The Association between Elevated Blood Lead Levels and Reading Readiness in Kindergarten Children

By

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A dissertation submitted to Johns Hopkins University in conformity with the requirements for the degree of Doctor of Public Health

Baltimore, Maryland
February 2010

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Abstract

Background and Objective: Lead exposure effects on IQ are well known, and detrimental impact of lead exposure on reading, math and school progress have been described. We evaluated the relationship between blood lead levels (BLLs) and kindergarten reading readiness in a diverse urban school population.

Methods: School administrative data and Phonological Awareness and Literacy Screening Kindergarten (PALS-K) test scores, measures of kindergarten reading readiness, for children attending public school kindergarten in Providence, Rhode Island were linked to Department of Health BLLs. Children with at least one BLL and reading readiness scores in both the fall and spring were included in the study (N=3,406). Fifty-nine percent (59%) were Hispanic. Data were analyzed using multiple linear and logistic regression with progressive levels of adjustment.

Results: The median geometric mean (GM) BLL was 4.2 (IQR 2.9-6.0)μg/dL. In the fall, children whose BLLs were 5-9 and ≥10μg/dL were 1.44 and 2.51 times more likely to fail to achieve fall benchmark for reading readiness [OR 1.44 (95%CI 1.23,1.69) and OR 2.51 (95%CI 1.86, 3.40)] compared to children whose BLLs were 0-4μg/dL. Fall reading readiness scores were decreased by 4.5 and 10 points for children with BLLs in the 5-9 and 10+μg/dL categories, respectively, compared to children with BLLs 0-4μg/dL [-4.5 points (95%CI -6.2, -2.9) and -10.1 points (95%CI -13.3, -7.0)]. In the spring, children who had scored below the fall benchmark and who had GM BLLs ≥5μg/dL were approximately 1.5 times more likely to fail to achieve the benchmark compared to children with BLLs <5μg/dL. For children who achieved the fall benchmark, BLLs were not associated with an increased risk of failure in the spring.

Conclusions: Children who enter kindergarten with low levels of reading readiness and GM BLLs of >5μg/dL are at increased risk for failure to make adequate progress.

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Acknowledgments

The support and partnership of many individuals and organizations have been vital to my completion of this scholarly work. I am grateful for the support, guidance and encouragement of my advisor, Jackie Agnew, and the other members of my research committee, Ana Navas-Acien, Marie Diener-West, Toni Ungaretti, and Carolyn Fowler. Along with Madeleine Shea, these individuals also served as my dissertation readers and final examination committee. Special thanks to Ana Navas-Acien for her time and mentoring, including critical review of many early write-ups and to Marie Diener-West for her additional guidance with my data analyses. Many thanks to the Johns Hopkins Education and Resource Center staff and faculty, especially Jane Taylor, Keith Choi, Maureen Cadorette, Sheila Fitzgerald, and Mary Doyle, whose support, generosity, and kindness during my six-year stint helped me feel comfortable and welcome.

I would like to convey my deep appreciation to my three primary organizational partners, whose willingness to work together were crucial to my ability to conduct this research: the Rhode Island Department of Health, The Providence Plan, and the Providence Public School District. In particular, I am thankful for the following individuals who provided extraordinary moral and organizational support for this work over several years: Peter Simon, MD, Rhode Island Department of Health; Rebecca Lee, Jim Lucht, and Amy Pettine, The Providence Plan. Special thanks to the Providence Public Schools, in particular to Sandy Rainone, Abraham Williams, Lou DiPaola, and Sharon Contreras.

The opportunity to look at the relationship between blood lead levels and educational outcomes would not have been possible at all were it not for the "behind the scenes" individuals at Rhode Island Department of Health, Division of Community, Family Health and Equity: Magaly Angeloni, Bob Vanderslice, Daniela Quilliam and Anne Primeau-Faubert (Lead Team), Sam Viner Brown, Ellen Amore (KIDSNET Team); Bill Hollinshead, MD, Medical Director and Ana Novais, Executive Director. Many thanks to Beth Graziano, RN, VNA of Care New England, Kristene Campagna, Rhode Island Department of Health, and Donna Strobino, Johns Hopkins Bloomberg School of Public Health for their assistance in teaching me the importance of Rhode Island's Level One Birth Certificate Data.

Finally, the biggest thanks go to my husband, Alan McLaine, for his unfailing support during the long process of returning to graduate school and completing my dissertation. Our two sons, Joe and Mike, have encouraged me along this journey. I appreciate the thoughtfulness of many friends and colleagues who have regularly checked on my progress and offered words of encouragement, especially Rebecca Cohen, Anne Guilfoile, Michelle Bashin, Lori Edwards and Joanna Gaitens. For timely review and editing assistance during the home stretch, a big thank you to my sister Barbara Bowman.

My doctoral education and this research were supported (in part) by funding from the NIOSH Education and Research Center for Occupational Safety and Health at the Johns Hopkins Bloomberg School of Public Health (#T42-OH 008428). Portions of this study were supported by contract # 200-2006-15969-93 from the Centers for Disease Control and Prevention, U.S. Department of Health and Human Services.

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Commonly Used Abbreviations

BLL	blood lead level
CI	confidence interval
GM	geometric mean
KIDSNET	Rhode Island Department of Health's confidential, computerized child health information system, providing child-specific information from nine public health databases including blood lead test results, immunizations, and Early Intervention.
PALS-K	Phonological Awareness Literacy Screening Kindergarten test
PPSD	Providence Public Schools District
RIDH	Rhode Island Department of Health
SES	socioeconomic status

Chapter One - Introduction

1.1 Statement of the Problem

Lead exposure has been long associated with impairment of cognitive function in children, with effects on IQ, attention, executive function, language, memory, learning, and behavior [1-3]. A relatively few number of studies have associated lead exposure with decrements in academic performance, such as lower standardized reading and math test scores [3-6]. However, the association of lead exposure with reading readiness has not previously been described.

Lead hazard control and some primary prevention efforts have been associated with reduction in children's blood lead levels (BLLS) [7,8]. Nutritional [9-11] and pharmacological (e.g. succimer) [12,13] interventions alone, absent attempts to reduce environmental lead exposure, have been unsuccessful in reducing BLLs or improving cognitive outcomes [3] . There is no published literature concerning the success or failure of school-based educational interventions with lead exposed children.

Children's BLLs have fallen dramatically in recent years in the United States. National estimates for the period 1999 to 2004 have suggested that the average BLL for 1-5 year olds is 1.9 μg/dL and the average prevalence of elevated BLLs (≥10μg/dL) for U.S. children aged 1-5 is 1.4% [14]. But BLLs have remained higher among non-Hispanic Black children and children from low income families, with average BLLs of 2.8μg/dL and 2.4μg/dL, respectively [14]. In Providence, Rhode Island, however, 13.7% of children screened during the same 1999 through 2004 period had BLLs ≥10μg/dL, nearly

10 times the national average [15,16]. In addition, the Rhode Island Department of Health (RIDH) estimated that 10.8%, 9.8% and 8.4% of children who would enter kindergarten in the years 2004, 2005 and 2006, respectively, had a history of a confirmed BLL $\geq 10\mu g/dL$ [15].

Despite many published reports concerning the effect of lead on children's IQ, many elementary educators do not associate school performance problems with earlier environmental lead exposures. Although a number of states require BLL testing prior to school entrance, many states, including Rhode Island, only require reporting of a date (not the result) of blood lead testing [17]. Consequently, at school entrance, educators rarely know much about an individual student's history of lead exposure unless that student has already been identified for special education as a result of high BLLs. Because most health and education departments do not share data or have an interest in using linked data, these relationships are hidden.

In Providence, most children are tested for lead exposure multiple times prior to kindergarten, and complete BLL test results are reported by laboratories to the RIDH's Lead Elimination Surveillance System. In Rhode Island, these data are linked together with other child health information from nine separate RIDH programs, and maintained in a database known as KIDSNET, a centralized registry that is available on-line to public and private health care providers [18].

Each child attending public school in Providence, Rhode Island undergoes a reading readiness evaluation in the fall and spring of kindergarten. From the 2003-2004 school year until recently, the Providence Public Schools District (PPSD) employed the well-standardized Phonological Awareness Literacy Screening Kindergarten (PALS-K) test [19] to conduct this evaluation. Children who did not meet the national benchmark in the fall received regular in-class educational interventions during kindergarten to improve their reading skills.

The existence of both BLL and educational data for a population of kindergarten children presented a unique opportunity for us to evaluate the associations between children's exposure to lead, measured by BLL test results and reading readiness in kindergarten, measured by the PALS-K.

The Providence Plan, a community data provider with a long-time interest in school readiness, had the capacity and interest in linking health and education data records for this study. But the feasibility for this research was based on long-standing relationships between public and private sector organizations and individuals who have made data sharing a priority in Rhode Island.

1.2 Research Questions

In partnership with the Rhode Island Department of Health and Providence Plan we were able to pursue the following important research questions:

- Are pre-kindergarten BLLs associated with reading readiness, measured by PALS-K test, in the fall of kindergarten?
    - Hypothesis 1: Children with higher BLLs will have lower fall reading readiness (PALS-K) scores
    - Hypothesis 2: Children with higher BLLs will have a higher likelihood of failure to achieve national benchmark standards in the fall
- Are pre-kindergarten BLLs associated with improvement in reading readiness (PALS-K score) from fall to spring in: (1) children who achieved national PALS-K benchmark standards in the fall (received no intervention); and in (2) children who did not achieve the national PALS-K benchmark standards (received educational intervention)?
    - Hypothesis 3: Among children who achieved national PALS-K benchmark standards in the fall, lower pre-kindergarten BLLs are associated with greater improvement in reading readiness (PALS-K score) from fall to spring.
    - Hypothesis 4: Among children who did **not** achieve national PALS-K benchmark standards in the fall and thus received intervention, pre-kindergarten BLLs are not associated with improvement in reading readiness (PALS-K score) from fall to spring.

1.3 Organization of the Dissertation

This dissertation is arranged in the following chapters, followed by a short synopsis of what you will read in each:

Chapter One - Introduction (this section)

Chapter Two – Background: a critical review of existing literature for lead exposure and blood lead measurement, lead and cognitive outcomes, including school performance, studies of enriched and nurturing environments, and reading readiness.

Chapter Three – Methods: a detailed review of methods used for this dissertation, including description of enrollment of the study population, description of the four databases used for this study (school enrollment data; PALS-K test results, our outcome measure of reading readiness; blood lead screening results, our measure of lead exposure; and birth data), details on data linkage, and an overview of data analysis.

Chapter Four – First Manuscript: addresses the association of BLLs and reading readiness in the fall of kindergarten.

Chapter Five – Second manuscript: addresses the association of BLLs and reading readiness in the spring of kindergarten.

Chapter Six – Discussion: summarizes important findings from the two papers, including public health implications of this work.

Chapter Seven – Conclusion: summarizes conclusions for the two papers.

Chapter Two – Background

Unlike many other metals, lead is not required for any known biological function. However, it affects nearly every system in the body, including the hemopoietic, cardio-vascular, nervous, kidney and urinary, gastro-intestinal, skeletal, and reproductive systems [3]. Adverse effects of lead on the central nervous system and cognitive function are well known, and include IQ, attention, executive functioning, language, memory and learning, and behavior [1,2]. However, relatively few studies have focused on the relationship between lead exposure and early school measures [3]. Specifically, the association between lead and reading readiness has not been described.

2.1 Sources of Environmental Lead

In the United States, the most important sources of environmental lead exposure for children are non-intact household paint, dust and soil, typically in and around older housing. Beginning in the 1800s, lead was used extensively in paint. Older housing is more likely to contain lead-based paint of higher lead concentration. Although manufacturers voluntarily reduced lead levels in paint in the early 1950s, federal law lowered the amount of lead allowable in paint to 1% in 1971 and 0.06% in 1977[20]. A national study of U.S. homes conducted in 1998-2000 found that 68% of homes built before 1940 and 43% of homes built between 1940 and 1959 contained significant lead-based paint hazards [21]. Leaded gasoline additives represented a significant source of exposure in the United States beginning in the 1920s until the phase-out of leaded gasoline that occurred between 1976 and 1996. Lead in gasoline in the United States was completely banned by the U.S. Environmental Protection Agency (EPA) as of February 1996 [20].

Lead dust exposures can be very high in deteriorated, poorly maintained older housing and in older homes undergoing home renovation or remodeling [22]. Urban soils may be highly contaminated from years of deposition of lead from vehicle exhaust when leaded gasoline was in use, as well as from deterioration of exterior lead-based paint [23]. Children may also be exposed to lead in take-home occupational exposures, traditional ethnic remedies and consumer products, water and food. Because it is malleable and highly resistant to corrosion, lead is currently used in more than 100 industries in the United States and in a large variety of consumer products [20]. Imported toys and children's jewelry have been found to contain enough lead to kill a child [24,25], and current regulation by Consumer Product Safety Commission is thought to be inadequate. CDC has reported that up to 35% of children living in some jurisdictions who were identified with elevated BLLs have been exposed to lead in consumer products [26]. The increase in the number and availability of such products has spurred interest in identifying and eliminating [26] or banning nonessential uses of lead and reducing levels of lead in air, dust, soil, water and consumer products to prevent exposure[27,28]. Federal standards have been set for environmental lead exposures, which have typically been measured in dust [29], residential soil [29], ambient air [30], water [20], food [31], and paint and consumer products [32]. Within the U.S. population, disparities in exposure by race, poverty, gender and age of housing have been clearly documented [14,33-35].

In children, inorganic lead typically enters the body through ingestion of lead dust and/or soil [3]. Exposure to interior dust and paint usually increases during early childhood as children begin to explore their home environment and as normal hand-to-mouth behavior increases. Exposures to soil and exterior paint often increase at about three years of age, when children spend more time outdoors and on porches. Typical average daily lead intake for children has been estimated at 29.2μg/day, 8.4μg/day directly from food [36]. Up to 50% of lead may be absorbed in the gastrointestinal tract, and absorption is increased when a child's diet is low in iron, calcium, phosphorus or zinc [37,38].

2.2 Lead Exposure in Providence, Rhode Island

Children in Providence, Rhode Island are at particular risk for lead exposure and lead toxicity as a result of older housing stock and poverty. According to the 2000 Census, approximately 59% of the housing stock in Providence was built before 1950 and is very likely to contain lead-based paint [39]. Nearly all of the properties listed on Rhode Island's Highest Risk (for lead) Premises List [40] and Properties with Multiple (Lead) Poisonings Public Lists [41] are in Providence. Poverty rates are high: in 2003, Providence had the lowest median household income ($26,867) [42] and the second highest rent burden (33.5% of income) in Rhode Island [42]. In 2004, Providence had the third highest poverty rate in the United States among cities with population of at least 100,000 [43], with one in four children living in poverty [43]. The gap between wealth and poverty is estimated to be one of the widest in the nation [43]. In 2006, the Providence Public Schools enrolled 81.2% of children living in Providence, approximately 75% of whom were eligible for free or reduced-price school lunches [44].

2.3 Biological Measures of Lead Exposure

After absorption, lead is distributed to other tissues via the bloodstream, where it accumulates in the blood, soft tissues and target organs, and bone. Blood lead is in a dynamic equilibrium with lead levels in bone and target organ tissues [20]. In children's bodies, approximately 72% of lead is accumulated in bone - primarily in trabecular bone, which undergoes calcification [45]. Turnover of bone mineral is estimated to be much more rapid in children compared to adults [45]. However, the biological half-life of lead in bone is estimated to be at least 10 years [37], and excretion is slow. Lead can remain in bone throughout the lifetime, serving as an internal source of lead and presenting potential problems during periods of bone turn-overs (such as pregnancy, lactation, healing a broken bone, menopause, chemotherapy, tumor infiltration of the bone, osteoporosis, or periods of illness and inactivity) [46-50]. Bone lead is considered to be the biomarker of long-term, cumulative lead dose as well as an endogenous source of lead that can be re-mobilized into circulation [51]. Bone lead measurement using K-shell XRF has been used in research but is impractical for surveillance or medical management. Accumulation in the liver accounts for up to one-third of the lead stored in the soft tissue/target organ compartment [3] Dentin tooth lead from shed deciduous teeth was used in landmark research studies [52] and is also considered to be a biomarker of cumulative lead exposure [3,53] , but has not been used for surveillance.

Blood lead level (BLL), expressed in μg/dL, remains the principal biomarker for exposure in young children and the measure of exposure used by health care professionals. Changes in BLLs occur as a result of change in exposure to both external and internal (endogenous) sources. Even after an abrupt end to environmental lead exposure it may take a very long time to see decreases in children's BLLs if large amounts of lead have been accumulated in bone. One study estimated that it took 6.5 months to three years for BLL to decrease from 7 to 5μg/dL [54].

2.4 Blood Lead Surveillance

Average BLL (95%CI) for the U.S. population of 1-5 year-old children between 1999 and 2004 was 1.9 (1.8-2.0), with higher average BLLs of 2.8 (95%CI=2.5-3.0) for blacks and 1.9 (1.7-2.0) for Mexican Americans, compared to whites 1.7 (1.6-1.8) [14]. Children's BLLs have fallen dramatically over time in the United States, but children living in urban areas remain at higher risk for elevated BLLs. Between 1999 and 2004, approximately 13.7% of children screened in Providence, Rhode Island had BLLs ≥10μg/dL [15,16], compared to NHANES' estimate of 1.4% for 1-5 year-olds nation-wide [14].

The CDC now recommends BLL testing at 12 and 24 months of age for all children regardless of health care insurance status who live in older housing (built before 1950) or who belong to a potentially exposed population group, based on state-specific screening plans [55,56]. Only about one-third of U.S. children less than 6 years of age have been screened (33.3%, 95% CI 29.1-37.7%) [14]. Rhode Island recommends screening annually for children less than 6 years of age and estimates that about 70% of children are tested at least once by 18 months of age [57].

In 1991, the Centers for Disease Control and Prevention (CDC) established a BLL $\geq$ 10μg/dL as a "blood lead level (BLL) of concern" in order to trigger prevention efforts in communities [26]. Eliminating BLLs $\geq$10μg/dL is a national 2010 health objective [58].

2.5 The Link between Lead Exposure and School Performance

Early observations of behavioral problems in school children with lead exposure noted lack of impulse control and distractibility [59-61]. A large body of epidemiological literature, including more than 10 prospective and 30 cross-sectional studies, has confirmed the early observations and has consistently found dose-response associations of lead with decreased measures of intelligence (IQ) [3,62]. At the population level, lead exposure has been associated with a leftward shift of the population IQ distribution [52]. Adjustment for effect modifiers and confounders has typically decreased but not eliminated the estimated magnitude of the lead-IQ relationship. A recent meta-analysis found that more than half of an estimated 6.4 IQ point loss associated with an increase in BLL from 2.4 to 30μg/dL could be attributed to the increase in BLL from 2.4 to 10μg/dL and suggested that there appeared to be no evidence of a threshold BLL below which cognitive effects do not occur [1]. The effect of lead on learning and cognition, particularly at lower BLLs, therefore remains a critical concern.

A number of researchers have suggested that socioeconomic status (SES) is an effect modifier of the relationship between lead and cognition [63-65]. Because lead accounts for a relatively small amount of variation in cognitive outcomes, several researchers have suggested that social and parenting factors, many associated with higher SES status

[63,66-68], are more important from the standpoint of causality as well as intervention [68]. However, school and community based intervention studies that have focused on improving parenting skills or children's literacy have not addressed BLL.

Cognitive effects impact school performance, and dose-response effects have been reported between lead and measures of teacher ratings, vocabulary and school performance [1,52,69-71]. Lead levels as small as 2μg/dL have been associated with a significant decline in standardized reading test scores, in both a national cross-sectional health study [4] and in a two cohort studies in North Carolina, using linked blood lead results from the state registry and end-of-grade reading test scores for 3rd and 4th graders[5,6]. In North Carolina, Miranda and colleagues demonstrated differences in blood lead distribution between Black and White children, showing increased proportions of Blacks with higher BLL compared to Whites [5], consistent with national prevalence studies [14]. The size of the effect of lead exposure on reading score was found to be larger at lower levels of reading scores [6]. Increased lead exposure has been associated with failure to read at grade level [69], failure to graduate from high school [70,71], and delinquency [72,73]. Among children exposed to lead, the failure to achieve in school may independently increase the likelihood of delinquency [72].

2.6 Studies of Enriched/Nurturing Environments

Studies have shown improvements in learning capacity for lead-exposed rats when placed in enriched environments (cages with toys, exercise wheels, and other rats). Animal behavioral changes seen with enrichment include enhancement of memory and learning, reduction in memory decline in aging animals, decreased anxiety and increased exploratory activity [74]. These behavior changes have been attributed to changes at the biochemical, cellular, and organ levels, particularly in the hippocampus [74] and associated with changes in brain size and weight, brain structures (including the hippocampus and the cortex) and brain function (including increases in neurons and new neurocircuitry, improvement of neuronal signaling processes and promotion of synaptic plasticity) [75]. Increased motor activity alone has also been shown to improve learning [74] and central nervous system changes that support learning [75], and may be a particularly important component of the enriched environment. Environmental enrichment can be effective regardless of when it is initiated, but exposure to the enriched environment must be on-going in order for animals to show benefits in cognition [76]. Based on these findings, Guilarte and colleagues have suggested that environmental enrichment might be considered as the basis for treatment of children with lead exposure [77].

