary schools, 2002.

Category	Variable	n
Outcome Measures		
	Averaged Reading and Math Standard Test scores	60
	Reading comprehension	60
	Mathematic skill	60
Predictor Variables		
Race/ethnicity	Percent White*	60 (Census data within school boundary)
	Percent Black	60 (Census data within school boundary)
	Percent Non-White	60 (Census data within school boundary)
	Percent Non-White-non-Asian	60 (Census data within school boundary)
Income	Percent <$15,000	60 (Households within school boundary)
	Percent $15-24	60 (Households within school boundary)
	Percent $25-44	60 (Households within school boundary)
	Percent $45-74	60 (Households within school boundary)
	Percent >$75,000	60 (Households within school boundary)
	Average Income*	60 (Households within school boundary)
	Average Income/1000	60 (Households within school boundary)
Stability Index	Stability Index*	60
Students/Staff	Students/FTE*	60
	Students/Teacher	60
Old Construction	Percent pre-1950	60 (Dwellings within school boundary)
	Percent pre-1960	60 (Dwellings within school boundary)
Blood Lead	Percent < 5 ug/dl	60 (Average number per zip code = 141)
	Percent 5-9 ug/dl	60 (Average number per zip code = 48)
	Percent ≥ 10 ug/dl	60 (Average number per zip code = 4)
	Percent ≥ 5 ug/dl*	60 (Average number per zip code = 52)
	% Elevated Lead	60(Average number per zip code = 52)
	Adjusted Lead Measure	60(Average number per zip code = 52)
Medicaid eligible	Percent Medicaid eligible	60 (Percent of school population)
Non-Medicaid eligible students and age of housing	Non-Med_%Pre60	60 (Percent of school population)

* = Variable selected as most highly associated with the primary outcome measure for the identified category; FTE = Full time equivalent salary; Stability Index: A percentage derived by dividing the number of students who completed the entire school year by the number of students enrolled on Oct. 1st; Percent pre-1950 = Percent of housing built before 1950; Percent pre-1960 = Percent of housing built before 1960; ug/dl = microgram per deciliter; % Elevated Lead = the percent with greater than or equal to 5 micrograms per deciliter blood lead; Adjusted Lead Measure = the percent of the total school population that is Medicaid eligible x the percent with greater than or equal to 5 micrograms per deciliter blood lead; Non-Med_%Pre60 = Interaction term combining percent non-Medicaid eligible students and percent of housing built before 1960.

Table 3. Descriptive measures for selected variables in a study of blood lead levels and academic performance in the Portland Public elementary schools, 2002.

Variable	Mean	Std dev	Minimum	Maximum	n
Percent White	.820	.147	.370	.950	60
Average Income/1000	35.805	6.642	26.30	55.91	60
Stability Index	85.750	5.908	73.50	99.50	60
Students/FTE	13.44	2.020	8.34	16.81	60
% Elevated Lead	26.00	5.149	9.20	39.30	60
% $<$ 5 ug/dl	.743	.051	.61	.91	60
% 5-9 ug/dl	.234	.049	.09	.35	60
% $\geq$ 10 ug/dl	.023	.012	.00	.08	60
Adj. Lead Measure	736.070	622.658	12.320	2501.460	60

Std dev = Standard deviation; n = Sample size; Stability Index: A percentage derived by dividing the number of students who completed the entire school year by the number of students enrolled on Oct. 1st; FTE = Full time equivalent salary; % Elevated Lead = the percent with greater than or equal to 5 micrograms per deciliter blood lead; % $<$ 5 ug/dl = the percent with less than 5 micrograms per deciliter blood lead; % 5-9 ug/dl = the percent with 5 to 9 micrograms per deciliter blood lead; % $>$ 10 ug/dl = the percent with 10 or more micrograms per deciliter blood lead; Adj. Lead Measure = the percent of the total school population that is Medicaid eligible x the percent with greater than or equal to 5 micrograms per deciliter blood lead.

Table 4: Results of linear regressions of academic performance on single predictor variables for study of blood lead levels and academic performance in the Portland Public elementary schools, 2002.