Factors that could be considered elements of an enriched human environment and have been positively associated with cognition include: income, number of books in the home, parents' education, early childhood education, and relationships between parents and children. Alternatively, children exposed to poorly enriched and stressful environments, including abused and neglected children [78], adopted children previously housed in orphanages [79], and children with depressed mothers [80], have been shown to have deficits in intellectual, academic and cognitive functioning. Such deficits have been shown to be associated with observed physiologic findings such as MRI abnormalities

[81], increased stress hormones [80], and reduced hippocampal volume [78]. According to Sameroff, independent of SES, maternal IQ and race, the total number of social and family risk factors to which a child is exposed could explain one-third to one-half of the variance in IQ at four (4) and 13 years of age [82]. A recent review suggests that the enriched environment is an environmental modulator of brain pathogenesis in humans [75].

A number of protective factors have been identified that also improve cognitive and social behavioral outcomes in children who are at risk for social and cognitive effects of non-nurturing environments. These include the degree of cognitive control [83], maternal use of more sophisticated teaching strategies in children aged 4, increased social support, fewer disruptive life events, and mothers who valued self-direction and less conforming behavior, and had more social support (e.g., a confidante) for young teens [78]. These protective factors appear to benefit children in non-nurturing environments, but not those in nurturing environments [84].

2.7 School Readiness

In the United States, school readiness is a national problem. An estimated 25% of American children enter kindergarten deficient in basic literacy skills that are necessary for them to succeed in school; the percentage is higher in large urban areas with a large percentage of disadvantaged children [85]. The gap in standardized test scores of school readiness for ethnic and racial minorities is estimated to range from just below one-half to just above one standard deviation [86]. By 12^{th} grade, the gap in educational performance shows significant disparities by race/ethnicity for academic achievement and the proportion who graduate from high school [87,88].

A large body of research has demonstrated the importance of early identification and intervention in preventing reading disabilities [89]. The cost of remedial or special education for children who are unable to read by 2^{nd} grade is estimated to be more than three times higher than the cost of early intervention in pre-school or kindergarten [90]. The success of educational intervention is considered to be much higher in early grades (82%) compared to grades 3-5 (46%) or later grades (10-15%) [91]. The National Academy of Sciences has identified the importance of the early childhood period in terms of the development of the brain, neurological system and human behavior, and the importance of using targeted interventions at an early age to enable children to develop their full capacities and improve the likelihood of positive developmental outcomes [92].

Learning to read is a critical step in the process of formal education. Reading ability has been associated with school performance in higher grades [93]. Many researchers suggest that children who have not learned to read by the time they reach third grade will face a lifetime of struggle trying to learn in an educational system that requires grade-level reading proficiency [94,95]. In 4th grade, children whose reading skills are not adequate will have difficulty at the critical transition from "learning to read" to "reading to learn" [96]. All public elementary and secondary schools are mandated to track school success by the Federal No Child Left Behind Act of 2001 [97], increasing state and local initiatives to address continuing problems.[a] Therefore, there is great interest among educators in how to successfully intervene early with children at highest risk for school and reading failure. The goal of many early education initiatives, in pre-school and kindergarten, is to close the gap using assessment and intervention programs, often targeting geographic areas at highest risk [98]. Many tools used to assess children's development of early literacy skills are used for screening, diagnostic and evaluation purposes. Most are criterion-referenced (rather than standardized or norm-referenced) instruments, because the goal of screening is to determine if the student's level of performance meets a set level of performance or benchmark. The Phonological Awareness Literacy Screening Kindergarten (PALS-K) screening test is one such instrument [99].

However, screening tools for early intervention programs, which target children from birth to age 5, currently do not correctly identify all children who are at-risk for failure to read [100]. The current system appears to result in a relatively high rate of false negatives, meaning that children who could benefit from early intervention services are designated as "negative," not provided with services, and later begin kindergarten at very low levels of readiness, a problem of concern to educators [89].

Educators suggest that the differences in health status and health behaviors of children and their mothers (including asthma, Attention Deficit Hyperactivity Disorder (ADHD),

[a] The No Child Left Behind (NCLB) Act, Public Law PL 107-110, requires states to measure their student's educational progress annually using standardized tests. States are evaluated on progress made by their students. Schools receiving Federal Title 1 funding must make "Adequate Yearly Progress" (AYP), measured by improvement on standardized test scores.

lead poisoning, maternal depression and breast feeding) together account for up to one-quarter of the difference in school readiness between Blacks and Whites [101]. Within urban school districts with a large proportion of poor children living in older, deteriorated housing, the impact of lead on school readiness may be much larger than these estimates suggest. The gap in school readiness may also increase if there are racial differences in the distribution of other environmental hazards that affect cognition [101], such as nicotine, mercury, PCBs, or manganese [102].

Learning to read successfully requires a child to be proficient in phonological processing skills (skills based on using the sounds of one's language to process written and oral language) [103] and to be able to decode non-words. The lack of such skills, not IQ deficits (assuming at least low-average intelligence), has been identified as a cause of failure to develop basic reading skills [78,104]. SES also appears to modulate the relationship between phonological awareness and reading. Children with high levels of phonological awareness read well, regardless of SES. But at low levels of phonological awareness, children from higher SES backgrounds read much better than children from lower SES backgrounds [78,105].

Deficits in three domain-specific cognitive areas are thought to be associated with reading disability: (1) having an understanding of the relationship between speech-sound structure and written language, known as linguistic awareness or phenome awareness; (2) being able to encode information into working memory; and (3) being able to retrieve information from long-term memory [104]. Among these, phoneme awareness has been identified as especially important. Studies of the relative effectiveness of various instructional methods that focus on these domains have informed the development of interventions and programs for at-risk children. While school-based intervention studies have been limited in size and duration of follow-up, several have demonstrated positive relationships between programs and short-term cognitive outcomes [106,107]. Instructional methods focused on decoding and phonological awareness have been shown to be the most effective for young children. Successful programs for at-risk children have provided explicit teaching of the alphabetic code, taught reading and spelling together, provided intensive reading instruction and large amounts of practice using connected materials and texts and ensured that the children continued to read even when school was not in session [104,108]. Successful intervention programs in Virginia provided in conjunction with the Phonological Awareness Literacy Screening Kindergarten (PALS-K) screening included many of these strategies [19,109].

We had an opportunity to study the association between lead exposure and kindergarten reading readiness in a diverse urban population with excellent records of high quality for lead exposure and reading readiness that included comprehensive population data. This study explores the association between children's blood lead (BLL) test results and standardized assessments of reading readiness during kindergarten, measured by the Phonological Awareness Literacy Screening Kindergarten (PALS-K) test [19], in the fall and spring of kindergarten, using linked data from Rhode Island's Lead Elimination Surveillance System, Rhode Island Health Department's birth record information and the Providence Public School District (PPSD) for three school years (2004-2005, 2005-2006 and 2006-2007).

Chapter Three - Methods

3.1 Overview

This population study used linked data from children's health records, including blood lead levels (BLLs) collected prior to kindergarten, and school kindergarten records to examine associations between lead exposure and reading readiness in the fall and spring of kindergarten. The Institutional Review Board of the Johns Hopkins Bloomberg School of Public Health reviewed our proposal and determined that this research was exempt from review. Records were obtained for 5,240 children who were enrolled in kindergarten in Providence, Rhode Island Public Schools during three school years (2004-2005, 2005-2006 and 2006-2007). Two datasets were provided by the Providence Public School District (PPSD): school enrollment data and Phonological Awareness Literacy Screening-Kindergarten (PALS-K) test results. Two datasets were provided by the Rhode Island Department of Health (RIDH): blood lead screening data and data routinely collected at the time of birth, which will be referred to as birth data. After data from these four data sets were linked and de-identified, we examined the associations between pre-kindergarten BLLs and measures of kindergarten reading readiness, based on the PALS-K test, while controlling for covariates such as race, language, age and socioeconomic status (SES), measured by free and reduced lunch status.

3.2 Study Population

Figure 3.1 shows how children were selected for enrollment into the study. Our base population for this study consisted of children who were enrolled in kindergarten in Providence Public Schools during the three year study period (N=5,240). A total of 644 of these children had no lead test results, were determined to have repeated kindergarten (N=74) or had been miscoded as kindergarten (N=29), thus were excluded. Of the remaining 4,493 first time kindergarten children, children who did not have any PALS-K test results (466) were excluded. Children with only fall (N=190) or only spring (N=182) PALS-K scores were also excluded. This left a total of 3,655 first time enrolled kindergarten children with enrollment data, fall and spring PALS-K scores and blood lead measurements.

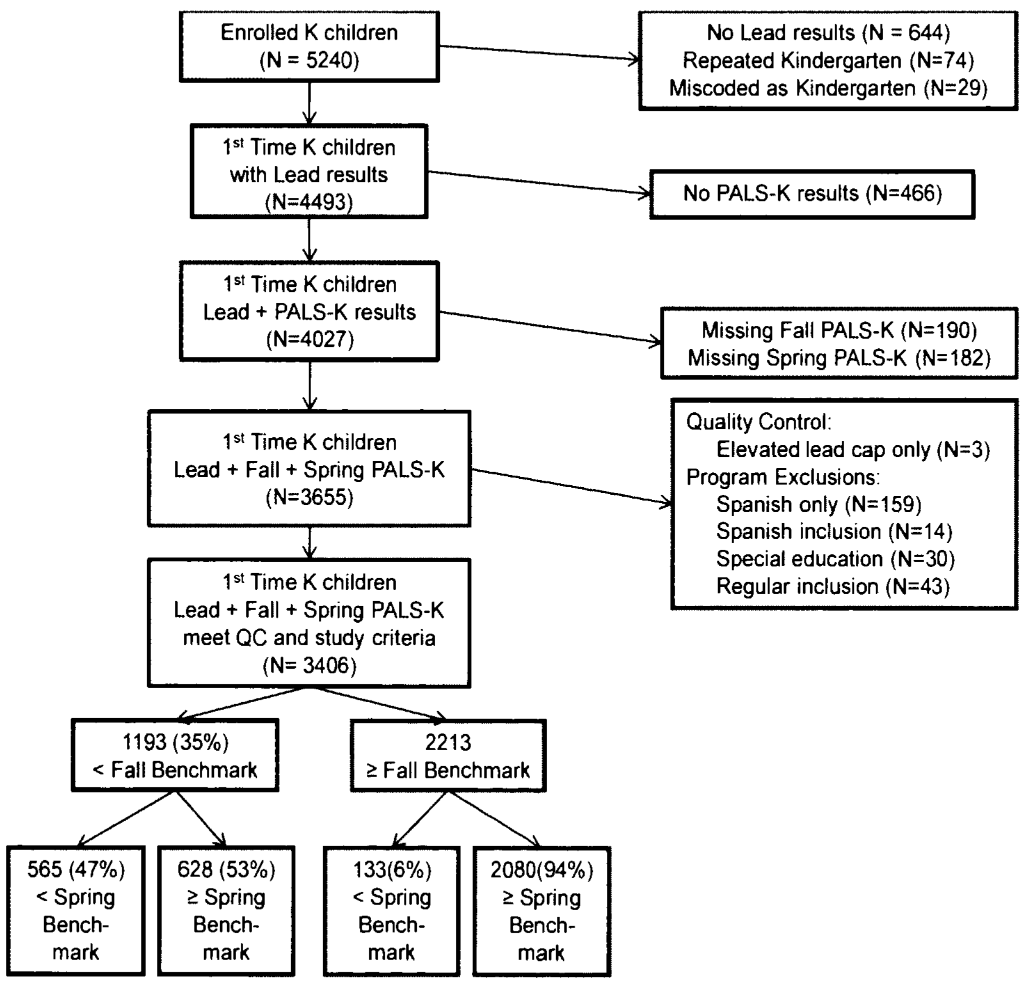

Figure 3.1: Study Enrollment

Based on quality control investigations, we excluded children whose only lead measurement was an elevated capillary BLL (n=3). We restricted our analysis to children who were taught in English (referred to as the Regular Education and English as a Second Language Programs) or in English and Spanish (the Dual Language Program). We therefore excluded children taught only in Spanish (N=173), including 14 inclusion[b] students. We also excluded children who otherwise met enrollment criteria but were enrolled in special education classes (N=30) or were inclusion students in regular education classrooms (N= 43).

3.3 Demographic and School Data

Enrollment data from PPSD served as the base file for this evaluation. This consisted of demographic data collected at the time of the child's registration for school, verified by school officials, and entered directly into the PPSD electronic system. Individual enrollment information used only to link records for this study (described below) included student name and school ID number. Our data set used for analysis also included individual child information such as date of birth, sex, birth place, race and language.

We received very rich data on languages spoken in the home, including child's first language, child's language, adult's language, usual language spoken in the home and a list of all languages spoken in the home. We used only the variable for the child's language in our analyses. Results for race, language, and place of birth were collapsed

[b] Inclusion students are special education students with an Individualized Educational Plan (IEP) who are able to benefit from receiving instruction in a regular classroom, rather than a special education classroom.

into categories for the purpose of descriptive and other analyses. Asian languages made up 80% of those included in the "other" languages category. With regard to race, Asian ethnicities made up 92% of those classified as "other."

The child's status as a participant in the Federal free and reduced-price school lunch program [110] served as our variable for SES. Children qualify for a free or reduced price lunch based on family income; children from families with incomes at or below 130% of the national poverty level are eligible for free school lunch. Children from families with incomes between 130 and 185% of this level are eligible for reduced price meals. Children from families with incomes above 185% of the national poverty level pay for their lunch [110]. Free and reduced lunch status is a typical measure of socio economic status used for educational research. Information on free and reduced lunch status received from PPSD was initially missing for 15% of children who did have lead data (N=670/4596). By linking to other city and state records, Providence Plan was able to identify free/reduced lunch status information for more than 99% of children, including all children in the final analyses (n=3406).

School level data included: child's elementary school (N=25); child's kindergarten program (N=3, described above); and whether the school received additional funding for reading from the Federal Reading First program [111]. Reading First is a Federally-funded program, administered by the states and focused on making sure that all children learn to read well by the end of third grade. Schools have qualified on the basis of need (poor student achievement and poverty) and a competitive grant process. In Rhode

Island, funds were awarded in January 2004 to eight Providence elementary schools for Reading First programs during all three years of this study and in February 2006 to one additional school for a Reading First program during the last year of this study [112]. Our study included 891 students in Reading First schools.

3.4 PALS-K Tests and Databases

The PALS-K test, developed at the University of Virginia, is a screening, diagnostic and evaluation tool used to assess children's development of early literacy skills [113]. PALS-K is a criterion-referenced[c] assessment [99]; few standardized, or norm-referenced,[d] instruments are available to evaluate children's early literacy performance [114]. PALS-K has been used as the universal screening tool in the state of Virginia since 1997, in all 50 US states, and in six other countries [115].

The test is administered individually and in small groups in English by kindergarten teachers, usually in both fall and spring of kindergarten [113]. The PALS-K fall test is used as a screening and diagnostic test to identify children who need early literacy intervention and to assist the teacher in developing and choosing appropriate classroom strategies to address deficiencies. The test is usually given in early October, close to the start of school. Scores are recorded by classroom teachers, and logged into an internet database. Teacher data entry has been evaluated and found to be 99.1% accurate [19]. A child's total fall score is evaluated against a national benchmark score. Total fall scores

[c] **Criterion-referenced**: "An assessment in which a student's response(s) is compared to a pre-established level of performance in an area of knowledge or skill, rather than to a group of children or normative group. Results are typically reported as levels of proficiency, such as emerging skill level or mastery level." [134]
[d] **Norm-referenced**: A standardized instrument by which a student's performance is interpreted in relation to the that of a group of peers who have previously taken the same test [134].

less than 28/102 points are considered to be "below benchmark." Students who scored below the fall benchmark received additional in-classroom instruction on a regular basis, focused on the areas of deficiency in specific cognitive elements (or sub-tests), for the duration of the school year. In the late spring, children were tested again with the PALS-K test to measure improvement that had occurred in reading readiness throughout the kindergarten year and to determine the effectiveness of the additional instruction provided to individual children who scored below benchmark in the fall. Success at the end of kindergarten was based on a child achieving the spring benchmark (at least 81/102 points) [19].

The cognitive elements examined by the PALS-K test are decoding, cipher knowledge, letter knowledge, concepts about print, and phonological awareness [99].[c] The PALS-K test has six subtests, scored separately: rhyme awareness, beginning sound awareness, alphabet knowledge, letter sounds, spelling, and concept of word. Fall and spring benchmark standards, initially developed and validated in the population of Virginia students, have been established for each of the six sub-tests and for the total score of all sub-tests. The fall and spring PALS-K total scores are compiled by summing results of the six tasks, and compared to national benchmarks established for both scores [19] as shown in Table 3.1 (below):

[c] Definitions for the five elements are as follows: **decoding** - "a child's ability to recognize and process written information"; **cipher knowledge** - a child's ability to sound out regular words never seen before, based on sounds associated with letters in those words; **letter knowledge** - a child's ability to identify letters of the alphabet, both lower and upper case, and discriminate between letters that look alike; **concepts about print** - a child's understanding that text represents individual words, is read from left to right, top to bottom, and front to back in books; and **phonological awareness** or a child's awareness that words are made up of sounds and syllables, that words rhyme, that letters at the beginning of words have a similar sound, etc. [94].

Table 3.1: PALS-K Summed Score Tasks and Benchmarks [19]

Task (maximum)	Fall Benchmark	Spring Benchmark
Rhyme Awareness (10)	5	9
Beginning Sounds (10)	5	9
Alphabet Recognition (26)	12	24
Letter Sounds (26)	4	20
Spelling (20)	2	12
Concept of Word: Word List (10)	0	7
Summed Score (102)	**28**	**81**

Benchmarks were set by a formal standard-setting process that included reviews by panels of Virginia and US reading experts [113]. In Virginia in 2004-2005, mean total scores (standard deviation) for fall were 16.61 (6.96) for the group of children who did not meet benchmark standards and 60.50 (19.39) for the group of children who did [113]. On average, about 20% of Virginia students fail to achieve PALS-K benchmarks in the fall of kindergarten [113] compared to 35% of students enrolled in Providence Public Schools during the time of our study. However, there are substantial differences between the Virginia population and the population studied here.

Reliability and validity measures for the PALS-K have been evaluated annually since 1997. The PALS-K instrument was extensively field tested in Virginia across race/ethnicity, gender, and socioeconomic status, and found to provide valid and reliable measures of kindergarten readiness [113]. One study reported that average fall and spring PALS-K scores for Hispanic kindergarten students were both below national benchmarks, but their improvement from fall to spring was similar to the difference between national benchmark scores (e.g. 81-28 = 53 points). This study also reported that PALS-K scores for Hispanic students were associated with father's level of education, the child's length of residence in the US, and the child's pre-school educational experience [116]. The PALS-K testing for this study was conducted in English; a Spanish version is currently undergoing field testing [117].

PALS-K records from PPSD were available for 4,668 kindergarten children (89% of total enrolled), including 571 with no blood lead test information. Of the 4,097 enrolled children with PALS-K results and at least one blood lead test, 3711 (90%) had both fall and spring results reported. For quality control, we examined sub-test scores for children with the lowest fall and spring total scores and the lowest and highest fall to spring change scores. We found 87 discrepancies (18 for fall total score, 69 for spring total score) in score computation and corrected them using PALS-K scoring protocol [19]. We calculated the difference in PALS-K scores from fall to spring for each individual.

3.5 Blood Lead Screening Data

RIDH recommends annual testing for children, beginning at 9 months of age until 6 years (72 months) of age [118,119]. In Rhode Island, children are tested for lead exposure by their primary care providers, and the results of the blood lead tests are sent by analyzing laboratories to the RIDH's Lead Elimination Surveillance System (LESS). Two high quality, Clinical Laboratory Improvement Amendments (CLIA) approved laboratories, both with limits of detection for lead of 1 µg/dL, performed about 80% of the blood lead measurements reported to LESS during 1999-2005 [120]. A total of 15,320 blood lead values were available for 4,596 children, 88% of children enrolled in the three kindergarten cohorts. Our final dataset consisted of 11,196 blood lead values and the 3,406 children were tested on average three times prior to kindergarten (mean 3.2, SD 2.0, range 1-26). Data consisted of the BLL in whole integers in μg/dL, the type of test (venous or capillary/finger stick), the date the sample was drawn, and the name of the health care provider. Child address information at the time of the test was not available.

Nearly all samples were coded as venous (n=15,326) or capillary (n=1,212). Test results not coded for sample type (n=11) were determined to most likely be venous samples and were retained in analyses. The values of 206 (17%) of the blood lead capillary results were greater than or equal to 10μg/dL, the level above which a blood lead value would be considered to be "elevated" and by CDC recommendation[55] and RIDH protocol[119] should be repeated with a venous blood lead test. We found that the extent of confirmatory testing within a three month period varied with BLL: 93% for BLLs 20μg/dL and higher, 58% for BLLs 15-19μg/dL and 33% for BLLs 10-14μg/dL. However, confirmation of the capillary measurement was poor: 12% of BLLs 20μg/dL and higher, 30% of BLLs 15-19μg/dL and 33% of BLLs 10-14μg/dL. Therefore, we removed all capillary BLLs ≥10μg/dL from the dataset, resulting in the removal of three children who had no other BLL reported.

BLL measurements initially reported as "below the minimal detection limit (MDL)" (N=553) varied across laboratories, between 1 and 5μg/dL. RIDH was able to identify the reporting laboratory for 546 measurements. We determined that the seven (7) other results were most likely tested at a lab with MDL of 1µg/dL. We assigned new blood lead values to all 553 BLLs using their respective laboratory MDL/square root of 2, in accordance with *Third National Report on Human Exposure to Environmental Chemicals 2005* (CDC) [121].

We examined four measures of blood lead for this study: (1) a geometric mean (GM) BLLfor each child using his/her individual lead test results (N=3,406); (2) the child's highest BLL at lowest age (N=3,406); (3) a time weighted average BLL for children with two or more BLLs (N=2,830); and (4) an average "5-year old" BLL, for children with one or more BLLs obtained when the child was 52 months of age or older (N=1,276). We compared results of linear regression models using the first three measures of blood lead and found them to be very similar. We used geometric mean BLL value for our analysis because it was available for the largest number of children and represents a better measure of <u>average</u> lead exposure than the child's highest BLL at lowest age (measure 2). We found very similar results for the "5 year old" blood lead measure, but the geometric mean measure was available for twice as many children. We log transformed each child's GM BLL in order to examine the effect of a doubling of log GM BLL, reflecting the log-linear relationship of BLL with our outcome measures.

We explored the benefits of using linear, quartile, frequently used categories, and refined categories in the analysis. Other studies [4-6] have reported that the change in the BLL-reading score relationship is not linear. Miranda [5] employed individual BLL dummy variables in order to provide additional insight into the comparative size of the decrease in reading scores at lower and higher BLLs. We tested two approaches for categorizing geometric mean BLLs in linear regression models: quartiles and 3-categories (0-4, 5-9 and 10^{+}µg/dL), an analysis approach frequently used in the lead literature. The results were very similar but we found that using three categories improved our ability to explain variability and provided meaningful blood lead reference levels with which to interpret the results. We used the three category approach in our descriptive statistics and regression analyses. We also employed refined categories of GM BLLs in our linear regression analyses, similar to the approach used by Miranda, described above [5]. In these models, the refined GM BLL category of one (1) represents GM BLLs of 0.7 to 1.99µg/dL (the reference category); the refined GM BLL category of two (2) represents GM BLLs of 2.0 to 2.99µg/dL; the refined GM BLL category of three (3) represents GM BLLs of 3.0 to 3.99µg/dL, and so forth. The final refined GM BLL category of 10+ represents all GM BLLs of 10.0µg/dL and above. Use of this more refined categorization approach provided more specificity for the association between fall PALS-K summary scores across the range of BLLs.

3.6 Birth Data

Birth data were available for a total of 3,651 children, 70% of the three-year kindergarten cohort, and slightly less than 80% of the children in our final study population. This information is routinely abstracted from each child and mother pair's pre-natal, delivery and post natal hospital records by community health nurses who visit maternity hospitals five days a week. These data are considered to be highly accurate and reliable and include birth weight, gestational age, admission to the neonatal intensive care unit (NICU), parent and child risk factors, maternal age and education, presence of siblings, and payer of record for the child's delivery. Mother's age was categorized as: <20 years, 20-34 years, and 35+ years. Mother's marital status was collapsed into a 2-category variable: married, not married. We also collapsed insurance payer information into a two-category variable to differentiate public from private insurance. Although data reported by the mother were available on education for both mother and father, we decided to retain only mother's education, which is considered to be more accurate and reliable since the majority of births (73%) were to single mothers. Maternal education was collapsed into high school graduate (yes/no). Birth weight was available for all children and collapsed into 3 categories: less than 1500 grams, 1500-2499 grams, and greater than/equal to 2500grams. Gestational age in weeks was available for all children and collapsed into three categories for analysis: less than 34 weeks, 34-36 weeks, and 37+ weeks. We also collapsed information on delivery type, anesthesia, birth order, number of siblings at home, and maternal risk factors.

3.7 Data Linkage

Our data partner, The Providence Plan, a non-profit community organization with extensive experience working with public and private databases, linked information from the four datasets using a unique identifier (ID) created for each individual child and making use of the child's school ID (assigned to each child by PPSD) and the child's KIDSNET ID (assigned by RIDH). At every step of the process, discrepancies were resolved by manual examination of the records and by confirmation with school or health department staff. As a final step, Providence Plan generated a study ID for each child and provided de-identified data files for this study. After data cleaning and exploration, we merged the files by study ID into one file for our analyses. Specific details on how data were linked can be found in Appendix, page 126.

3.8 Data Analysis

We used STATA 10.1 (StataCorp, College Station, TX) to examine the statistical relationships between PALS-K total fall and spring scores and blood lead concentration, using descriptive techniques and linear and logistic multi-variate models. In our initial analyses, we addressed the relationship between lead and the PALS-K fall score (reported in Chapter Four) using: age at start of kindergarten (4 categories); gender (female, male); race (Hispanic, White, Black, other); child language (English, Spanish, other); birthplace (RI, US not RI, Central/South America, other); year of kindergarten (2003-2004, 2004-2005, 2005-2006); and participation in the Federal free/reduced price school lunch program (free lunch, reduced lunch, pay for lunch), our measure of SES. We examined other co-variates from birth records (including mother's education, mother's marital status, child's birth weight, child's gestational age) but did not include them in our final models because data were missing for more than 20% of children in the study population (N=710/3406). We calculated median geometric mean BLLs by all co-variates, stratifying on fall benchmark status (fall PALS-K score above or below benchmark). We also calculated the mean fall PALS-K scores for all co-variates, stratifying on fall benchmark status. We examined differences across levels of each variable for both the geometric mean BLL and the fall PALS-K score using t-tests with Bonferroni adjustments for multiple comparisons.

In our first set of analyses, we investigated the linear relationship between geometric mean BLL, using both the 3-categories and the refined categories models, and fall PALS-K score. We used log geometric mean BLL to predict the change in fall score given a doubling in log BLLs. In all linear regressions, we used progressive levels of adjustment to examine the effect of additional variables on the relationship of the fall PALS-K score with lead. We selected covariates known to affect reading readiness, including age, gender, race, child language, free and reduced lunch status (our measure of SES). Gender, race and free and reduced lunch status were used in similar studies looking at end of grade reading scores [5,6], but those studies excluded children who were Hispanic, who made up nearly 60% of our population. We also used dummy variables to assess for differences in scores across the three study years. Because we had multiple BLLs available for most children and used a geometric mean value for blood lead, we did not have reason to use the child's age at time of test in our models[f]. Co-variates were entered into the models in the following manner: (1) lead; (2) add gender, age, year; (3) add race; (4) add child language; and (5) add free and reduced lunch status. We investigated the odds of failure to achieve fall benchmark using logistic models and the same progressive levels of adjustment, using GM BLL categories and log GM BLL to estimate the odds of failure associated with a doubling of log BLLs.

[f] We used age at time of test in a model where lead exposure was measured by the highest BLL, youngest age. However, we found that the age at start of kindergarten explained more of the variability that we observed in reading readiness. Findings for age at time of test were not significant when age at start of kindergarten was in the model.

Our second set of analyses (Chapter Five) addressed our second research question: at the end of kindergarten, are child BLLs associated with failure to achieve spring benchmark standards? We stratified by fall benchmark status (above or below fall PALS-K benchmark) and reported the spring PALS-K test scores, change in test scores from fall to spring, proportion of groups above spring benchmark, and proportion of groups achieving highest readiness levels. We used t-tests with Bonferroni adjustments for multiple comparisons to determine the significance of differences observed within groups. Because the spring scores for our "above benchmark" group were not normally distributed, we used logistic models to examine the odds of scoring below the PALS-K Spring benchmark (score=81) by GM BLL category, stratifying by fall benchmark status (above and below fall benchmark). We adjusted these models in the same manner as we did the fall models, as described above, and added three additional co-variates: the child's kindergarten program (Regular, English as a Second Language, and Dual Language), whether or not the child's school was designated as a Reading First School, and the child's fall PALS-K score. We also used log GM BLLs, stratified by fall benchmark status and adjusted by co-variates as described above, to estimate the odds of failure to achieve spring benchmark associated with a doubling of log BLLs. Finally, we used linear models to examine relationships between lead and (a) spring score and (b) changes in score from fall to spring for children who scored below the benchmark in the fall.

Chapter Four: (Manuscript One)

Association between Elevated Blood Lead Levels and Reading Readiness at the Start of Kindergarten

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4.1 Abstract

Background and Objective: Despite important decreases in blood lead levels (BLLs) in the US, many children living in urban areas continue to be affected by early and ongoing exposures to lead. Lead exposure effects on IQ are well known, and the detrimental impact of lead exposure on reading, math and school progress has been described. Our objective was to evaluate the relationship between BLLs and kindergarten reading readiness, an earlier marker of school performance, in a diverse urban school population.

Methods: School administrative data and Phonological Awareness and Literacy Screening Kindergarten (PALS-K) test scores, measures of kindergarten reading readiness, for 4,027 children attending public school kindergarten in Providence, Rhode Island were linked to Rhode Island Department of Health records of blood lead testing using individual identifiers. Children with at least one BLL test and reading readiness test scores for both the fall and spring were included in the study (N=3,406). Fifty-nine percent (59%) were Hispanic and 36% spoke Spanish as their first language. On average, each child had 3 available BLL tests. For each child, the geometric mean (GM) BLL was estimated. Data were adjusted for sex, age, year enrolled, race, child language, and free/reduced lunch status, a measure of socioeconomic status, and analyzed using multiple linear and logistic regressions with progressive levels of adjustment.

Results: The median GM BLL was 4.2(IQR 2.9-6.0)μg/dL. Twenty percent of children had a history of at least one venous BLL of 10μg/dL or above. At the beginning of kindergarten, children whose BLLs were 5-9 and ≥10μg/dL were 1.44 and 2.51 times

more likely to fail to achieve national fall benchmark standards for reading readiness [OR 1.44 (95%CI 1.23,1.69) and OR 2.51 (95%CI 1.86, 3.40)] compared to children whose BLLs were 0-4µg/dL. A doubling of log BLL resulted in a 1.35 increased likelihood of failure (95%CI 1.24, 1.49). On average, the fall reading readiness scores were decreased by 4.5 and 10 points for children with BLLs in the 5-9 and 10+µg/dL categories respectively, compared to children with BLLs 0-4µg/dL [-4.5 points (95%CI -6.2, -2.9) and -10.1 points (95%CI -13.3, -7.0)]. A doubling of log BLL resulted in a 3.5 point decrease in fall reading readiness score (95% CI -4.4, -2.6).

Conclusions: These results suggest that lead exposure at levels of 5µg/dL and higher contributes to decreased reading readiness at kindergarten entry. The finding of high prevalence of elevated BLLs warrants additional investigation in other high-risk US populations. Targeting children with a history of elevated BLLs for additional early childhood education prior to kindergarten might help reduce the gap in reading readiness. This work demonstrates the importance of collaboration between public health and public education agencies and community data providers. Similar approaches could be used to learn more about lead and school outcomes, including longer-term measures of success.

4.2 Introduction

A large body of epidemiological literature has shown that childhood lead exposure has detrimental effects on cognition, including IQ, executive function, and delinquency [122]. Adverse effects have been found at levels well below 10μg/dL, the current level of concern set by the Center for Disease Control and Prevention (CDC) [1]. Several studies have demonstrated significant effects of lead exposure on learning using standardized school tests and functional measures of school performance [4-6,69,71]. These studies have used cross-sectional and longitudinal population study approaches and have examined outcomes such as reading and math test scores [4,6,123], reading at grade level and graduation from high school[71].

Learning to read is critical to the entire process of formal education. Children who are successful at learning to read in the first grade will be successful in the next step of their education: applying their reading skills to other areas of learning (known as "reading to learn") [96]. Reading ability has been associated with school performance in higher grades [93]. Learning to read successfully requires proficiency in phonological processing skills (skills based on using the sounds of one's language to process written and oral language) and in the ability to de-code new words [94,103]. The lack of these skills, not IQ deficits, has been associated with failure to learn to read [78,104]. Educators have found that students who have mastered such skills by the end of kindergarten are more likely to be successful in learning to read in first grade.

Kindergarten, therefore, is a critical time for identifying children who lack the requisite knowledge and skills associated with reading readiness. Most school systems test children when they enter kindergarten in the fall. One instrument, the Phonological Awareness Literacy Screening - Kindergarten (PALS-K) test, has been used extensively in the US and internationally [124]. If a child's score indicates that s/he is "not ready," most schools provide additional instruction that focuses on the development of these skills in an enriched classroom environment.

Reading readiness, therefore, is an early measure of a child's capacity to integrate cognitive ability and skills learned to-date from a multitude of educational, enrichment and environmental exposures. We set out to answer the question: are elevated blood lead levels (BLLs) measured during early childhood associated with reading readiness in kindergarten? The association between lead exposure and reading readiness has not been previously described.

We had an excellent opportunity to investigate this relationship using linked secondary data sets in Providence, Rhode Island. Strong partnerships between the Rhode Island Department of Health (RIDH), Providence Public School District (PPSD) and the Providence Plan, a non-profit community organization, have been fostered for years, culminating in interest in and agreement to use available data to try to address larger social issues, such as school readiness and teen pregnancies. Unlike other states, Rhode Island mandates for annual blood lead testing from 12 to 72 months of age are routinely followed by health care providers, with approximately 75% of young children tested at least once by 18 months of age. Childhood lead screening information is maintained in a central registry and made available on-line to providers along with child immunization records. The Providence Public School District, long concerned about school readiness and Federal "No Child Left Behind" mandates [97], has been using the PALS-K assessment program since 2002. These data on reading readiness in the fall and spring of kindergarten as well as information on relevant co-variates from administrative school data were available for three kindergarten cohorts. The Providence Plan, our key data partner, was willing and able to link educational and health data for purposes of this evaluation. By linking individual data maintained by two public systems, health and education, and collected at two different periods of time, we were able to examine the relationship between kindergarten reading readiness and measures of earlier lead exposure.

4.3 Methods

4.3.1 Overview

This population study used linked data from children's health records, including BLLs collected prior to kindergarten, and kindergarten records, to examine associations between lead exposure and reading readiness in the fall and spring of kindergarten. The Institutional Review Board of the Johns Hopkins Bloomberg School of Public Health reviewed our proposal and determined that this research was exempt from review. Records were obtained for 5,240 children who were enrolled in kindergarten in Providence, Rhode Island Public Schools during three school years (2004-2005, 2005-2006 and 2006-2007). Two datasets provided by the Providence Public School District

(PPSD)(school enrollment data and Phonological Awareness Literacy Screening-Kindergarten (PALS-K) test results) and two datasets provided by the Rhode Island Department of Health (RIDH) (blood lead screening data and data routinely collected at the time of birth, which will be referred to as birth data) were linked and the data de-identified. We examined the associations between pre-kindergarten BLLs and measures of kindergarten reading readiness, based on the Phonological and Literacy Screening in Kindergarten (PALS-K) test, while controlling for covariates such as gender, age, year of kindergarten, race, child language, and socioeconomic status, measured by free and reduced-price lunch status.

4.3.2 Study Population

Our base population for this study consisted of children enrolled in kindergarten in the Providence Public Schools during a three year period (N=5,240). A total of 644 children had no lead test results, were determined to be repeating kindergarten (N=74), or had been mis-coded as kindergarten (N=29), and thus were excluded. Of the remaining 4,493 first time kindergarten children, 466 without PALS-K test results were excluded, and children with only one PALS-K score [fall (N=190),spring (N=182)] were also excluded. This left a total of 3,655 first time enrolled kindergarten children with enrollment data, fall and spring PALS-K scores, and blood lead measurements. Next we excluded children whose only lead measurement was an elevated capillary BLL (n=3). We restricted our analysis to children who were taught in English (referred to as Regular Education and English as a Second Language Programs) or in English and Spanish (the Dual Language Program), excluding children taught only in Spanish (N=173), including

14 inclusion[g] students. We also excluded children who were enrolled in special education classes (N=30) and inclusion students in regular education classrooms (N= 43). Figure 4.1 shows how children were selected for enrollment into the study:

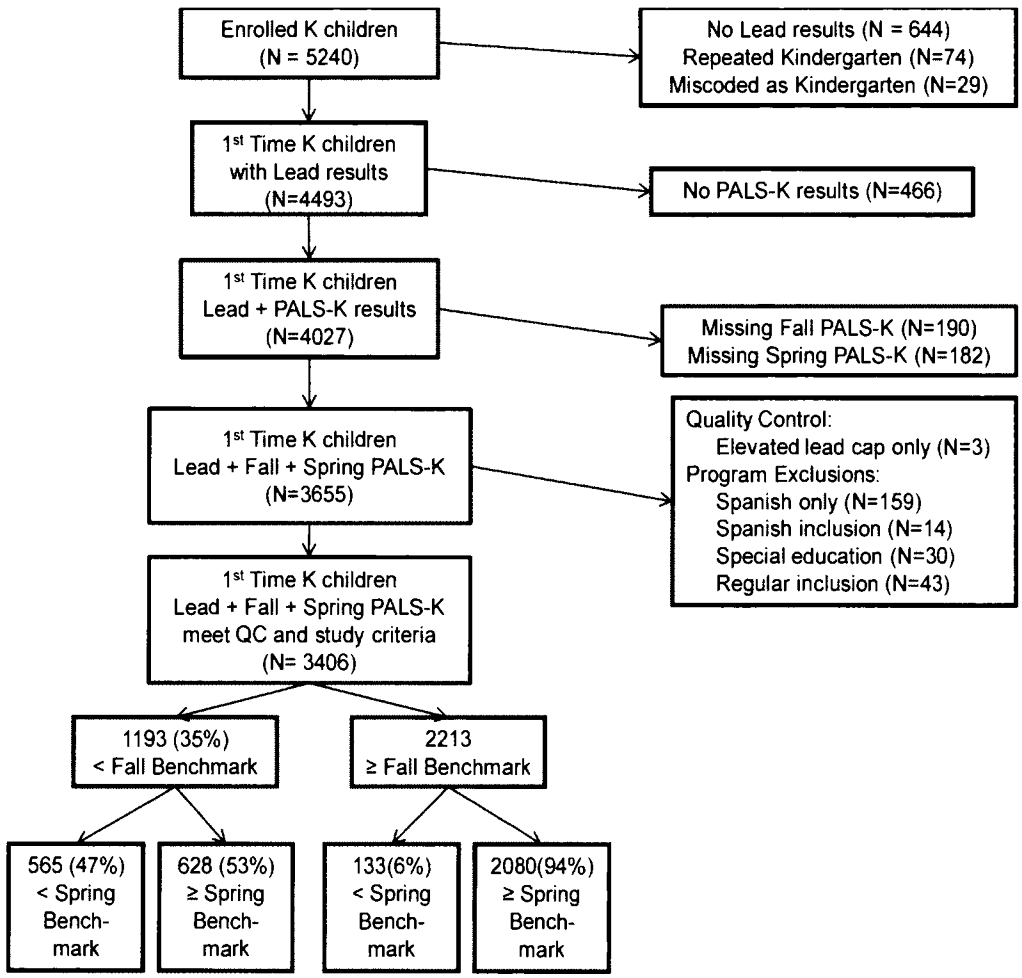

Figure 4.1: Study Enrollment

4.3.3 Demographic and School Data

Enrollment data from PPSD served as the base file for this evaluation, consisting of demographic data collected at the time of the child's registration for school, verified by

[g] Inclusion students are special education students with an Individualized Educational Plan (IEP) who are able to benefit from receiving instruction in a regular classroom, rather than a special education classroom.

school officials, and entered directly into the PPSD electronic system. The data set used for our analyses included individual child information (date of birth, sex, birth place, race and language), and very rich data on languages spoken in the home, but we used only the variable for the child's language in our analyses. The child's status for the Federal free and reduced-price school lunch program served as our variable for socioeconomic status (SES). Children qualify for the program based on family income; children from families with incomes at or below 130% and between 130 and 185% of the national poverty level are eligible for free or reduced price lunch respectively [110]. Free and reduced lunch status is a typical measure of SES for educational research. School level data included: child's elementary school (N=25); child's kindergarten program (N=3, described above); and whether the school received additional funding for reading from the Federal Reading First[h] program [111,112].

4.3.4 PALS-K Tests and Databases

The PALS-K test, developed at the University of Virginia, is a screening, diagnostic and evaluation tool used to assess children's development of early literacy skills [113]. PALS -K is a criterion-referenced[i] assessment [99]; few standardized, or norm-referenced,[j] instruments are available to evaluate children's early literacy performance [114].

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[h] **Reading First** was a Federally-funded program focused on making sure that all children learn to read well by the end of third grade and administered by the states. Schools qualified on the basis of need (poor student achievement and poverty) and a competitive grant process. In Rhode Island, funds were awarded in January 2004 to eight Providence elementary schools for Reading First programs during all three years of this study and in February 2006 to one additional school for a Reading First program during the last year of this study [112]. Our study included 891 students in Reading First schools.

[i] **Criterion-referenced**: "An assessment in which a student's response(s) is compared to a pre-established level of performance in an area of knowledge or skill, rather than to a group of children or normative group. Results are typically reported as levels of proficiency, such as emerging skill level or mastery level [134]."

[j] **Norm-referenced**: A standardized instrument by which a student's performance is interpreted in relation to that of a group of peers who have previously taken the same test [134].

PALS-K has been used as the universal screening tool in the state of Virginia since 1997, in all 50 US states, and in six other countries [115,124].