Category	Variable	r^2	St Beta	Beta	Sig	df	n
Race/ethnicity	Percent White*	.393	.627	25.928	.000	59	60
	Percent Black	.180	-.424	-19.231	.001	59	60
	Percent Non-White-non-Asian	.274	-.523	-20.425	.000	59	60
Income	Percent <$15,000	.264	-.514	-35.361	.000	59	60
	Percent $15-24	.330	-.574	-80.064	.000	59	60
	Percent $25-44	.074	-.271	-33.958	.036	59	60
	Percent $45-74	.158	.397	47.822	.002	59	60
	Percent>$75,000	.463	.681	44.336	.000	59	60
	Average Inc/1000*	.426	.653	.598	.000	59	60
	Median Income	.368	.607	.399	.000	59	60
Stability Index	Stability Index*	.543	.737	.759	.000	59	60
Students/FTE	Students/FTE*	.198	.445	1.340	.000	59	60
	Students/Teacher	.001	.033	.064	.801	59	60
Old Construction	Percent pre-1950	.003	-.053	-1.386	.689	59	60
	Percent pre-1960	.020	-.141	-4.884	.282	59	60
Blood Lead	Percent < 5 ug/dl	.253	.503	59.575	.000	59	60
	Percent 5-9 ug/dl	.298	-.546	-67.849	.000	59	60
	Percent $\geq$ 10 ug/dl	.015	-.124	-75.397	.349	59	60
	% Elevated Lead*	.268	-.518	-61.284	.000	59	60
	Adj. Lead Measure	.406	-.637	-.006	.000	59	60

* = Variable selected as most highly associated with the primary outcome measure for the identified category; St Beta = Standardized Beta; Sig = Significance; df = degrees of freedom; Stability Index: A percentage derived by dividing the number of students who completed the entire school year by the number of students enrolled on Oct. 1st; FTE = Full time equivalent salary; Percent pre-1950 = Percent of housing built before 1950; Percent pre-1960 = Percent of housing built before 1960; ug/dl = microgram per deciliter; % Elevated Lead = the percent with greater than or equal to 5 micrograms per deciliter blood lead.

Table 5: Correlations among selected predictor variables for predicting academic performance in study of blood lead levels and academic performance in the Portland Public elementary schools, 2002.

	%White	AveInc/1000	Stability Index	Students per FTE	% Elevated Lead	% Medicaid Eligible	Adj. Lead Measure
% White	1	.642**	.498**	.368**	-.553**	-.492**	-.564**
AveInc/1000		1	.661**	.479**	-.526**	-.509**	-.543**
Stability Index			1	.487**	-.371**	-.538**	-.551**
Students/FTE				1	-.220	-.303*	-.309*
% Elevated Lead					1	.342**	.422**
% Medicaid Eligible						1	.992**
Adj. Lead Measure							1

*Correlation is significant at the 0.05 level (2-tailed); ** Correlation is significant at the 0.01 level (2-tailed); %White = Percent White; AveInc/1000 = Average Income divided by 1000; Stability Index: A percentage derived by dividing the number of students who completed the entire school year by the number of students enrolled on Oct. 1st; Students/FTE = Number of students per full-time equivalent salary; % Elevated Lead = Percent greater than or equal to 5 micrograms per deciliter; % Medicaid Eligible = Percent Medicaid Eligible; Adj. Lead Measure = the percent of the total school population that is Medicaid eligible x the percent with greater than or equal to 5 micrograms per deciliter blood lead.

Table 6: Results of single-variable linear regression of average academic performance on various levels of measured blood lead in a study of blood lead levels and academic performance in the Portland Public elementary schools, 2002.

Variables	Beta Coefficient	Significance	Degrees of Freedom
Percent < 5 ug/dl	59.575	.000	59
Percent 5-9 ug/dl	-67.849	.000	59
Percent ≥ 10 ug/dl	-75.397	.349	58

ug/dl = microgram per deciliter.

Table 7: Results of linear regression model for average academic performance regressed on variables for Race/Ethnicity, Income, Stability Index and % Elevated Lead in a study of blood lead levels and academic performance in the Portland Public elementary schools, 2002.