The test is administered individually and in small groups in English by kindergarten teachers, usually in both fall and spring of kindergarten [113]. The PALS-K fall test is used as a screening and diagnostic test to identify children who need early literacy intervention and to assist the teacher in developing and choosing appropriate classroom strategies to address deficiencies. The test is usually given in early October, close to the start of school. Scores are recorded by classroom teachers, and logged into an internet database. Teacher data entry has been evaluated and was found to be 99.1% accurate [19]. A child's total fall score is evaluated against a national benchmark score. Total fall scores less than 28/102 points are considered to be "below benchmark." Students who scored below the fall benchmark received additional in-classroom instruction on a regular basis, focused on the areas of deficiency in specific cognitive elements (or sub-tests), for the duration of the school year. In the late spring, children were tested again with the PALS-K test to measure improvement that had occurred in reading readiness throughout the kindergarten year and to determine the effectiveness of the additional instruction provided to individual children who scored below benchmark in the fall. Success at the end of kindergarten was based on a child achieving the spring benchmark (at least 81/102 points) [19].

The cognitive elements examined by the PALS-K test are decoding, cipher knowledge, letter knowledge, concepts about print, and phonological awareness [99]. The PALS-K test has six subtests, scored separately. The fall and spring PALS-K total scores are compiled by summing results of the six subtests, with a maximum possible score of 102 points [125]. The results are compared to national fall and spring benchmarks of 28 and 81 points. These benchmarks were set by a formal standard-setting process that included reviews by panels of Virginia and US reading experts [113]. In Virginia in 2004-2005, mean total scores for fall were 16.61 (SD 6.96) for the group of children who did not meet benchmark standards and 60.50 (SD 19.39) for the group of children who did [113]. Reliability and validity measures for the PALS-K have been evaluated annually since 1997. The PALS-K instrument was extensively field tested in Virginia across race/ethnicity, gender, and socioeconomic status, and found to provide valid and reliable measures of kindergarten readiness [113]. The PALS-K testing for this study was conducted in English. A version of PALS-K in Spanish has been developed and is currently undergoing field testing [117].

PALS-K records from PPSD were available for 4,668 kindergarten children (89% of total enrolled), including 571 with no BLL information. We found 87 discrepancies in score computation and corrected them using PALS-K scoring protocol [19].

4.3.5 Blood Lead Screening Data

RIDH recommends annual testing for children, beginning at 9 months of age until 6 years (72 months) of age [118,119]. In Rhode Island, children are tested for lead exposure by their primary care providers, and the results of the blood lead tests are sent by analyzing laboratories to the RIDH's Lead Elimination Surveillance System (LESS). Two high-quality, Clinical Laboratory Improvement Amendments (CLIA)-approved laboratories, both with limits of detection for lead of 1μg/dL, performed about 80% of the blood lead measurements reported to LESS during 1999-2005 [120]. A total of 15,320 blood lead values were available for 4,596 children, 88% of children enrolled in the three kindergarten cohorts. Our final dataset consisted of 11,196 blood lead values and the 3,406 children were tested on average three times prior to kindergarten (mean 3.2, SD 2.0, range 1-26).

Nearly all samples were coded as venous (n=15,326) or capillary (n=1,212). Test results not coded for sample type (n=11) were determined to most likely be venous samples and were retained in analyses. We conducted a sub-analysis to evaluate the accuracy of capillary blood lead measurements greater than or equal to 10μg/dL (n=206), the level above which a blood lead value would be considered to be "elevated" and by CDC recommendation and RIDH protocol should be repeated with a venous blood lead test. We found that the extent of confirmatory testing within a three month period varied with BLL (93% for BLLs 20μg/dL and higher, 58% for BLLs 15-19μg/dL and 33% for BLLs 10-14μg/dL), but where such testing occurred, confirmation of the capillary measurement was poor (12% of BLLs 20μg/dL and higher, 30% of BLLs 15=-19μg/dL and 33% of BLLs 10-14μg/dL). We removed all capillary BLLs ≥10μg/dL from the dataset, resulting in the removal of three children who had no other BLL reported.

BLL measurements initially reported as "below the minimal detection limit (MDL)" (N=553) were assigned new blood lead values using their respective laboratory

MDL/square root of 2, in accordance with *Third National Report on Human Exposure to Environmental Chemicals 2005* (CDC)[121]. The number of blood lead measurements per child ranged from one to 26, with most children having 3 or more reported BLLs.

We examined four measures of blood lead for this study: (1) a geometric mean BLL (GM) for each child using his/her individual lead test results (N=3,406); (2) the child's highest BLL at lowest age (N=3,406); (3) a time weighted average BLL for children with two or more BLLs (N=2,830); and (4) an average "5-year old" BLL, for children with one or more BLLs obtained when the child was 52 months of age or older (N=1,276). We compared results of linear regression models using the first three measures of blood lead and found them to be very similar. We used geometric mean BLL value for our analysis because it was available for the largest number of children and represents a better measure of <u>average</u> lead exposure than the child's highest BLL at lowest age (measure 2). We log transformed each child's geometric mean BLL in order to examine the effect of a doubling of log GM BLL, reflecting the log-linear relationship of BLL with our outcome measures.

We explored the benefits of using linear, quartile, frequently used BLL categories and refined categories of GM BLLs in the analysis. Other studies [4-6] have reported that the change in the BLL-reading score relationship is not linear. Miranda [5] employed individual BLL dummy variables in order to provide additional insight into the comparative size of the decrease in reading scores at lower and higher BLLs. We tested two approaches for categorizing geometric mean BLLs in linear regression models:

quartiles and three categories (0-4, 5-9 and 10+μg/dL), an analysis approach frequently used in the lead literature. Using three categories improved our ability to explain variability and provided meaningful blood lead reference levels with which to interpret the results, so we used the three-category approach for descriptive statistics and regression analyses. We also employed refined categories of GM BLLs in our linear regression analyses. In these models, the refined GM BLL category of one (1) represents GM BLLs of 0.7 to 1.99μg/dL (the reference category); the refined GM BLL category of two (2) represents GM BLLs of 2.0 to 2.99μg/dL; the refined GM BLL category of three (3) represents GM BLLs of 3.0 to 3.99μg/dL, and so forth. The final refined GM BLL category of 10+ represents all GM BLLs of 10.0μg/dL and above. Using this refined categorization approach provided more specificity for the association between fall PALS-K summary scores across the range of BLLs.

4.3.6 Birth Data

Birth data were available for a total of 3,651 children, 70% of the three-year kindergarten cohort and slightly less than 80% of the children in our final study population. Information is routinely abstracted from each child and mother pair's pre-natal, delivery and post natal hospital records by community health nurses who visit maternity hospitals five days a week. These data are considered to be highly accurate and reliable and include birth weight, gestational age, admission to the neonatal intensive care unit (NICU), parent and child risk factors, maternal age and education, presence of siblings, and payer of record for the child's delivery.

4.3.7 Data Linkage

Our data partner, The Providence Plan, a non-profit community organization with extensive experience working with public and private databases, linked information from the four datasets using a unique identifier (ID) created for each individual and making use of the child's school ID (assigned to each child by PPSD) and the child's KIDSNET ID (assigned by RIDH) to ensure data quality. Discrepancies were resolved by manual examination of the records and by confirmation with school or health department staff. As a final step, Providence Plan generated a study ID for each child and provided de-identified data files for this study. After data cleaning and exploration, we merged the files by study ID into one file for our analyses. Specific details on how data were linked can be found in Appendix, page 126.

4.3.8 Data Analysis

We used STATA 10.1 (StataCorp, College Station, TX) to examine the statistical relationships between PALS-K total score and blood lead concentration, using descriptive techniques and linear and logistic multi-variate models. We addressed the relationship between lead and the PALS-K fall score using variables available for all enrolled children (age at start of kindergarten, gender, race, child language, birthplace); school characteristics (year of kindergarten); and socioeconomic status (free/reduced price lunch status). We examined other co-variates from birth records but did not include them in our final models because data were missing for more than 20% of children in the study population. We calculated median geometric mean BLLs for all co-variates, stratifying on fall benchmark status (fall PALS-K score above or below benchmark). We also calculated the mean fall PALS-K scores by all co-variates, stratifying on fall benchmark status. We examined differences across levels of each variable for both the geometric mean BLL and the fall PALS-K score using t-tests with Bonferroni adjustments for multiple comparisons.

Our first set of analyses investigated the linear relationship between geometric mean BLL and fall PALS-K score. We used log geometric mean BLL to predict the change in fall score given a doubling in log BLLs. In both linear regressions, we used progressive levels of adjustment to examine the effect of additional variables on the relationship of the fall PALS-K score with BLLs. We selected covariates known to affect reading readiness, including age, gender, race, child language, free and reduced lunch status. Gender, race and free and reduced lunch status were used in similar studies looking at end of grade reading scores [4,6,123], but the North Carolina studies excluded children who were Hispanic, who made up nearly 60% of our population. We also used a variable for year to assess for differences in scores across the three study years. Because we had multiple BLLs available for most children and used a geometric mean value for blood lead, we did not have reason to use the child's age at time of test in our models[k]. We investigated the odds of failure to achieve fall benchmark using logistic models and the same progressive levels of adjustment, using GM BLL categories and log GM BLL to estimate the odds of failure associated with a doubling of log BLLs.

[k] We used age at time of test in a model where lead exposure was measured by the highest BLL, youngest age. However, we found that the age at start of kindergarten explained more of the variability that we observed in reading readiness. Findings for age at time of test were not significant when age at start of kindergarten was in the model.

4.4 Results

Students in the Providence Public School District represent a diversity of backgrounds (see Table 4.1). A large proportion, almost 60%, of the students we studied were Hispanic, 21% were Black, 13% were White and 7% were of other, primarily Asian, descent. Although parents of 61% of students spoke English, more than one language was spoken in the homes of 43% of students. More than 90% of students qualified for the Federal free or reduced-price school lunch program.

The population BLLs of kindergarten children in this study were high compared to national prevalence estimates for 1999-2004 based on the National Health and Nutrition Examination Survey (NHANES). Nearly 20% had at least one BLL at or above 10µg/dL and more than two thirds (69%) had at least one BLL as high as 5µg/dL. In comparison, the national prevalence estimates were 1.4% and 7.4%, respectively [14].

Median geometric mean BLLs were typically higher for children whose PALS-K fall score was below benchmark and varied across population characteristics and (see Table 4.1). Among racial/ethnic groups, Black children had the highest and Hispanic children the lowest BLLs. Consistent with comparisons to place of birth, Spanish-speaking children had lower BLLs than children who spoke English or other languages. Children who spoke other languages, 80% of whom were of Asian descent, had higher BLLs than children who spoke English or Spanish. For all measures that represent lower socio-economic status, i.e. eligibility for the Federal free or reduced-price lunch program, fewer years of maternal education, and public insurance status, we consistently observed higher BLLs. No trends in BLLs were observed by birth weight or gestational age.

On average, about 35% of students failed to achieve PALS-K benchmarks in the fall of kindergarten. Differences in mean fall PALS-K summary scores were observed for most population characteristics (see Table 4.2) when stratified by benchmark status, i.e., children who scored above or below the national fall benchmark standard score of 28 or higher [19]. Fall PALS-K summary scores were consistently lower for children who were: male, Hispanic ethnicity, enrolled in the English as a Second Language program, spoke "other" and Spanish languages, received free lunch, had a geometric mean (GM) BLL of 10μg/dL or higher, and who were born in South or Central America. Fall PALS-K summary scores were lower for children whose mothers had not graduated from high school or had public insurance at the time of the child's birth, and for children in the lowest birth weight and gestational age categories. Figure 4.2 presents the difference in proportion of students who achieved fall PALS-K benchmark score, indicating that 18% more children were ready for school in the lowest GM BLL category compared to the highest. Half of the children who had at least one BLL at or above 10μg/dL scored below the fall PALS-K benchmark.

We used linear regression with progressive levels of adjustment to examine the relationship between GM blood lead categories and total fall PALS-K scores (see table 4.3). Co-variates entered the models in the following manner: (1) lead; (2) adjustment for gender, age, year; (3) further adjusted for race; (4) further adjusted for child language;

and (5) further adjusted for free and reduced lunch status. The magnitude of difference in score by lead categories did not attenuate with increased adjustment. In the fully adjusted model, we observed statistically significant decreases in reading readiness of 4.5 points (95%CI:-6.2,-2.9) for children with GM BLLs of 5-9μg/dL and 10.1 points (95%CI: -13.3, -7.0) for children with GM BLLs of 10+μg/dL, compared to children with GM BLLs less than 5μg/dL. We evaluated potential effect modification of the association between BLL with PALS-K by participant characteristics using interaction terms and found consistent results with no evidence of interaction (data not shown). This model accounted for 13% of the variance in scores. Models using alternate measures of exposure, the highest BLL at lowest age, a time-weighted average BLL, and an average 5-year old BLL, produced similar results. Table 4.4 provides additional information about the association of other model covariates with the fall PALS-K summary score in the fully adjusted model. Similar results for lead exposure categories were obtained when we regressed the fall PALS-K summary score on free/reduced school lunch status and adjusted for the same co-variates with lead added last. Adjustment for lead in the final step resulted in a less than 5% decrease in the magnitude of effect associated with free school lunch status and less than 1% decrease in magnitude of effect associated with reduced price school lunch status (results not shown). We conducted additional sensitivity analyses for children with birth data (N=2697). Further adjustment for years of maternal education increased the variance in scores accounted for by the model to nearly 17% but decreased the magnitude of effect associated with BLL 5-9μg/dL (BLL 10+μg/dL) by 1.5% (18%), with similar decreases in effect for free and reduced lunch status. Adding variables for either public insurance at birth or whether parents were married at birth resulted in minimal changes in effect for BLL (<10% for either category), with similar changes for free and reduced lunch status (results not shown).

We also used linear regression with the same progressive levels of covariate adjustment to examine the relationship between refined categories of GM BLLs and total fall PALS-K scores. Results are shown in Table 4.3. This model accounted for 13.7% of the variance in scores, similar to 13.5% observed for the three category model. Figure 4.3 displays differences in adjusted fall PALS-K mean summary scores between each refined category of GM BLLs and the reference category. The steepest decline in PALS-K scores occurred up to the refined GM BLL category of 6µg/dL. The decrement in fall PALS-K summary score for the category 10+µg/dL compared to the reference category was 13 points.

A fully adjusted linear regression model using log values of BLL showed a significant decrease of 3.5 points in the fall PALS-K score associated with a doubling of log BLLs (see Table 4.3). This model accounted for about 13% of the variance in scores.

We used logistic regression modeling with the same progressive levels of adjustment to examine the odds of scoring below fall PALS-K benchmark (score = 28) by GM BLL category (see table 4.5). In the fully adjusted model, children with GM BLLs 5-9µg/dL and 10^{+}µg/dL were 44% and 151% more likely to score below benchmark compared to children with GM BLLs below 5µg/dL. A fully adjusted logistic model, using log values of BLL showed that a doubling of BLL was accompanied by a 36% increase in the likelihood of scoring below benchmark in the fall.

4.5 Discussion

This is the first study of the association between childhood lead exposure and reading readiness at the start of kindergarten. Our models demonstrate a clear dose-response effect between exposure to lead in early childhood, measured by GM BLLs, and reading readiness at the beginning of kindergarten, measured by the total PALS-K score. The negative impact of blood lead on kindergarten reading readiness is statistically significant and consistent across all levels of adjustment. Effects are seen at BLLs below 10μg/dL. The doubling model suggests a log-linear relationship, with larger effect sizes at lower BLLs, as does the individual dummy variable model. Similar to Miranda's observations of end of grade test scores [123], the magnitude of the change in fall PALS-K score associated with lead exposure in this study is similar to the change associated with eligibility for free and reduced lunch, a measure of low SES. The results of the model using refined categories of BLL suggest that the largest population decline in fall PALS-K scores, 8.1 out of 13 points, occurred just prior to GM blood lead of 6μg/dL.

About half of the students with BLL in the highest category (GM>=10μg/dL) scored above benchmark standards when they entered kindergarten in the fall. Since we do not have information on early childhood education, the quality of the home environment, or more informative measures of socioeconomic status for these children, it is difficult to conjecture what other factors may have accounted for this achievement of higher levels of reading readiness. It will be important in future studies to examine the effect of these factors on reading readiness.

Success in school is dependent on a variety of factors. Reading ability has been associated with school performance in higher grades [93]. An evaluation of student performance on end of grade tests later in elementary school (3rd and 4th grades) in this diverse cohort could help us to better understand the long-term educational impacts of both kindergarten reading readiness and childhood lead exposure.

The student populations of urban school districts such as Providence are very diverse, with white students often in the minority and a large number of students who speak languages other than English. This diversity, coupled with poverty, creates unique challenges for educators who wish to narrow the gap in educational performance. Most educational researchers have focused attention on differences between Black and White children without examining the size of the achievement gap for other racial or ethnic groups, notably Hispanic or Asian children [126]. The relationship between race and language in the US is complex. Children may grow up speaking English as their primary language even though another language is spoken in the home. English may be spoken in the home even though it is not the primary language of the child. For example, among Hispanic students in this study who spoke English as their primary language (40% of all Hispanic students), half did not speak Spanish in their homes. Likewise, among Hispanic students whose primary language was Spanish (the remaining 60% of Hispanic students), 40% spoke English as well as Spanish in their homes. We had reliable information about both race and language and were thus able to examine the effect of lead on reading readiness while controlling for language. Because race and language are important determinants of reading and reading readiness in the US, it is important to include Hispanic children and children of other racial/ethnic groups in population level analyses such as these, along with adjustment for language.

On average, about 35% of Providence kindergarten students in our study failed to achieve PALS-K benchmarks in the fall of kindergarten, compared to 20% of students studied in Virginia during a similar time period [113]. This is likely the result of differences in population, primarily the large proportion of Hispanic children enrolled in Providence (60%) compared to an average of about 9% for Virginia for the 2004-2005 and 2005-2006 school years [125], and the high proportion of Providence students classified as recipients of free and reduced lunch (90%). The rates of failure to achieve fall benchmark seen in this study compare favorably with the 2005-2006 rates for children attending Virginia public schools with more than 72.3% of children qualifying for free or reduced lunch, where 42.6% of Hispanic, 24.3% of Black, 20.6% of White and 8.1% of Asian/Pacific Islanders failed to achieve fall benchmarks [125].

The proportion of children attending Providence public schools who have had at least one elevated BLL (e.g. greater than or equal to 10μg/dL), 20% or one in five children, is more than 14 times higher than national estimates of US children aged 1-5 based on NHANES data collected during the same period of time[14]. This is the first time that a prevalence estimate has been calculated for a population of urban school children and suggests that national population estimates may seriously underestimate the lead problem in urban schools.

Unlike national population estimates [14], children who spoke Spanish and were classified as Hispanic or were reported by their parents to have been born in Central or South America had the lowest BLLs in our study. There is no evidence to suspect that Hispanics in Providence were living in newer housing. However, anecdotal evidence that housekeeping in the homes of many Spanish-speaking immigrant families in Rhode Island is excellent[1] may be associated with this finding.

Exposure to lead in older housing may help to explain some of the disparities in reading readiness seen in populations of at-risk urban children throughout the US. The higher BLLs for Black children and children of other races, primarily Asian, in this study suggest that they were more likely living in lower quality housing, although other exposure factors may have also been present. Children eligible for a free school lunch would have been more likely to live in lower quality housing, compared to children paying for their lunch, so the higher BLLs observed for these children were also consistent. The results of this study suggest the need to continue to emphasize primary prevention efforts focused on housing and to re-evaluate the effectiveness of current public health measures in protecting young children who live in older housing.

[1] This would include regular wet cleaning of floors and horizontal surfaces, which may afford some protection from lead exposure to young children

Our data show that 88% of Providence kindergarten children attending kindergarten during these three years had been tested for lead at least once, suggesting that children living in Rhode Island have benefitted from the RIDH's position as a national leader on the issue of blood lead screening. RIDH has also given health care providers on-line access to the state records of lab-reported blood lead testing results for individual children, which may encourage more screening of at-risk children, particularly children who move and change providers with some frequency.

We were able to conduct this study because (1) 88% of Providence kindergarteners had been tested for lead; and (2) on-going relationships and strong cooperation between the state health department, local public schools and a local community data provider made linkage of existing data sets possible. Such relationships can provide opportunities to link existing health and education data sets and to potentially identify critical associations between environmental factors, health, and educational success at potentially lower cost than a clinical trial or other epidemiological study. Although such relationships have long been encouraged [92], at the present time they appear to be the exception rather than the rule.

The results of this study suggest the need to evaluate the current screening approaches for early intervention in Providence to determine whether adding a history of an elevated BLL to the program qualifying criteria might improve targeting of children who are at-risk for school failure but are not presently being captured in that system. These data also suggest that nearly one in 10 students already attending school in Providence (e.g. half of the children with any BLL >10 who failed to achieve fall benchmark) may be at higher risk for school failure because of poor reading readiness at the start of kindergarten and a history of high levels of lead exposure. Using a similar approach, linking BLL and test outcome data, to evaluate the success of at-risk children currently placed in reading intervention programs could help identify the best approaches for children with history of elevated BLLs.

Other strengths of this study include the large number of high quality blood lead test results available for each child, which enabled us to estimate average lead exposure levels rather than relying on a single blood lead measure; the quality of school enrollment and birth data; longitudinal measurements of kindergarten reading readiness for fall and spring; and high quality linkage of multiple datasets. However, it is important to acknowledge that data were originally collected for other purposes. As a result, we had limited measures of SES or indicators of the enrichment of the child's early education and home environment.

4.6 Conclusions

This study showed an association between high levels of lead exposure and low levels of kindergarten readiness, occurring at levels below the current CDC level of concern. This is the first study to use linked kindergarten reading readiness and child health data for a diverse population of school children and shows the importance of collaboration between public health and public education agencies and community data providers. This approach will enable researchers to learn more about lead and school outcomes, including longer term measures of success. Replication of this effort is feasible, given the existence of relationships and on-going partnerships and commitment to improving outcomes for at-risk children.

The high level of BLL testing made it possible to examine these effects in the population of Providence school children rather than in a smaller percent of screened children. Because data on language, race/ethnicity, and birthplace were available at the individual child level, it was possible to examine the association of lead and reading readiness within a diverse urban population, without excluding children on the basis of race/ethnicity. The availability of multiple blood lead tests made it possible to use a more accurate estimate of lead dose (GM BLL, an average measure of the child's lead exposure), in analyses rather than a single blood lead value. Use of time-weighted average measures of BLL, potentially better estimates of cumulative lead dose, in future evaluation of school performance may improve our ability to discriminate the associations of lead with educational outcomes.

These findings suggest the need to reevaluate current screening approaches that identify children in need of early intervention, raising the possibility that knowledge of BLL data may aid that decision. Future evaluation of student performance on end of grade tests later in elementary school (3^{rd} and 4^{th} grades) in this diverse cohort could help us to better understand the long-term educational impacts of both kindergarten reading readiness and childhood lead exposure. Perhaps most importantly, the availability of good blood lead data and these results provide Providence Public Schools with an opportunity (and the impetus!) to set the benchmark for the Nation for using linked population health and school performance data to improve school success for all children.

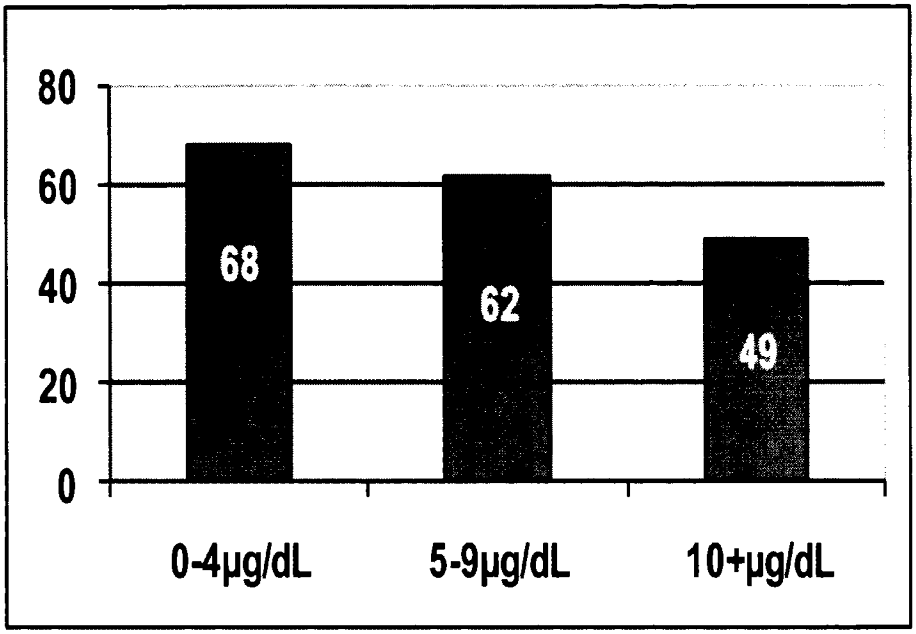
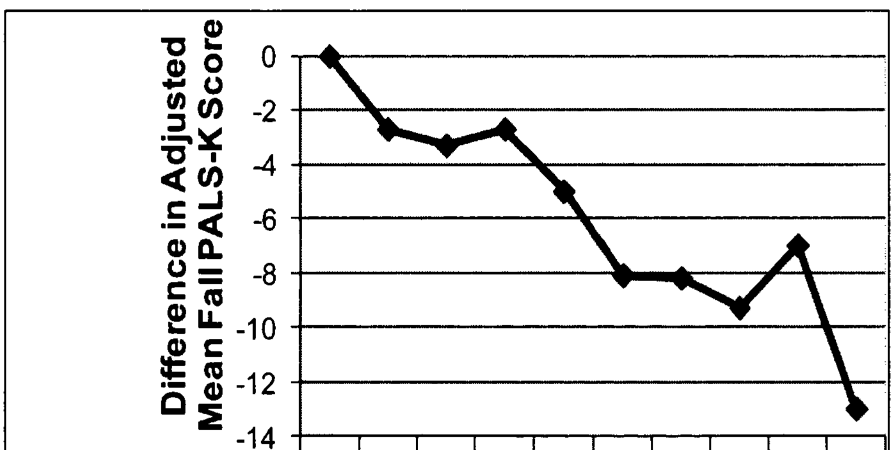


Figure 4.2
Proportions of Children above Fall PALS-K Benchmark, by BLL



GM BLL Category	1	2	3	4	5	6	7	8	9	10+
Difference in Adjusted Mean Fall PALS-K Score	Ref.	-2.7	-3.3	-2.7	-5	-8.1	-8.2	-9.3	-7	-13

Figure 4.3 Differences in Mean Fall PALS-K Scores between Refined GM BLL Category and Reference Category, in fully-adjusted linear regression model

Table 4.1: Median (IQR) Geometric Mean (GM) Blood Lead Levels (BLLs) by Study Population Characteristics (N= 3,406)

	Overall		Below Benchmark			Above Benchmark
Variable	N (%)	BLL (IQR)*	N (%)	BLL (IQR)*	N (%)	BLL (IQR)*
Entire Group	3406 (100)	4.2 (2.9-6.0)	1193(23)	4.5 (3.0-6.6)	2213 (65)	4.0 (2.7-5.8)
Blood Lead Categories		p<0.0001				
BLL <5 µg/dL	2091 (61.5)	3.1 (2.2-4.0)	668 (32)	3.2 (2.5-4.0)	1423 (68)	3.0 (2.1-4.0)
BLL 5-9 µg/dL	1098 (32)	6.3 (5.5-7.5)	415 (38)	6.5 (5.6-7.5)	683 (62)	6.2 (5.5-7.5)
BLL 10+ µg/dL	217 (6.5)	11.7(10.8-14.2)	110 (51)	12.0 (10.8-13.9)	107 (49)	11.4 (10.6-14.4)
Individual Demographic Characteristics						
Gender		p=0.34				
Female	1679 (49)	4.2 (2.9-6.0)	535 (32)	4.6 (3.0-6.6)	1144 (68)	4.0 (2.8-5.7)
Male	1727 (51)	4.2 (2.8-6.0)	658 (38)	4.5 (3.0-6.7)	1069 (62)	4.1 (2.7-5.9)
Age at Start of Kindergarten		p<0.0001				
<5 years 3 months	901 (26)	4.2 (2.9-6.0)	372 (41)	4.5 (3.0-6.5)	529 (59)	4.0 (2.8-5.8)
5 years 3 months to <5 years 6 months	881 (26)	4.0 (2.7-5.5)	323 (36)	4.2 (3.0-6.2)	558 (63)	3.9 (2.6-5.3)
5 years 6 months to <5 years 9 months	888 (26)	4.2 (2.8-6.0)	275 (31)	4.3 (2.9-6.5)	613 (69)	4.1 (2.7-5.9)
5 years 9 months +	736 (24)	4.6 (3.1-6.6)	223 (30)	5.2 (3.5-7.8)	513 (70)	4.5 (3.0-6.0)
Race		p<0.0001				
White	442 (13)	4.2 (2.7-6.0)	100 (23)	5.0 (3.0-7.3)	342 (77)	4.2 (2.6-5.8)
Black	707 (21)	5.0 (3.2-7.0)	174(25)	5.8 (3.9-8.0)	533 (75)	4.6 (3.1-6.9
Hispanic	2021 (59)	4.0 (2.7-5.6)	835 (41)	4.2 (2.9-6.0)	1186 (59)	3.9 (2.5-5.3)
Other**	236 (7)	4.5 (3.0-6.5)	84 (36)	5.5 (3.8-8.2)	152 (64)	4.2 (2.8-5.6)
Child Language		p<0.0001				
English	2074 (61)	4.3 (3.0-6.1)	570 (28)	4.9 (3.2-7.0)	1504 (72)	4.2 (2.8-6.0)
Spanish	1219 (36)	4.0 (2.7-5.5)	565 (46)	4.0 (2.8-6.0)	654 (54)	3.9 (2.6-5.3)
Other***	98 (3)	5.0 (3.5-8.0)	53 (54)	6.0 (4.0-8.4)	45 (46)	4.4 (2.8-6.8)
Missing	15 (<1)	3.9 (2.4-6.6)	5 (33)	5.7 (5.4-8.0)	10 (67)	3.0 (1.8-4.1)
Birthplace		p<0.0001				
Rhode Island	2796 (82)	4.2 (2.9-6.0)	937 (34)	4.6 (3.0-6.7)	1859 (66)	4.1 (2.8-5.7)
Other USA	424 (12)	4.0 (2.7-6.0)	173 (41)	4.0 (3.0-5.8)	251 (59)	3.7 (2.3-6.0)
Central/South America	100 (3)	3.9 (2.9-5.7)	51 (51)	4.0 (3.0-5.7)	49 (49)	3.7 (2.5-5.6)
Other	57 (2)	6.3 (3.6-9.9)	23 (40)	6.9 (4.2-9.9)	34 (59)	6.0 (3.5-9.9)
Missing	29 (1)	4.0 (2.7-5.7)	9 (31)	5.4 (3.9-6.7)	20 (69)	3.6 (2.1-4.6)
School Characteristics						
Kindergarten Year		p=0.55				
2004/2005	870 (26)	4.0 (2.7-6.0)	350 (40)	4.2 (3.0-6.3)	520 (60)	4.0 (2.5-5.9)
2005/2006	1272 (37)	4.2 (2.9-6.0)	439 (35)	4.6 (3.2-6.6)	833 (65)	4.0 (2.8-5.6)
2006/007	1264 (37)	4.3 (2.9-6.1)	404 (32)	4.6 (3.0-7.0)	860 (68)	4.2 (2.9-5.9)

	Overall		Below Benchmark			Above Benchmark
Variable	N (%)	BLL (IQR)	N (%)	BLL (IQR)	N (%)	N, Median of GM BLL (IQR)
Kindergarten Program		p=0.30				
Dual Language	115 (3)	3.9 (2.9-5.7)	43(37)	4.1 (2.9-5.9)	72 (63)	3.9 (2.9-5.5)
English as a Second Language	568 (17)	4.2 (2.9-6.2)	354 (62)	4.2 (3.0-6.7)	214 (38)	4.0 (2.4-5.4)
Regular	2723 (80)	4.2 (2.8-6.0)	796 (29)	4.6 (3.0-6.7)	1927 (71)	4.0 (2.7-5.9)
Reading First School		p=0.66		P=0.62		P=0.27
Yes	891 (26)	4.2 (2.9-6.0)	304 (26)	4.3 (3.0-6.2)	587 (27)	4.0 (2.8-5.9)
No	2515 (74)	4.2 (2.9-6.0)	889 (74)	4.6 (3.0-6.7)	1626 (73)	4.0 (2.7-5.8)
Socioeconomic Status						
Free/Reduced/Pay Lunch Status		p<0.0001				
Free	2713 (80)	4.3 (3.0-6.1)	1026 (38)	4.6 (3.2-6.8)	1687 (62)	4.2 (2.9-5.9)
Reduced	357 (10)	3.8 (2.5-5.2)	97 (27)	3.3 (2.4-5.0)	260 (73)	3.9 (2.5-5.2)
Pay	336 (10)	3.9 (2.3-5.6)	70 (21)	4.0 (2.5-6.5)	266 (79)	3.5 (2.2-5.5)
Birth Data						
Birth weight Category		p=0.66				
Below 1500 grams	42 (1)	4.0 (2.8-6.0)	16 (38)	5.0 (3.3-7.7)	26 (62)	3.4 (2.5-5.5)
1500-2499 grams	175 (5)	4.6 (2.8-6.0)	58 (34)	5.3 (3.0-6.5)	117 (66)	4.4 (2.7-5.9)
2500 grams and above	2479 (73)	4.2 (2.9-6.0)	828 (33)	4.6 (3.0-6.7)	1651 67)	4.1 (2.8-5.7)
Missing	710 (21)	4.0 (2.8-6.0)	291 (41)	4.1 (3.0-6.3)	419 (59)	4.0 (2.5-6.0)
Gestational Age		p=0.76				
Below 34 weeks	66 (2)	4.1 (3.0–5.7)	25(38)	3.9 (3.1-5.7)	41 (62)	4.2 (2.9 – 5.5)
34-36 weeks	200 (6)	4.5 (3.0–6.2)	67 (33)	5.5 (3.8-7.0)	134 (67)	4.0 (2.7 – 5.9)
37 weeks and above	2430 (71)	4.2 (2.9–6.0)	811 (33)	4.5 (3.0-6.7)	1619 (67)	4.1 (2.8 – 5.7)
Missing	710 (21)	4.0 (2.8–6.0)	291 (41)	4.1 (3.0-6.3)	419 (59)	4.0 (2.5-6.0)
Maternal HS Education		p<0.0001				
No	1164 (34)	4.6 (3.1-6.5)	501 (43)	4.9 (3.2-7.0)	663 (57)	4.5 (3.0-6.0)
Yes	1437 (42)	4.0 (2.7-5.8)	376 (26)	4.4 (2.8-6.2)	1061 (74)	4.0 (2.6-5.5)
Missing	805 (24)	4.0 (2.7-6.0)	316 (39)	4.0 (3.0-6.4)	489 (61)	4.0 (2.6-5.9)
Public Insurance at Birth		p<0.0001				
No	608 (18)	3.9 (2.5-5.5)	137(23)	4.2 (2.8–5.8)	471 (77)	3.8 (2.3-5.2)
Yes	2088 (61)	4.4 (3.0-6.2)	765 (37)	4.7 (3.1-6.9)	1323 (63)	4.2 (3.0-5.9)
Missing	710 (21)	4.0 (2.8-6.0)	291 (41)	4.1 (3.0-6.3)	419 (59)	4.0 (2.5-6.0)
Parents married at child's birth		p<0.0001				
Yes	731 (21)	3.8 (2.5-5.4)	200 (27)	3.9 (2.6-5.8)	531 (73)	3.7 (2.3-5.2)
No	1965 (58)	4.5 (3.0-6.2)	702 (36)	4.9 (3.2-7.0)	1263 (64)	4.3 (3.0-6.0)
Missing	710 (21)	4.0 (2.8-6.0)	291 (41)	4.1 (3.0-6.3)	419 (59)	4.0 (2.4-6.0)

* IQR = Inter quartile range **race – Asians make up 92% of "other" ***child language – Asian languages make up 80% of "other"

The p-values shown for each category are the results of test differences across categories using t-tests for 2-category variables and t-tests with Bonferroni adjustments for variables with more than 2 categories. Data as of November 28, 2009, December 17, 2009

Table 4.2: Mean (SD) of Fall PALS-K Total Test Score by Study Population Characteristics

Variable	Total		Below Fall Benchmark		Above Fall Benchmark	
	Score (SD)	N	Score (SD)	(%)	Score (SD)	(%)
Entire Group	41.2 (24.0)	3406	15.7 (6.8)	35	55.0 (17.7)	65
Blood Lead Categories	p<0.0001					
BLL <5 μg/dL	42.9 (23.9)	2091	16.0 (6.7)	32	55.6 (17.7)	68
BLL 5-9 μg/dL	39.5 (23.9)	1098	15.4 (7.0)	38	54.2 (17.8)	62
BLL 10+ μg/dL	33.8 (23.3)	217	15.0 (7.0)	51	53.2 (17.6)	49
Individual Demographic Characteristics						
Gender	p=0.0032					
Female	42.5 (23.7)	1679	15.9 (6.8)	32	54.9 (17.7)	68
Male	40.1 (24.2)	1727	15.5 (6.8)	38	55.2 (17.8)	62
Age at Start of Kindergarten	P<0.0001					
<5 yrs3 mos	37.1 (22.6)	901	15.7 (6.7)	41	52.1 (17.1)	59
5 yrs 3 mos to <5 yrs 6mos	39.7 (23.7)	881	15.5 (7.2)	37	53.7 (17.9)	62
5 yrs 6 mos to <5 yrs 9 mos	43.7 (23.6)	888	16.2 (6.5)	31	56.0 (17.3)	69
5 yrs 9 mos +	45.4 (25.2)	736	15.4 (6.9)	30	58.4 (18.2)	70
Race	p<0.0001					
White	50.3 (25.1)	442	15.7(6.1)	23	60.5 (18.8)	77
Black	46.9 (23.0)	707	17.1 (7.4)	25	56.7 (17.3)	75
Hispanic	37.3 (23.0)	2021	15.4 (6.8)	41	52.7 (17.2)	59
Other*	41.1 (24.2)	236	15.5 (6.7)	36	55.2 (18.0)	64
Child Language	p<0.0001					
English	46.0 (24.0)	2074	16.4 (6.8)	28	57.2 (17.9)	72
Spanish	33.9 (21.9)	1219	14.9 (6.8)	46	50.3 (16.6)	54
Other**	32.1 (21.9)	98	15.5 (7.0)	54	51.6 (16.7)	46
Missing	43.3 (21.3)	15	19.8 (5.8)	33	55.1 (15.2)	67
Birthplace	p<0.0001					
Rhode Island	42.0 (23.8)	2796	15.8 (6.9)	34	55.2 (17.6)	66
US = not Rhode Island	39.1 (24.9)	424	15.4 (6.8)	41	55.4 (19.1)	59
Central/South America	31.2 (21.1)	100	15.1 (7.1)	51	48.0 (17.4)	49
Other	38.4 (23.9)	57	15.2 (6.7)	40	54.1 (17.6)	59
Missing	44.1 (22.7)	29	16.2 (4.2)	31	56.7 (14.9)	69
School Characteristics						
Kindergarten Year	P<0.0001					
2004/2005	37.9 (22.5)	870	16.2 (6.7)	40	52.5 (16.8)	60
2005/2006	42.1 (24.3)	1272	15.9 (6.8)	35	55.9 (18.0)	65
2006/2007	42.7 (24.4)	1264	15.0 (6.9)	32	55.7 (17.9)	68
Kinder. Program	p<0.001					
Dual Language	36.2 (17.9)	115	18.1 (5.9)	37	47.0 (13.3)	63
English as a 2nd Lang.	25.2 (17.6)	568	14.0 (6.9)	62	43.9 (13.8)	38
Regular	44.8 (23.9)	2723	16.3 (6.7)	29	56.6 (17.8)	71
Socioeconomic Status						
Free/Reduced Lunch Status	p<0.0001					
Free	39.3 (23.4)	2713	15.6 (6.8)	38	53.8 (17.3)	62
Reduced	45.5 (24.5)	357	15.6 (6.5)	27	56.7 (18.6)	73
Pay	52.2 (24.5)	336	16.8 (7.4)	21	61.5 (18.1)	79

Variable	Total		Below Fall Benchmark		Above Fall Benchmark	
	Score (SD)	**N**	**Score (SD)**	**(%)**	**Score (SD)**	**(%)**
Birth Data						
Birth weight Category	p=0.30					
Below 1500 grams	37.4 (21.4)	42	17.5 (6.4)	38	49.6 (17.8)	62
1500-2499 grams	43.6 (25.8)	175	14.7 (7.1)	33	57.9 (18.6)	67
2500 grams and above	41.9 (23.7)	2479	15.8 (6.8)	33	55.0 (17.5)	67
Missing	38.7 (24.4)	710	15.6 (6.8)	41	54.8 (18.6)	59
Gestational Age	p=0.30					
Below 34 weeks	38.3 (23.4)	66	15.6 (7.8)	38	52.2 (18.2)	62
34-36 weeks	43.5 (25.3)	200	15.4 (7.3)	33	57.3 (18.6)	67
37 weeks and above	41.9 (23.7)	2430	15.8 (6.8)	33	55.0 (17.4)	67
Missing	38.7 (24.4)	710	15.6 (6.8)	41	54.8 (18.6)	59
Maternal HS Education	p<0.0001					
No	35.6 (22.3)	1164	15.0 (6.9)	43	51.2 (16.5)	57
Yes	46.8 (23.9)	1437	16.5 (6.7)	26	57.6 (17.8)	74
Missing	39.4 (24.2)	805	15.8 (6.7)	39	54.6 (18.4)	61
Public Insurance at Birth	p<0.001					
No	48.3 (23.6)	608	16.5 (7.0)	23	57.6 (18.0)	77
Yes	40.1 (23.5)	2088	15.6 (6.8)	37	54.2 (17.3)	63
Missing	38.7 (24.4)	710	15.6 (6.8)	41	54.8 (18.6)	59
Parents married at child's birth	p<0.0001					
Yes	46.0 (24.2)	731	16.0 (6.7)	27	57.4 (17.9)	73
No	40.4 (23.5)	1965	15.7 (6.9)	36	54.1 (17.3)	64
Unknown	38.7 (24.4)	710	15.6 (6.8)	41	54.8 (18.6)	59

*race – Asians make up 92% of "other" **child language – Asian languages make up 80% of "other"
Data as of November 28, 2009 and December 17, 2009

The p-values shown for each category are the results of test differences across categories using t-tests for 2-category variables and t-tests with Bonferroni adjustments for variables with more than 2 categories.