Variables entered	Standardized Beta Coefficient	Significance	Degrees of Freedom
% White	9.589	.039	59
Ave. Income/1000	.071	.487	59
Stability Index	.520	.000	59
% Elevated Lead	-.189	.110	59

Ave. Income/1000 = Average Income divided by 1000; Stability Index: A percentage derived by dividing the number of students who completed the entire school year by the number of students enrolled on Oct. 1st; % Elevated Lead = the percent with greater than or equal to 5 micrograms per deciliter blood lead; Students/FTE = Number of students per full time equivalent salary.

Table 8: Comparison of stratified linear models regressing average academic performance on Stability Index and various variables reflecting blood lead levels in a study of blood lead levels and academic performance in the Portland Public elementary schools, 2002.

Model	Variables	df	R^2	Sig	St Beta
1. Model with % Elevated Lead		59	.676	.000	
	Stability Index			.000	.457
	% Elevated Lead			.059	-.176
	Hi/Low			.116	-.150
	Low/Hi			.029	-.220
	Low/Low			.003	-.367
2. Model with Adjusted Lead Measure		59	.685	.000	
	Stability Index			.001	.389
	Adj. Lead Measure			.023	-.242
	Hi/Low			.088	-.161
	Low/Hi			.006	-.264
	Low/Low			.005	-.341
3. Main effects + Adjusted Lead Measure		59	.706	.000	
	Stability Index			.001	.368
	% Medicaid Eligible			.332	-.814
	% Elevated Lead			.065	-.214
	Adj. Lead Measure			.472	.629
	Hi/Low			.101	-.153
	Low/Hi			.016	-.243
	Low/Low			.014	-.314
4. Main effects		59	.703	.000	
	Stability Index			.001	.375
	% Medicaid Eligible			.033	-.216
	% Elevated Lead			.071	-.163
	Hi/Low			.101	-.152
	Low/Hi			.020	-.228
	Low/Low			.017	-.290
5. Model with % Medicaid Eligible		59	.684	.000	
	Stability Index			.001	.390
	% Medicaid Eligible			.027	-.228
	Hi/Low			.068	-.162
	Low/Hi			.004	-.276
	Low/Low			.003	-.360

R2= Coefficient of Determination; Sig = Significance; St Beta = Standardized Beta coefficient; df = degrees of freedom; Stability Index: A percentage derived by dividing the number of students who completed the entire school year by the number of students enrolled on Oct. 1st; % Elevated Lead = the percent with greater than or equal to 5 micrograms per deciliter blood lead; Hi/Low = High Percent White/Low Average_Income; Low/Hi = Low Percent White/High Average Income; Low/Low = Low Percent White/Low Average Income; Adj. Lead Measure = the percent of the total school population that is Medicaid eligible x the percent with greater than or equal to 5 micrograms per deciliter blood lead.

Table 9: Results of the linear regression model for average academic performance regressed on four strata of race/income, Stability Index, Adj. Lead Measure and (1-ME)(% pre60) in a study of blood lead levels and academic performance in the Portland Public elementary schools, 2002.

Variables entered	Standardized Beta Coefficient	Significance	Degrees of freedom
Stability Index	.434	.000	59
Adj. Lead Measure	-.005	.017	59
Hi/Hi	Referent	-	59
Hi/Low	-2.697	.087	59
Low/Hi	-4.712	.009	59
Low/Low	-4.011	.009	59
(1-ME)(%pre60)	-.075	.150	59

Stability Index: A percentage derived by dividing the number of students who completed the entire school year by the number of students enrolled on Oct. 1st;Hi/Hi = High Percent White/High Average Income; Hi/Low = High Percent White/Low Average Income; Low/Hi = Low Percent White/High Average Income; Low/Low = Low Percent White/Low Average Income; Adj. Lead Measure = the percent of the total school population that is Medicaid eligible x the percent with greater than or equal to 5 micrograms per deciliter blood lead; (1-ME)(%pre60) = Non-Medicaid eligible x percent living in housing built before 1960.

Table 10: Comparison of a linear regression of average academic performance on 4 strata of race/income and on Percent White and Average Income/1000 in a study of blood lead levels and academic performance in the Portland Public elementary schools, 2002.