Table 4.3 Mean Difference (95% Confidence Intervals) in PALS-K Fall Scores by Blood Lead Level Categories (N=3,406)

	Group Size (N)		Model 1[a]	Model 2[b]	Model 3[c]	Model 4[d]	Model 5[e]
	Below Fall BM	Above Fall BM					
GM BLL Categories	1193	2213					
0-4μg/dL	668	1423	Reference	Reference	Reference	Reference	Reference
5-9μg/dL	415	683	-3.4 (-5.2, -1.7)	-3.8 (-5.5, -2.1)	-4.9 (-6.6, -3.2)	-4.8 (-6.5, -3.1)	-4.5 (-6.2, -2.9)
10+μg/dL	110	107	-9.1 (-12.5, -5.8)	-9.9 (-13.2, -6.6)	-11.7 (-15.0, -8.5)	-11.1 (-14.3, -7.9)	-10.1 (-13.3, -7.0)
p-trend			<0.001	<0.001	<0.001	<0.001	<0.001
r^2			0.0109	0.0380	0.0904	0.1150	.1345
Refined GM BLL Categories[1]	1193	2213					
1μg/dL	83	213	Reference	Reference	Reference	Reference	Reference
2μg/dL	197	416	-2.6 (-5.9, 0.8)*	-2.1 (-5.4, 1.2)*	-2.4 (-5.6, 0.8)*	-2.8 (-5.9, 0.4)*	-2.7 (-5.8, 0.5)*
3μg/dL	209	409	-3.8 (-7.1, -0.5)	-3.6 (-6.8, -0.3)	-3.8 (-7.0, -0.7)	-4.1 (-7.3, -1.0)	-3.3 (-6.5, -0.2)
4μg/dL	179	385	-2.7 (-6.0, 0.7)*	-2.6 (-5.9, 0.7)*	-3.2 (-6.4, 0.04)**	-3.6 (-6.8, -0.4)	-2.7 (-4.9, 4.7)*
5μg/dL	148	272	-4.4 (-7.9, -0.8)	-4.6 (-8.1, -1.1)	-5.6 (-9.0, -2.2)	-5.6 (-9.0, -2.3)	-5.0 (-8.4, -1.7)
6μg/dL	130	193	-6.7 (-10.5, -3.0)	-6.7 (-10.4, -3.0)	-8.4 (-12.1, -4.8)	-9.0 (-12.6, -5.4)	-8.1 (-11.7, -4.5)
7μg/dL	56	91	-6.4 (-11.1, -1.6)	-7.2 (-11.9, -2.6)	-8.9 (-13.5, -4.4)	-9.3 (-13.8, -4.9)	-8.2 (-12.7, -3.8)
8μg/dL	55	79	-8.5 (-13.3, -3.6)	-8.5 (-13.3, -3.7)	-10.0 (-14.7, -5.3)	-10.3 (-14.9, -5.6)	-9.3 (-13.9, -4.7)
9μg/dL	26	48	-7.1 (-13.1, -1.0)	-6.8 (-12.8, -0.8)	-8.0 (-13,9, -2.2)	-7.9 (-13.7, -2.2)	-7.0 (-12.7, -1.3)
10+μg/dL	110	107	-11.7 (-15.9, -7.5)	-12.3 (-16.4, -8.1)	-14.5 (-18.5, -10.4)	-14.1(-18.1,-10.1)	-12.7 (-16.6, -8.7)
p-trend			<0.001	<0.001	<0.001	<0.001	<0.001
r^2			0.0135	0.0402	0.0933	0.1187	0.1372
Log $_2$GM BLL Doubling Model Per 2-fold Increase	1194	2213	-3.2 (-4.2, -2.3)	-3.5 (-4.4, -2.5)	-4.1 (-5.0, -3.1)	-4.0 (-4.9, -3.0)	-3.5 (-4.4, -2.6)
p-value			<0.001	<0.001	<0.001	<0.001	<0.001
r^2			0.0129	0.0394	0.0911	0.1165	0.1343

[a]Model 1 – lead
[b]Model 2 – further adjusted for age at start of kindergarten, gender and year
[c]Model 3 – further adjusted for race
[d]Model 4 – further adjusted for child language
[e]Model 5 – further adjusted for free/reduced lunch status

* = not statistically significant (p>0.08)
** = p=0.053

[1]Refined GM BLL Categories: 1μg/dL=0.7-1.99; 2μg/dL=2.0-2.99; 3μg/dL=3.0 to 3.99; 4μg/dL = 4.0-4.99μg/dL; and so forth to 10+μg/dL = 10.0μg/dL and above

Source: November 28, 2009, December 21, 2009

Table 4.4 Adjusted Mean Difference (95% Confidence Interval) in Fall PALS-K Summary Score by Participant Characteristics from a Multiple Linear Regression Model

Covariates	Fall PALS-K Summary Score	95% CI
BLL 0-4µg/dL	Reference	Reference
BLL 5-9µg/dL	-4.51	-6.16,-2.85
BLL 10+µg/dL	-10.13	-13.30, -6.96
Female	Reference	Reference
Male	-2.80	-4.31, -1.30
Year 2004-2005	Reference	Reference
Year 2005-2006	3.53	1.58, 5.49
Year 2006-2007	3.71	1.74, 5.69
Age group 5-5¼ years	Reference	Reference
Age group 5¼ - 5½ years	2.68	0.60, 4.77
Age group 5½ - 5¾ years	6.57	4.49, 8.65
Age group 5¾ years and older	8.26	6.03, 10.49
Race Hispanic	Reference	Reference
Race White	6.85	4.23, 9.47
Race Black	6.05	3.77, 8.32
Race Other	2.51	-1.18, 6.20[1]
Language English	Reference	Reference
Language Spanish	-8.43	-10.41,-6.44
Language Other	-12.74	-17.91,-7.57
Pay for lunch	Reference	Reference
Reduced lunch	-4.18	-7.56,-0.80
Free lunch	-10.31	-12.91,-7.71
Constant*	50.41	46.37, 54.45
R^2	.1345	

[1] p=0.182

Final model adjusted for GM BLL category, sex, year, age at time of test, race, child language, and free/reduced lunch status

* Refers to average score for a 5-5¼ year old Hispanic female, speaking English, paying for lunch with a BLL of 0-4µg/dL in 2004-2005.

Source: November 25, 2009

Table 4.5: Odds Ratio of Scoring Below PALS-K Fall Benchmark (95% Confidence Intervals) by Blood Lead Categories (N=3,406)

	Group Size (N)		Model 1[a]	Model 2[b]	Model 3[c]	Model 4[d]	Model 5[e]
	Below Fall BM	Above Fall BM					
GM BLL Categories	1193	2213					
0-4 μg/dL	668	1423	Reference	Reference	Reference	Reference	Reference
5-9 μg/dL	415	683	1.29 (1.11, 1.51)	1.33 (1.14, 1.56)	1.47 (1.26, 1.73)	1.46 (1.25, 1.72)	1.44 (1.23, 1.69)
10+ μg/dL	110	107	2.19 (1.65, 2.90)	2.31 (1.73, 3.07)	2.78 (2.07, 3.73)	2.65 (1.97, 3.58)	2.51 (1.86, 3.40)
p-trend			<0.001	<0.001	<0.001	<0.001	<0.001
Log GM BLL Doubling Model – per 2-fold Increase	1193	2213	1.29 (1.19, 1.41)	1.31 (1.21, 1.43)	1.40 (1.28, 1.53)	1.39 (1.27, 1.52)	1.36 (1.24, 1.49)
p-value			<0.001	<0.001	<0.001	<0.001	<0.001

[a]Model 1 – lead
[b]Model 2 – further adjusted for age at kindergarten, gender and year
[c]Model 3 – further adjusted for race
[d]Model 4 – further adjusted for child language
[e]Model 5 – further adjusted for free/reduced lunch status

all statistically significant at p=0.001

Source: November 25, 200

Chapter Five: (Manuscript Two)

Association between Elevated Blood Lead Levels and The Development of Reading Readiness during Kindergarten

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5.1 Abstract

Background and Objective: Despite important decreases in blood lead levels (BLLs) in the US, many children living in urban areas continue to be affected by early and ongoing exposures to lead. Lead exposure effects on IQ are well known, and the detrimental impact of lead exposure on reading, math and reading readiness in the fall of kindergarten has been described. Our objective was to evaluate the relationship between BLLs and kindergarten reading readiness at the end of kindergarten in a diverse urban school population.

Methods: As described in our earlier paper, school administrative data and kindergarten reading readiness test scores (the Phonological Awareness and Literacy Screening Kindergarten (PALS-K) Test) for 4,027 children attending public school kindergarten in Providence, Rhode Island were linked to Rhode Island Department of Health records of blood lead testing (average 3 BLL tests/child) using individual identifiers. Children included in the study had at least one BLL test and reading readiness test scores for both the fall and spring of kindergarten (N=3,406). The population was diverse: 59% were Hispanic and 36% spoke Spanish as their first language. A geometric mean (GM) BLL was estimated for each child. Data were analyzed using multiple logistic regression with progressive levels of adjustment. Analyses were adjusted for sex, age, year enrolled, race, child language, free/reduced lunch status (a measure of socioeconomic status), kindergarten program, designation of the child's school as a Reading First school and the child's fall PALS-K score.

Results: In the spring, children who had scored below the national benchmark standard in the fall and who had GM BLLs ≥5µg/dL were approximately 1.5 times more likely to fail to achieve the national **spring** benchmark compared to children with BLLs below 5µg/dL. For these same children, a doubling of log BLLs resulted in an increased likelihood of spring failure of 1.28 (95% CI 1.10, 1.49). For the children who achieved the national benchmark standard in the fall, BLLs were **not** associated with increased risk of failure in the spring. Dose effect relationships were demonstrated for BLL and high levels of readiness at the end of kindergarten.

Conclusions: The association between lead and reading readiness during kindergarten occurred at BLLs of 5µg/dL and above, well below 10µg/dL, the current CDC level of concern. These results suggest that children who enter kindergarten with **both** low levels of reading readiness and GM BLLs of 5µg/dL and above are at increased risk for failure to make adequate progress during kindergarten. Evaluation of the effect of additional school reading interventions provided to children who entered kindergarten with low levels of readiness would be informative. An evaluation of performance on end of grade tests later in elementary school (3rd or 4th grades) for this cohort could help us to better understand the long-term educational impacts of both reading readiness and childhood lead exposure. Similar opportunities to link existing data sets could potentially uncover critical associations between environmental factors, health and educational success.

5.2 Introduction

Many studies have shown that childhood lead exposure has detrimental effects on cognition, at blood lead levels (BLLs) well below 10μg/dL, the current level of concern established by the Centers for Disease Control and Prevention (CDC) [1,122]. Additionally, lead has been shown to affect children's reading ability [4-6], a functional measure of school performance, and on reading readiness at the start of kindergarten [127].

Learning to read is a critical step in the process of formal education. Children who are successful at learning to read will be able to use those skills to learn and master a variety of subjects [96]{{}}. Reading ability has been associated with school performance in higher grades [93]. Many researchers suggest that children who have not learned to read by the time they reach third grade will face a life-time of struggle trying to learn in an educational system that requires grade-level reading proficiency [94,95].

Educators have found that mastery of a well-defined set of pre-reading skills in kindergarten, including phonological awareness, alphabet knowledge, concept of word, correspondence between letters and sounds, and decoding, predicts reading success in first grade [78,78,103,104,113,113]. Kindergarten, then, is a critical time to identify children whose skills are insufficient and to provide them with the necessary skills, knowledge and experience so that they will be ready to learn to read by year end. We have shown elevated BLLs to be associated with decreases in reading readiness in the fall of kindergarten and with increased risk of failing to meet fall standards for reading readiness. Our question: in kindergarten children, does a history of elevated BLLs continue to be associated with increased risk of failure to meet reading readiness standards in the spring of kindergarten?

We had the opportunity to investigate this relationship using linked secondary data sets in Providence, Rhode Island, continuing our investigation of childhood lead exposure and reading readiness. All 3,406 children in our study population had been tested at least once for lead and had fall and spring measurements of reading readiness (the Phonological Awareness Literacy Screening – Kindergarten (PALS-K) test scores). Lead levels were high, with close to twenty percent (20%) of children having had at least one BLL of 10μg/dL or higher. In the fall, 35% of children in our study population tested below national benchmarks for reading readiness. Kindergarten teachers provided these children with additional classroom instruction, focused on reading skills. Children testing above the benchmark received their regular kindergarten program. We evaluated the association of lead with improvement in readiness scores and success in meeting end of kindergarten benchmarks for reading readiness.

5.3 Methods

5.3.1 Overview

This study examines the progress made in reading readiness during kindergarten of a population of students living in Providence, Rhode Island, whose reading readiness in the fall of kindergarten was described in Chapter Four. This study used the same linked datasets, including child health records (historical BLL and birth data), school enrollment records and the results of reading readiness tests given in the fall and spring of kindergarten. The study was reviewed by the Institutional Review Board of the Johns Hopkins Bloomberg School of Public Health and found to be exempt. We obtained records for 5,240 children who were enrolled in kindergarten in Providence Public Schools during three school years (2004-2005, 2005-2006 and 2006-2007). The Providence Plan, our data provider, secured and linked two datasets from the Providence Public School District (PPSD) (school enrollment data and Phonological Awareness Literacy Screening-Kindergarten (PALS-K) test results) and two datasets from the Rhode Island Department of Health (RIDH) (blood lead screening data and data routinely collected at the time of birth, which will be referred to as birth data). Providence Plan de-identified the data and assisted with quality assurance throughout the study. In this study, we examined the associations between pre-kindergarten BLLs and the change in kindergarten reading readiness from fall to spring, based on the PALS-K total summary test results, while controlling for child-specific (gender, age, year of kindergarten, race, child language, socioeconomic status, measured by eligibility for the Federal free and reduced price school lunch program, and the child's fall PALS-K score) and school-specific covariates (kindergarten program, Reading First School status).

5.3.2 Study Population

Our base population consisted of records for all children enrolled in kindergarten in Providence Public Schools during a three-year period (N=5,240). Of these, we excluded records for children who had no BLL test results (N=644); children who were repeating kindergarten (N=74) or had been miscoded as kindergarten (N=29); children without

PALS-K test results (N=465); children with only one PALS-K score [fall (N=190), spring (N=182)] and children who had only elevated capillary BLL results (N=3). Finally, we excluded children taught only in Spanish (N=173), including 14 inclusion[m] students, children who were enrolled in special education classes (N=30) and inclusion students in regular education classrooms (N= 43). Our final analysis group (N=3406) included children who were taught in English (Regular Education and English as a Second Language Programs) or in English and Spanish (Dual Language Program).

5.3.3 Demographic and School Data

The base file for this evaluation consisted of enrollment records from PPSD consisting of demographic data collected at the time of the child's registration for school, verified by school officials, and entered directly into the PPSD electronic system. Individual child enrollment data included date of birth, sex, birth place, race, child language and additional data on languages spoken in the home. Our variable for socioeconomic status (SES) was the child's eligibility for the Federal free or reduced-price school lunch program, the typical measure of SES in educational research. Children from families with incomes at or below 130% and between 130 and 185% of the national poverty level are eligible for free or reduced price lunch respectively [110]. Our dataset also included several school level variables such as: the child's elementary school (N=25); child's kindergarten program (N=5, described above); and whether the school received additional funding for reading from the Federal Reading First[n] program [111,112].

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[m] Inclusion students are special education students with an Individualized Educational Plan (IEP) who are able to benefit from receiving instruction in a regular classroom, rather than a special education classroom.
[n] Reading First was a Federally-funded program focused on ensuring that all children learn to read well by the end of third grade and administered by the states. Schools qualified in a competitive grant process on

5.3.4 PALS-K Tests and Databases

The Spring PALS-K total test score served as our educational outcome measure for this study. The PALS-K is a screening, diagnostic and evaluation tool used to assess children's development of early literacy skills, developed at the University of Virginia[19]. A criterion-referenced[o] assessment [99], the PALS-K has been used as the universal screening tool in the state of Virginia since 1997, in all 50 US states, and in six other countries [115,124].

The cognitive elements examined by the PALS-K test are decoding, cipher knowledge, letter knowledge, concepts about print, and phonological awareness [99]. Reliability and validity measures for the PALS-K have been evaluated annually since 1997. The PALS-K has been evaluated for reliability and validity annually since 1997 and tested extensively in the field to ensure valid and reliable measures of kindergarten readiness across race/ethnicity, gender, and SES [113].

The PALS-K test was administered to children in our study according to protocol: individually and in small groups in English by kindergarten teachers, in the early fall and late spring of their kindergarten year [113]. Additional detail on the PALS-K test administration can be found in Chapter 4. A child's total fall and spring scores are evaluated against national benchmark standards [19]: total fall and spring scores less than

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the basis of need: poor student achievement and poverty. In Rhode Island, funds were awarded in January 2004 to eight Providence elementary schools for Reading First programs during all three years of this study, and in February 2006 to one additional school for a Reading First program during the last year of this study [112]. Our study included 891 students in Reading First schools.

[o] **Criterion-referenced**: An assessment in which a student's response(s) is compared to a pre-established level of performance in an area of knowledge or skill, rather than to a group of children or normative group. Results are typically reported as levels of proficiency, such as emerging skill level or mastery level [134].

28/102 points and 81/102 points respectively are considered to be "below benchmark." In Providence, students who scored below the fall benchmark received additional in-classroom instruction on a regular basis to help them improve in areas of identified deficiency. Although PALS-K records were available for 4,668 kindergarten children (89% of total enrolled), including 571 with no blood lead test information, we only used the records with both fall and spring scores, as described above. We found 87 discrepancies in score computation and corrected them using PALS-K scoring protocol[19].

5.3.5 Blood Lead Screening Data

RIDH recommends that children between 9 months and 72 months of age be tested annually with a blood lead test by their primary care providers [118,119]. In Rhode Island, analyzing laboratories report the results of all samples to RIDH's state registry, known as the Lead Elimination Surveillance System (LESS). Two laboratories, both CLIA-approved and with limits of detection for lead of 1µg/dL, accounted for about 80% of the blood lead measurements reported to LESS during the period of our study (1999-2005)[120]. We received a total of 15,320 blood lead values for 4,596 children, 88% of children enrolled in the three kindergarten cohorts. Based on results of a sub-analysis that revealed that capillary measurements greater than or equal to 10µg/dL were not reliable, we restricted the dataset to venous and capillary measures less than 10µg/dL, resulting in the loss of 3 children from the analysis. BLL measurements initially reported as "below the minimal detection limit (MDL)" (N=553) were assigned new blood lead values using their respective laboratory MDL/square root of 2, in accordance with *Third National Report on Human Exposure to Environmental Chemicals 2005* (CDC)[121]. Our analysis dataset contained 11,196 blood lead values for the 3,406 children who were tested on average three times prior to kindergarten (mean 3.2, SD 2.0, range 1-26).

Consistent with our previous analysis in Chapter 4, this study employed two measures of BLL: (1) an individually calculated geometric mean (GM) BLL, represented in analysis by three categories (0-4, 5-9 and 10+μg/dL); and (2) the log-transformed GM BLL which was used to examine the effect of a doubling of log GM BLL, reflecting the log-linear relationship of BLL with our outcome measures.

5.3.6 Birth Data

Although high-quality birth data were available for a slightly less than 80% of the children in our final study population (see Chapter Four) and were part of our linked dataset, we did not use this information in analysis for this study.

5.3.7 Data Linkage

Our data partner, The Providence Plan, a non-profit community organization with extensive experience working with public and private databases, linked information from the four datasets (school enrollment, PALS-K test scores, blood lead screening data and birth data), as shown in Figure 1 (below). Data quality was ensured by using a unique identifier (ID) created for each child, making use of existing individual IDs used by PPSD and RIDH and using a systematic process to resolve discrepancies. After ensuring quality of the linked data, Providence Plan generated a study ID for each child and provided de-identified data files for this study. Following data cleaning and exploration, we merged the files by study ID into one file for our analyses. Additional details on how data were linked can be found in Appendix, page 126.