Model	Variables	Beta	Sig	R^2	df
Stratified			.000	.519	59
	Hi/Hi	Referent			59
	Hi/Low	-6.057	.001		59
	Low/Hi	-9.039	.000		59
	Low/Low	-9.584	.000		59
Main Effects			.000	.500	59
	Percent White	14.634	.005		59
	AveInc/1000	3.90	.001		59

Beta = Beta coefficient; Sig = Significance; R^2= Coefficient of Determination; df = degrees of freedom; Hi/Hi = High Percent White/High Average Income; Hi/Low = High Percent White/Low Average Income Low/Hi = Low Percent White/High Average Income; Low/Low = Low Percent White/Low Average Income; AveInc/1000 = Average Income divided by 1000.

Table 11: Comparison of results from three models for linear regression of school level reading performance in a study of blood lead levels and academic performance in the Portland Public elementary schools, 2002.

Model	Variables	Beta	Sig	R^2
Adjusted Lead Measure			.000	.637
	Stability Index	.382	.003	
	Adjusted Lead Measure	-.003	.012	
	Hi/Hi	Referent		
	Hi/Low	-3.192	.073	
	Low/Hi	-4.549	.023	
	Low/Low	-3.788	.024	
Adjusted Lead Measure			.000	.669
plus main effects	Stability Index	.362	.004	
	Adjusted Lead Measure	.002	.846	
	% Medicaid Eligible	-.119	.637	
	Hi/Hi	Referent		
	Hi/Low	-2.975	.068	
	Low/Hi	-3.597	.080	
	Low/Low	-2.949	.091	
Main effects			.000	.669
	Stability Index	.408	.001	
	% Elevated Lead	-10.546	.332	
	% Medicaid Eligible	-.049	.085	
	Hi/Hi	Referent		
	Hi/Low	-2.168	.177	
	Low/Hi	-5.055	.008	
	Low/Low	-4.488	.005	

Sig = Significance; Beta = Beta coefficient; R^2 adjusted = the coefficient of determination; Stability Index: A percentage derived by dividing the number of students who completed the entire school year by the number of students enrolled on Oct. 1st; Adj. Lead Measure = the percent of the total school population that is Medicaid eligible x the percent with greater than or equal to 5 micrograms per deciliter blood lead; Hi/Hi = High Percent White/High Average Income; Hi/Low = High Percent White/Low Average Income; Low/Hi = Low Percent White/High Average Income; Low/Low = Low Percent White/Low Average Income; % Elevated Lead = the percent with greater than or equal to 5 micrograms per deciliter blood lead.

Table 12: Comparison of results from three models for linear regression of school level mathematics performance in a study of blood lead levels and academic performance in the Portland Public elementary schools, 2002.

Model	Variables	Beta	Sig	R^2
Adjusted Lead Measure			.000	.682
	Stability Index	.420	.000	
	Adjusted Lead Measure	-.002	.087	
	Hi/Hi	Referent		
	Hi/Low	-2.243	.163	
	Low/Hi	-5.30	.004	
	Low/Low	-4.48	.002	
Adjusted Lead Measure			.000	.697
plus main effects	Stability Index	.395	.001	
	Adjusted Lead Measure	.010	.243	
	% Medicaid Eligible	-.321	.173	
	Hi/Hi	Referent		
	Hi/Low	-2.190	.172	
	Low/Hi	-5.542	.005	
	Low/Low	-4.999	.003	
Main effects			.000	.689
	Stability Index	.364	.003	
	% Elevated Lead	-27.841	.018	
	% Medicaid Eligible	-.070	.021	
	Hi/Hi	Referent		
	Hi/Low	-2.972	.083	
	Low/Hi	-3.511	.077	

Sig = Significance; Beta = Beta coefficient; R^2 adjusted = the coefficient of determination; Stability Index: A percentage derived by dividing the number of students who completed the entire school year by the number of students enrolled on Oct. 1st; Adj. Lead Measure = the percent of the total school population that is Medicaid eligible x the percent with greater than or equal to 5 micrograms per deciliter blood lead; Hi/Hi = High Percent White/High Average Income; Hi/Low = High Percent White/Low Average Income; Low/Hi = Low Percent White/High Average Income; Low/Low = Low Percent White/Low Average Income; % Elevated Lead = the percent with greater than or equal to 5 micrograms per deciliter blood lead.