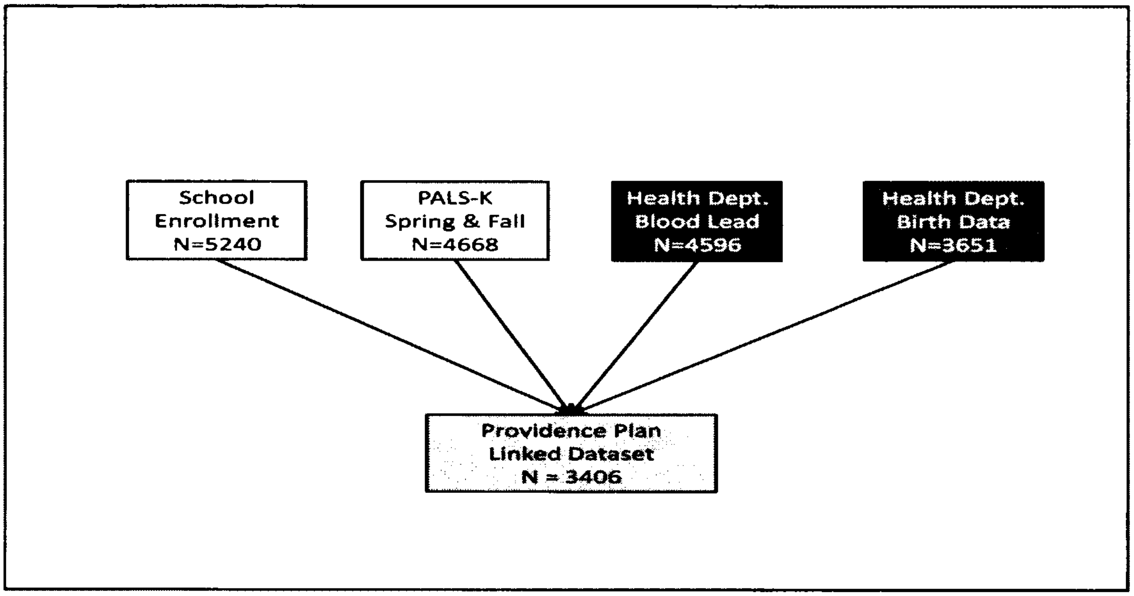

Figure 5.1: Data linkage

5.3.8 Data Analysis

These analyses addressed our research question: at the end of kindergarten, are child BLLs associated with failure to achieve spring benchmark standards? We used STATA 10.1 (StataCorp, College Station, TX) to examine the statistical relationships between PALS-K total spring score and BLL, using descriptive techniques and both linear and logistic multivariate models. We stratified by fall benchmark status (children who scored above or below PALS-K benchmark in the fall) and reported the spring PALS-K test scores, the change in test scores from fall to spring, the percent of group above spring benchmark and the percent of groups achieving highest spring scores. We examined differences across levels of each variable using t-tests and t-tests with Bonferroni adjustments for multiple comparisons. Because the spring scores for the group who scored above benchmark in the fall were not normally distributed, we used logistic models to examine the odds of failure to achieve the PALS-K Spring benchmark (score-81) by GM BLL category, stratifying by fall benchmark status. We used progressive levels of adjustment in a similar manner as we had for our fall models,[p] with three additional co-variates: the child's kindergarten program (Regular, English as a Second Language, and Dual Language); whether or not the child's school was designated as a Reading First School; and the child's fall PALS-K score. We also used log GM BLLs, stratified by fall benchmark status and progressively adjusted by the same co-variates to estimate the odds of failure to achieve the spring benchmark associated with a doubling of log BLLs. We used linear models to examine the association between PALS-K spring scores and BLL categories for children who scored below the benchmark in the fall.

5.4 Results

5.4.1 Spring Findings

As we have shown previously in Chapter Four, table 4.1, the population of Providence Public Schools kindergarten students enrolled in our study was poor and racially diverse. Approximately 80% qualified for free and 10% for reduced price lunch, our measure of SES. The majority of students (59%) were Hispanic, followed by Blacks (21%), Whites (13%) and "others" (7%), primarily Asian. In the fall, higher BLLs were seen for Black children, children who spoke "other" languages, different from English and Spanish

[p] Fall models were progressively adjusted in the following manner: (1) lead; (2) add gender, age, year; (3) add race; (4) add child language; and (5) add free and reduced lunch status.

(80% of Asian descent), children receiving free school lunches, and children in the oldest age group. Lower BLLs were seen for Hispanic children, children who spoke Spanish, and children who paid for or received reduced-price school lunches. Table 5.1 shows mean blood leads for population characteristics, stratified by fall and spring benchmark status.

During the course of kindergarten, this cohort of children in Providence improved their reading readiness. The overall proportion who achieved PALS-K benchmarks increased from 65% in the fall to 79% in the spring, but the proportion achieving success in the spring differed by fall benchmark status and BLL level. Among children who scored above benchmark in the fall, 94% scored above benchmark in the spring. But among children who scored below benchmark in the fall, 53% scored above benchmark in the spring. Within above and below benchmark groups, the distribution of success in spring also varied by BLL (see Figure 5.2).

We looked at PALS-K spring total scores in association with individual, school and SES factors, stratified according to the children's performance in meeting benchmark status in the fall (see Table 5.2). We found that children who had scored above benchmark in the fall scored 19 points higher on average on the PALS-K spring total score than those who had scored below benchmark in the fall. The associations of spring total score with individual, school and SES factors were strikingly different from associations observed in the fall.

For those who scored below benchmark in the fall, higher BLLs and male gender were both associated with significantly lower PALS-K spring scores, similar to what we observed in the fall. However, children in the oldest age category, who scored highest on the fall PALS-K, scored significantly lower on the spring PALS-K than children in other age groups. Children who attended a Reading First school scored significantly higher than their counter-parts; fall PALS-K scores had been similar for both. The spring scores of children enrolled in the Dual Language program were on average 6 points higher than the spring scores of children enrolled in other programs, but only the difference with English as a Second Language program achieved statistical significance (p= 0.079). Regarding race, Hispanics scored the highest and Blacks the lowest compared to other racial groups, but the differences in scores across race were not statistically significant, another major difference from the fall. In the spring, we did not observe differences in PALS-K score based on child language, birthplace, or free and reduced price school lunch status, all factors associated with differences in PALS-K scores in the fall.

For the above fall benchmark group, male gender, Black race, and receiving a free school lunch were all associated with significantly lower PALS-K spring scores, similar to what we had observed in the fall but of different magnitude. However, although the trend was positive, differences in PALS-K spring scores between BLL categories were significant only for children with BLLs of 5-9μg/dL when compared to children with BLLs less than 5μg/dL, but not for children with BLLs of 10+μg/dL. Children attending a Reading First school scored significantly higher on spring PALS-K than children who did not, different from our observation in the fall. Children enrolled in kindergarten in 2005 and 2006 had significantly higher scores than children enrolled in 2004, 0.5 and 1.2 points respectively. We observed no differences in spring score associated with age at start of kindergarten, child language, birthplace, and kindergarten program, also a change from the fall.

Overall, 238 children achieved a perfect spring score (102). This represented 10.7% of the children who scored above benchmark in the fall (N=237) but only one child, less than 0.1%, of the children who scored below benchmark in the fall. Furthermore, high levels of reading readiness were associated with lower BLLs. For those scoring above benchmark in the fall, the proportions achieving perfect spring scores were 11.0%, 10.7% and 7.5% for those in the 0-4μg/dL, 5-9μg/dL, and 10+μg/dL BLL groups respectively. We observed similar results when scores of 101 or 102 (99^{th} percentile) were considered (see Appendix, Table A.1, page 128).

We also evaluated the change in average PALS-K Score from Fall to Spring (see Table 5.3). Overall, the children who scored below the benchmark in the fall demonstrated larger improvements in score between fall and spring, with an average change in score of 59.4 points (SD 17.8) compared to 38.8 points (SD 15.5) for those who scored above the benchmark in the fall. These lesser changes in score from fall to spring appeared to be largely due to the fact that the children who scored high in the fall could not score higher than a perfect score in spring (see Appendix, Figure A.1, page 129.)! This issue will be further addressed below.

For the children who scored below benchmark in the fall, children in the lowest BLL (<5μg/dL) group showed significantly greater improvement (3-5 points) than children in the two higher BLL categories. Children attending Reading First schools improved more than children who did not, by 2.2 points. Improvement for boys was significantly less than for girls by 3.4 points. Children in the oldest age group showed significantly less improvement than all younger age groups by nearly 5 points. By race, Blacks had the least and Hispanics the greatest improvement and the 5.5 point difference between these two groups was statistically significant. We anticipated but did not see differences in improvement associated with English language speakers, birthplace, or free/reduced lunch status. Although children in the Dual Language program showed the largest improvement in score, nearly 12 and 18 points higher than the other two programs, the differences between programs were not statistically significant.

For the children who scored above benchmark in the fall, children with the highest BLLs had the greatest change in score from fall to spring, but the differences between groups were not statistically significant. Younger aged children made significantly more improvement compared to children in the oldest age group. Girls made significantly more improvement than boys. With regards to race, Hispanics and others (mostly Asian) showed the most improvement and Whites showed the least improvement, significantly less than Hispanics and others. Blacks showed significantly less improvement than Hispanics. English speakers showed significantly less improvement than children speaking Spanish or other languages. Children born in Central/South America showed more improvement than children born in Rhode Island. Children enrolled in the 2004-

2005 kindergarten year experienced significantly more improvement than children enrolled in other school years. Children in the Regular Education program experienced significantly less improvement than children in the other two programs. Children attending a Reading First school showed a 3.8 point improvement compared to children attending a non-Reading First school, a significant difference. Children who paid for their lunch improved significantly less than children who received reduced-price or free school lunches.

5.4.2 Linear Models

We used linear regression to evaluate differences in spring scores as well as fall to spring improvement only for the children who scored below benchmark in the fall (see Tables 5.4 and 5.5). We were unable to use this method to examine changes for the children who scored above benchmark in the fall because their scores and change in scores were not normally distributed.

We used progressive levels of adjustment to characterize the differences associated with BLL categories. In addition to the six co-variates used in our fall analyses (age at kindergarten, gender, year, race, child language and free/reduced price lunch status), we adjusted for kindergarten program, Reading First School and fall PALS-K score.

After adjustment, we found that children with BLL in the 5-9 and 10+µg/dL categories had spring PALS-K scores that were 2.2 and 3.6 points lower, respectively, than children with BLL <5μg/dL. The differences for children with BLL 5-9μg/dL were statistically significant but the differences for children with BLL 10+μg/dL were of borderline statistical significance, possibly due in part to the small number of children in this group (N=110). The decrements in total spring score associated with BLLs 5-9 and 10+μg/dL account for 11% and 19% of one standard deviation in spring score for children who scored below the PALS-K benchmark in the spring.

In this adjusted model, as shown in Table 5.5, we observed significantly lower spring PALS-K scores for children in the oldest age group, for boys, and for Black children. Fall PALS-K scores were positively associated with spring PALS-K scores. Free and reduced lunch status, our measure of SES, child language and all school level characteristics (kindergarten year, kindergarten program, and Reading First school designation) were not associated with spring scores.

The results of the linear regression model characterizing the relationships between lead and improvement in PALS-K Score from fall to spring linear regression model are very similar to the results shown above for PALS-K spring score (data not shown - see Appendix, Tables A.2 and A.3, pages 130 and 131).

5.4.3. Logistic Models

We used logistic regression models to estimate the odds ratios associated with failing to achieve benchmark in the spring (spring score of 81 points or higher). The models were stratified by fall benchmark status (whether a child scored below or above benchmark in the fall) and progressively adjusted by covariates, as described above (see Tables 5.6 & 5.7).

For the children who scored below benchmark in the fall, we found that the likelihood of spring failure was approximately 50% higher for children with BLL 5-9µg/dL and BLL 10+µg/dL compared to those with BLL <5µg/dL, although the results were not significant for BLL 10+µg/dL, possibly due to small sample size. Final model co-variates positively associated with spring failure included older age and Black race compared to those of younger age (odds ratio 1.72) and Hispanics or Whites (odds ratios 1.90 and 1.62 respectively) (see Table 5.7); the confidence limits for Blacks vs Whites did not include unity. Linear increases in fall score (odds 0.87) and attending a Reading First school (odds 0.75) were negatively associated with spring failure, but this latter finding was of borderline significance (p=0.069). No significant associations were observed for gender, kindergarten year, language, free lunch status, or kindergarten program.

For the children who scored above benchmark in the fall, BLLs were not significantly associated with the likelihood of spring failure. Because children whose language was other all achieved spring benchmark, this sub-group was not included in the model. Two model co-variates were positively associated with spring failure: male gender (odds 1.50, compared to females) and receiving a free school lunch (odds 2.44, compared to paying for lunch). Lower confidence limits for each exceeded a value of one. Two co-variates were found to be negatively associated with spring failure: attending a Reading First school (odds 0.38 compared to non-Reading First school) and linear increases in fall scores (odds 0.93). No significant associations were observed for kindergarten year, age group, language (Spanish compared to English), and kindergarten program.

Our second model (see Table 5.6) examined the effect of doubling a child's log GM BLL. For children who scored below benchmark in the fall, a doubling in log BLL was associated with a 28% increased likelihood of spring failure (odds 1.28). For the children who scored above benchmark in the fall, a doubling of log BLL did not increase the likelihood of failure in spring. The associations observed between model covariates and spring failure for both groups of children were similar to those described for the first logistic model (data not shown – see Appendix, Table A.4, page 132).

5.5 Discussion

During the course of kindergarten, the overall proportion of children who achieved PALS-K benchmarks increased by about 15%, from 65% in the fall to about 80% in the spring. However, stratifying by BLL (see Figure 5.3), we saw that BLLs were associated with both achievement of benchmark status and with the proportion of children who improved during kindergarten. Between fall and spring, children with BLLs <5, 5-9 and 10+μg/dL improved 47%, 34% and 40% respectively. Stratifying by fall benchmark status (see Figure 5.2), we observed that 93-94% of the children who achieved benchmark in the fall also achieved benchmark in the spring, compared to 45-58% of the children who did not achieve benchmark in the fall. Clearly although BLLs impact readiness in the spring, the difference in impact is much greater between children who did and did not achieve benchmark in the fall.

For children who entered kindergarten with reading readiness levels below national PALS-K benchmark standards, a history of elevated BLLs above 5μg/dL adversely affected the development of reading readiness skills during kindergarten and put them at a 50% higher likelihood of spring failure. Children whose reading readiness levels were above national benchmark standards in the fall of kindergarten and who had BLLs in the 5-9μg/dL range showed evidence of a decrease in spring reading readiness scores of about one point, compared to children with lower BLLs (e.g. 0-4μg/dL), but were not at higher risk for failure to achieve national reading readiness benchmarks in the spring of kindergarten.

Achieving benchmark PALS-K standards in the fall may reflect some measure of a child's prior enriched environment, the result of earlier childhood education or experiences, which could potentially influence how lead affects cognitive outcomes during kindergarten and early elementary school, similarly to changes reported in animal models [74]. Improvement in learning capacity in animals has been associated with changes in brain size and weight, brain structures (including the hippocampus and the cortex) and brain function, including increases in the number of neurons and in new neuro-circuitry, improvement of neuronal signaling processes and promotion of synaptic plasticity [75]. Due to the limitations of this dataset, we were unable to examine the effect of early childhood education, quality of the home environment, or additional socioeconomic factors that might help to explain these results.

The intensive reading readiness intervention provided to below fall benchmark children during kindergarten in Providence could also be considered to be an "enriched environment" intervention that might improve outcomes for lead-exposed children. Based on the results of similar approaches in other research studies of children with reading disabilities [128,129], it is reasonable to believe that the intensive intervention provided to the below fall benchmark group might be sufficient to affect patterns of neural circuitry in the brain. Therefore, the improvement in reading readiness during kindergarten that we observed for the below benchmark group is likely to have been influenced by the additional reading interventions provided by their teachers and thereby underestimates the true association with lead that would occur in absence of these interventions.

These findings also suggest that earlier educational intervention (before kindergarten) may benefit children with average BLLs above 4µg/dL, particularly those with multiple risk factors for poor educational outcomes. It would be feasible to target children based on their history of one elevated venous BLL or on the basis of an average measure of two or more BLLs, such as a simple mean BLL or the GM BLL used for our study. We generated estimates of the number of Providence kindergarten children who might benefit from earlier enrichment opportunities as a result of elevated BLLs alone based on the following assumptions:

1. The size of new kindergarten classes in Providence remain similar (about 1,750 students)
2. The proportion of students with a history of elevated BLLs remains similar
    a. If based on one BLL: 20% if $\geq$ 10μg/dL and 67% if $\geq$5μg/dL
    b. If based on GM BLL: 6.5% if $\geq$10μg/dL and 39% if $\geq$5μg/dL

Using these assumptions, the estimates vary as shown in table 5.8 (below):

Table 5.8: Estimated number of Providence children who might benefit from early enrichment based on history of elevated BLLs

Target level Blood Lead	Number of children based on one elevated BLL	Number of children based on GM BLL
>10μg/dL	350	114
>5μg/dL	1173	683

If other factors for high-risk were part of the targeting criteria, the estimates could be lower. More than 20% of children aged 0-3 residing in Providence already receive placement into early childhood programs. In Providence in 2008, 779 children, 10% of the population aged 0-3, were placed in early intervention programs [130] and 867 children under the age of three received full or partial child care subsidy, available to families with incomes up to 180% of Federal Poverty Level [130]. Identification and/or eligibility for these programs are made without any systematic examination of BLL testing results. Resources are an issue for poor children in Providence because Rhode Island is one of a dozen states without a state pre-kindergarten program [131].

If schools and early intervention providers are willing to make early educational opportunities available based on a history of BLL elevation, public health departments could devise strategies to appropriately identify and refer children, possibly using the existing case management system for children with elevated BLLs. As a first step, localities could evaluate the effectiveness of their existing early intervention programs to provide adequate assistance to children with a history of elevated BLLs who are at risk for failure to achieve benchmarks in the fall of kindergarten.

Although our study was not designed to evaluate the intervention program for children who scored below benchmark standards in the fall, additional information available from PPSD [132] provides a window into the possible effectiveness of the PALS-K program. Data reported for the entire kindergarten population (not matched by child for fall to spring) for 2002-2003, the year before the program was put into place, and for the same three years as our study (2004, 2005 and 2006 school years) suggests that the gains we observed in the spring may have been substantially different than the progress from fall to spring observed prior to instituting the program (see Figure 5.4 below:

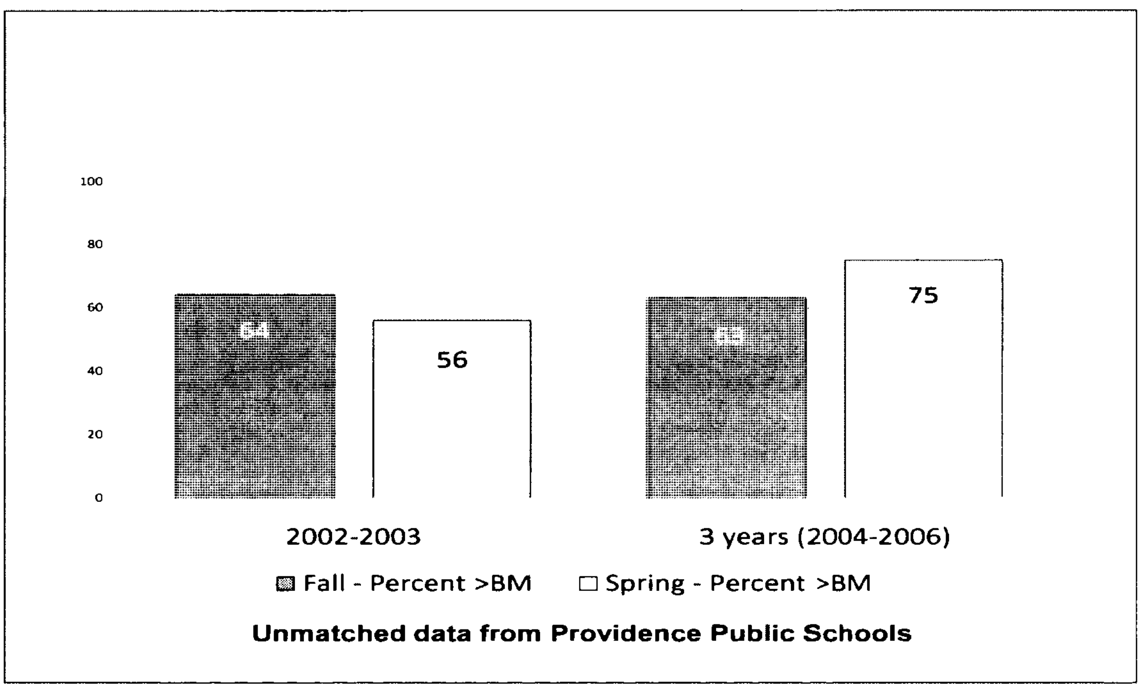

Figure 5.4: Achieving Fall and Spring Benchmarks – Before and After Intervention Program

Higher BLLs continued to be associated with lower PALS-K scores in the spring of kindergarten, as seen in both the bi-variate tables and the linear regression models. However, our ability to use linear models to show adjusted associations for lead with the children who scored above the PALS-K benchmark in the fall was affected by the "ceiling effect." Because 10.7% of the children who scored above benchmark in the fall achieved the highest possible PALS-K test score of 102 in the spring, we were unable to identify additional improvement above that level for these children. This decreased our ability to discriminate differences in improvement between sub-groups in the above-fall benchmark group. The below-fall benchmark group was not affected by the "ceiling effect" because only one child from this group achieved a perfect PALS-K spring score.

For children who scored above the PALS-K benchmark in the fall, we observed a dose response pattern in the bi-variate relationship between BLLs and spring score, but the differences observed for the 10+µg/dL BLL category were not statistically significant. This was most likely associated with the smaller group size (total N=110), greater variability and resulting lower power. We also observed a dose-response relationship in the proportion of children who achieved perfect spring scores.

The magnitude of the bi-variate association of lead with spring PALS-K score was larger for children who scored below the benchmark in the fall compared to children who scored above the benchmark in the fall, supporting Miranda's observation that deficits associated with lead exposure may be larger at lower levels of school performance [6]. Over-all, children who performed well in the spring had lower average BLLs than children who did not, particularly for the children who scored below BM in the fall where many differences across individual characteristics were significant (see Table 5.1).

The differences in average PALS-K scores between fall benchmark groups decreased from 39.2 points in the fall to 19 points in the spring. This suggests that the gap in readiness between the two groups was decreased during kindergarten, possibly as a result of the additional skills-based education the below fall benchmark group received.

The finding that the oldest group of kindergarten children had the lowest spring scores and the lowest fall to spring change compared to children of other ages could be associated with their significantly higher BLLs as well as other factors we do not know about that make this group different from the kindergarten population as a whole.

It is not clear from these data how well children who scored above national reading readiness benchmarks in the fall of kindergarten will continue to perform later in elementary school, in light of their historic exposures to lead. Examining reading end of grade test scores during elementary school using longitudinal analytical approaches could help shed light on the relationship between early reading readiness, a possible marker of early enrichment, and BLLs.

Findings by race suggest that Hispanic children and children of Asian descent enrolled in Providence public schools made substantial improvement in reading readiness during kindergarten, possibly in part as a result of improving fluency in English, while Black children failed to make similar improvements in reading readiness. Part of this racial disparity may be explained by higher BLLs observed for Black children, but lead may not fully account for the large difference in scores seen in children who scored below the benchmark in the fall. The higher spring scores and the 100% success in achieving spring benchmark for the above benchmark children whose race was categorized as "other" may reflect a cultural emphasis on education seen in many Asian nationalities.

Results according to the child's spoken language suggest that by the end of kindergarten, disparities in reading readiness observed in the fall for children who spoke a language other than English (40%) had largely been eliminated. Based on PALS-K research reported elsewhere, we would have expected English speakers to out-perform Spanish speakers in both the fall and the spring [19,19,116]. Overall, our findings suggest that Providence students who spoke English may not have experienced the same degree of educational progress during kindergarten as Hispanic and Asian immigrant groups, possibly due to over-all improvements in English proficiency in the latter groups.

In the fall of kindergarten, differences by SES, measured by free /reduced lunch status, were large and equal in size to differences associated with elevated BLLs. By spring, however, these differences were no longer significant for the children who scored below benchmark in the fall. However, only 6% of the children in this group paid for their lunch, resulting in increased variability and lower power to detect a difference. These surprising findings suggest that the environment of kindergarten along with the additional help focused on reading skills may also have provided sufficient enrichment to minimize some of the disparities associated with SES. But for children who scored above the benchmark in the fall, the association of PALS-K spring scores with SES was apparent, with a dose-response relationship and an odds of failure of 2.44 for children who received a free school lunch, compared to children who paid for their lunch.

The additional reading instruction received in Reading First schools, adjusted for other factors, did seem to be beneficial, particularly for those who scored above benchmark in the fall. These children improved significantly in the spring, whereas improvement for their below benchmark counterparts was more borderline. This supports the value of Reading First-type of approach for all students.

The above evidence indicates that many factors are at play with regard to fall to spring improvement in reading readiness for children who began kindergarten with low skills. Despite on-going secondary and primary lead poisoning prevention efforts, a very high proportion of Providence kindergarten children have experienced BLLs above 9μg/dL - 20%, more than 14 times higher than national estimates of U.S. children aged 1-5 reported by NHANES during a similar time period [14]. Therefore, it may be valuable to determine whether existing programs to remediate lead hazards in the homes of affected children have met with sufficient success, or whether the BLL targets for environmental intervention should be lowered further in an effort to decrease lead exposure for a large proportion of the population of young children in Providence.

With the help of the Providence Plan, we used the results of this study to identify neighborhoods where a high percentage of children failed to achieve benchmarks in both the fall and the spring (see figure 5.5). The additional mapping of existing community literacy assets, such as libraries, schools, early childhood education programs, community-based organizations, home visiting programs and parenting programs, would inform a discussion of possible next steps. These might include targeting additional community literacy assets to areas identified as high-risk, developing strategies to improve utilization of existing community resources, or securing additional slots for early education programs for individual children who live in identified neighborhoods.

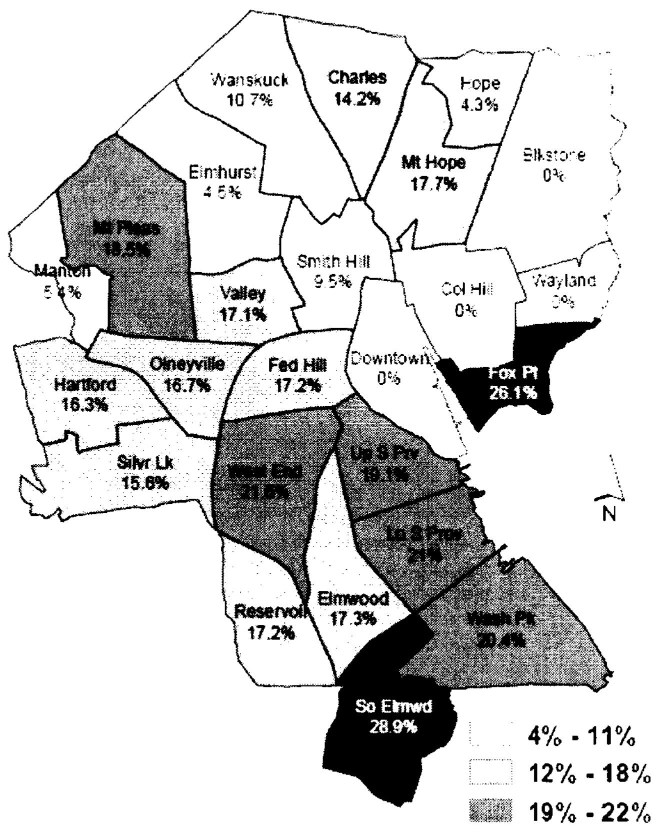

Figure 5.5: Percent of students falling below both fall and spring PALS-K benchmarks, by neighborhood, Providence, RI 2004-2006

5.6 Conclusions

This is the first study to explore longitudinal improvement in reading readiness associated with BLL during kindergarten in a diverse population of children and demonstrates the feasibility and value of linking school and child health data to examine academic progress. This relationship was particularly evident for children who entered kindergarten with low levels of reading readiness and BLLs of 5μg/dL, or greater who were less successful during kindergarten and 50% more likely to fail to achieve national reading readiness standards at the end of kindergarten than children with BLLs below 5μg/dL. This occurred even though these children were routinely provided additional in-class instruction focused on reading skills. Of note is the fact that these children were clearly at risk at levels well below a BLL of 10μg/dL, the CDC's current recommendation as level of concern.

Although we were not able to evaluate the effect of the educational intervention provided to children who scored below benchmark standards in the fall, the unmatched results from PPSD suggest that improvement did occur. Other study designs, such as a randomized clinical trial or a pre-post program evaluation, may be useful in determining whether such interventions are particularly effective for children with elevated BLLs. The improvements associated with Reading First schools, particularly for children who entered kindergarten with higher levels of reading readiness, suggest that additional enrichment efforts like these should be continued, particularly in populations at high risk for school failure.

These findings also suggest the need to evaluate current screening programs that identify and intervene early (before kindergarten) with at-risk children, raising the possibility that knowledge of BLL may improve targeting decisions. If schools and early intervention providers are willing to make additional early educational opportunities available based on a history of BLL elevation, public health departments could devise strategies to appropriately identify and refer children, using the existing case management system which is in place for children with elevated BLLs. Mapping of the results of reading readiness evaluations, such as this study, and community literacy assets could inform discussions of next steps at the community level.

Finally, a note of caution is in order. It is not clear from these data how the educational progress of children who scored above national reading readiness benchmarks in the fall of kindergarten in Providence will be affected by their history of elevated BLLs in later grades. Elevated BLLs have been associated with end of grade reading scores in 3rd and 4th grades [6,123]. Extension of longitudinal analytical approaches to evaluate later educational outcome measures for this population of children, for example at the end of 3rd or 4th grade, may contribute even more to our body of knowledge regarding the association between BLLs, reading performance and early reading readiness.

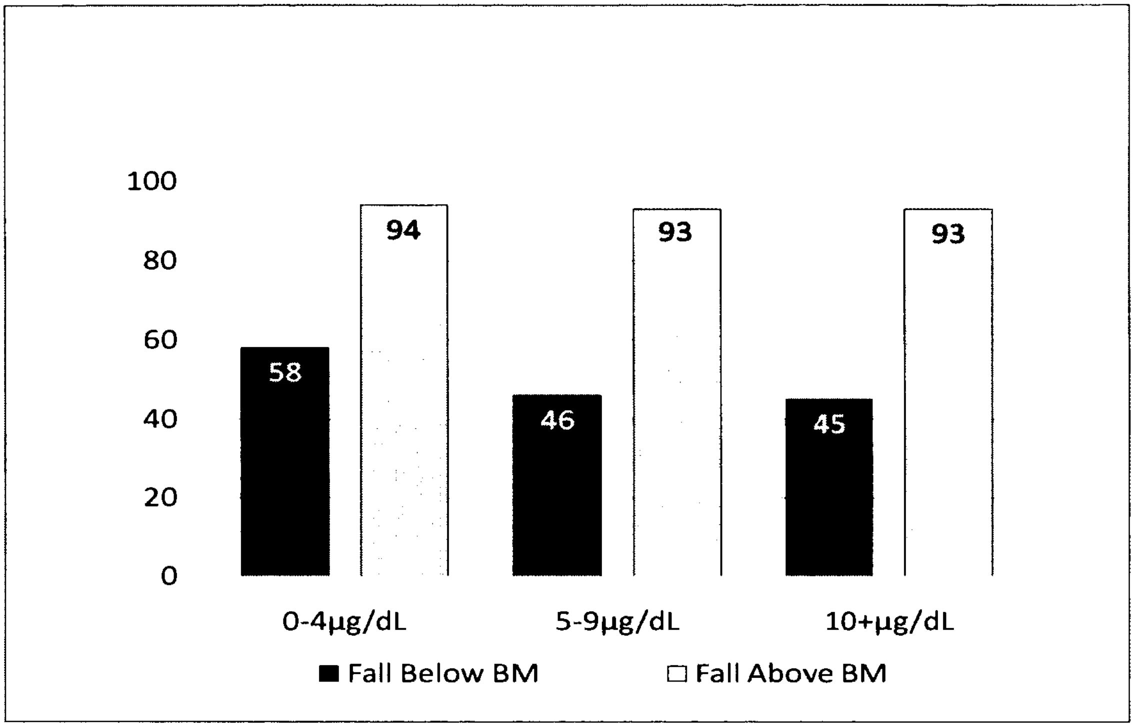

Figure 5.2: Proportion of children above spring PALS-K benchmark, by BLL and fall benchmark status

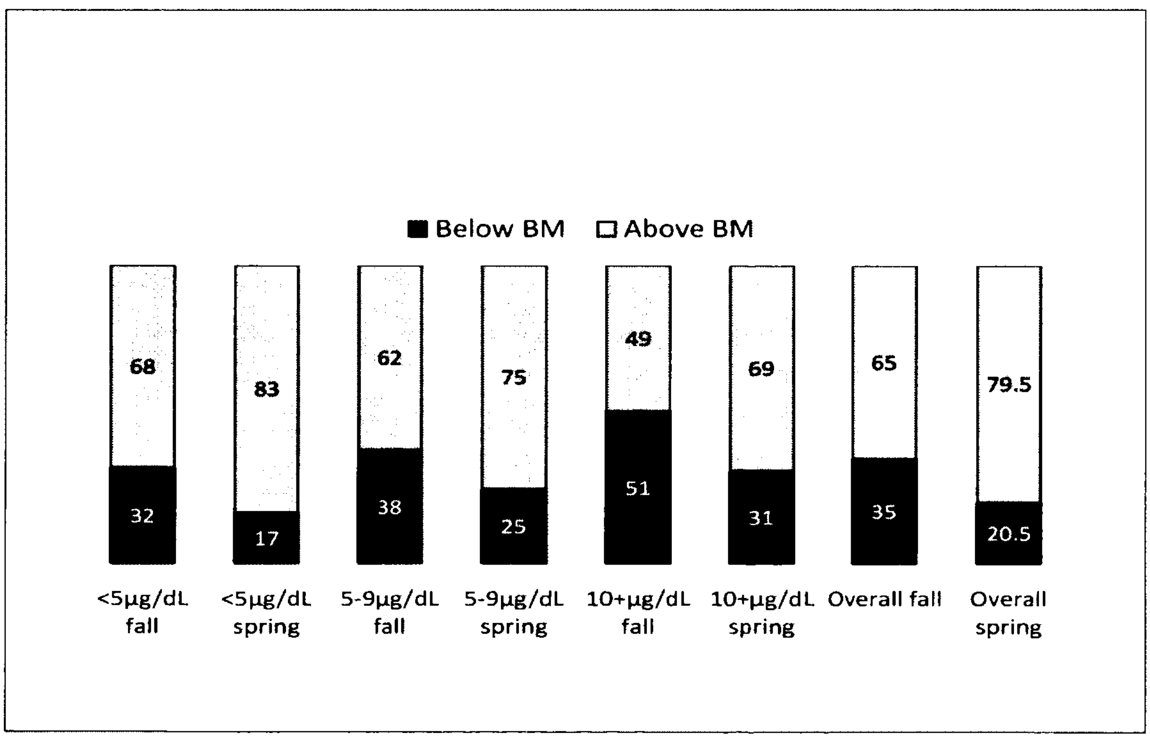

Figure 5.3 Proportion of children above PALS-K benchmarks, by BLL, fall vs spring test

Table 5.1: Median Geometric Mean (GM) Blood Lead Levels (BLLs) for Study Population Characteristics, stratified by fall & spring benchmark status

Variable	Total Group (N=3406)		Below Fall Benchmark (N=1193)					Above Fall Benchmark (N=2213)				
			Below Spring BM		p	Above Spring BM		Below Spring BM		p	Above Spring BM	
	N	Median GM BLL (IQR)	N	Median GM BLL (IQR)		N	Median GM BLL (IQR)	N	Median GM BLL (IQR)		N	Median GM BLL (IQR)
Entire Group	3406	4.2 (2.9-6.0)	565	5.0 (3.3-7.0)	1	628	4.1 (2.9-6.0)	133	4.2 (3.0-6.2)		2080	4.0 (2.7-5.7)
Blood Lead Categories		p<0.001										
BLL <5 µg/dL	2091	3.1 (2.2-4.0)	279	3.3 (2.5-4.0)		389	3.1 (2.4-4.0)	79	3.0 (2.5-4.0)		1344	3.0 (2.0-4.0)
BLL 5-9 µg/dL	1098	6.3 (5.5-7.5)	225	6.5 (5.7-7.6)		190	6.4 (5.6-7.5)	47	6.5 (5.7-8.2)	3	636	6.1 (5.5-7.5)
BLL 10+ µg/dL	217	11.7(10.8-14.2)	61	12.1(11.2-14.4)		49	11.8 (10.5-13.5)	7	11.4 (10.9-11.7)		100	11.4 (10.6-14.4)
Child Characteristics												
Gender		p=0.34										
Female	1679	4.2 (2.9-6.0)	238	5.0 (3.4-7.0)	2	297	4.0 (2.9-6.0)	56	3.5 (2.8-6.0)		1088	4.0 (2.8-5.7)
Male	1727	4.2 (2.8-6.0)	327	4.9 (3.2-7.0)	3	331	4.2 (2.8-6.3)	77	4.8 (3.0-6.5)	4	992	4.0 (2.7-5.8)
Age at Start of Kind.		p<0.0001										
<5yrs3mos	901	4.2 (2.9-6.0)	176	4.8 (3.4-6.6)		196	4.2 (2.8-5.9)	33	4.2 (3.0-8.0)	2	496	4.0 (2.8-5.7)
5yrs3mos -<5yrs6mos	881	4.0 (2.7-5.6)	141	4.6 (3.0-6.6)		182	4.1 (2.9-5.9)	37	3.4 (2.5-5.5)		521	3.9 (2.6-5.2)
5yrs6mos -<5yrs9mos	888	4.2 (2.8-6.0)	115	5.0 (3.3-7.1)	3	160	4.0 (2.8-5.9)	32	4.4 (2.9-5.9)		581	4.1 (2.7-5.9)
5 yrs9mos +	736	4.6 (3.1-6.6)	133	5.6 (3.9-8.0)		90	4.5 (3.2-7.0)	31	4.8 (3.9-6.0)		482	4.5 (3.0-6.0)
Race		p<0.0001										
White	442	4.2 (2.7-6.0)	50	6.3 (3.7-9.4)	1	50	4.0 (2.5-5.9)	23	3.9 (3.0-6.0)		319	4.2 (2.5-5.7)
Black	707	5.0 (3.2-7.0)	98	5.9 (4.0-8.0)		76	5.6 (3.2-8.1)	41	5.0 (2.9-6.1)		492	4.6 (3.1-6.9)
Hispanic	2021	4.0 (2.7-5.6)	375	4.4 (3.0-6.5)	3	460	4.0 (2.8-5.7)	64	4.0 (2.9-6.6)	4	1122	3.9 (2.5-5.3)
Other**	236	4.5 (3.0-6.5)	42	6.0 (4.5-8.3)		42	4.5 (2.9-8.0)	5	4.8 (4.2-4.8)		147	4.1 (2.6-5.6)
Child Language		p<0.0001										
English	2074	4.3 (3.0-6.1)	281	5.2 (3.6-7.4)	2	289	4.4 (3.0-6.5)	97	4.2 (3.0-6.0)		1407	4.2 (2.8-6.0)
Spanish	1219	4.0 (2.7-5.5)	258	4.4 (2.9-6.5)	3	307	3.9 (2.7-5.6)	34	4.5 (2.7-7.6)		620	3.9 (2.6-5.3)
Other***	98	5.0 (3.5-8.0)	25	6.2 (5.7-9.4)		28	4.7 (2.9-7.5)	0	--		45	4.4 (2.8-6.8)
Missing	15	3.9 (2.4-6.6)	1	8.0 (8.0-8.0)		4	5.6 (4.3-8.1)	2	3.1 (2.4-3.9)		8	3.0 (1.8-5.4)
Birthplace		p<0.0001										
Rhode Island	2796	4.2 (2.9-6.0)	445	5.0 (3.2-7.0)	2	492	4.2 (2.9-6.3)	107	4.2 (2.9-6.0)		1752	4.0 (2.8-5.7)
USA – not RI	424	4.0 (2.7-6.0)	85	4.4 (3.6-7.0)	1	88	3.6 (2.5-4.9)	16	3.9 (3.0-6.1)		235	3.7 (2.3-5.9)
Central/South Amer.	100	3.9 (2.9-5.7)	22	5.0 (3.6-7.0)	4	29	3.6 (2.9-5.0)	4	7.4 (4.5-9.2)	3	45	3.7 (2.5-5.0)
Other	57	6.3 (3.6-9.9)	7	8.0 (4.9-11.0)		16	6.8 (3.9-8.9)	4	5.7 (3.2-8.5)		30	6.0 (3.6-10.0)
Missing	29	4.0 (2.7-5.7)	6	4.6 (3.9-6.7)		3	5.7 (5.4-10.5)	2	3.1 (2.4-8.9)		18	3.7 (1.8-4.7)

Variable	Total Group (N=3406)		Below Fall Benchmark (N=1193)					Above Fall Benchmark (N=2213				
			Below Spring BM			Above Spring BM		Below Spring BM			Above Spring BM	
	N	Median GM BLL (IQR)	N	Median GM BLL (IQR)	p	N	Median GM BLL (IQR)	N	Median GM BLL (IQR)	p	N	Median GM BLL (IQR)
School Characteristics												
Kindergarten Year		p=0.55										
2004/2005	870	4.0 (2.7-6.0)	160	5.0 (3.2-7.0)	1	190	3.9 (2.8-5.5)	37	4.8 (3.1-7.0)		483	4.0 (2.5-5.7)
2005/2006	1272	4.2 (2.9-6.0)	212	5.0 (3.6-6.9)	3	227	4.2 (2.9-6.0)	52	4.0 (3.0-5.1		781	4.0 (2.8-5.7)
2006/2007	1264	4.3 (2.9-6.1)	193	4.9 (3.1-7.1)		211	4.4 (2.9-6.7)	44	4.5 (3.0-6.4)		816	4.2 (2.9-5.9)
Kindergarten Program		p=0.30										
Dual Language	115	3.9 (2.9-5.7)	16	4.6 (3.4-6.7)		27	3.9 (2.9-5.5)	2	5.7 (2.5-9.0		70	3.9 (2.9-5.4)
English as a 2nd Lang	568	4.2 (2.9-6.2)	158	4.9 (3.3-7.0)	3	196	3.8 (2.8-5.9)	10	4.9 (3.0-7.6)		204	4.0 (2.3-5.4)
Regular	2723	4.2 (2.8-6.0)	391	5.0 (3.3-7.0)	2	405	4.2 (2.9-6.3)	121	4.2 (3.0-6.0)		1806	4.0 (2.7-5.8)
Reading First School		p=0.66										
Yes	891	4.2 (2.9, 6.0)	126	4.9 (3.5-6.9)	4	178	4.2 (2.9-5.7)	17	3.2 (2.5-6.0)		570	4.0 (2.8-5.9)
No	2515	4.2 (2.9-6.0)	439	5.0 (3.3-7.0)	2	450	4.0 (2.8-6.3)	116	4.3 (3.0-6.2)		1510	4.0 (2.7-5.7)
Socioeconomic Status												
Free/Reduced Lunch Status		p<0.0001										
Free	2713	4.3 (3.0-6.1)	498	5.0 (3.5-7.0)	2	528	4.2 (3.0-6.3)	119	4.2 (3.0-6.0)		1568	4.2 (2.9-5.9)
Reduced	357	3.8 (2.5-5.2)	41	3.2 (2.4-5.6)		56	3.5 (2.3-4.9)	7	3.1 (2.5-8.1)		253	3.9 (2.5-5.2)
Pay	336	3.9 (2.3-5.6)	26	5.1 (2.9-7.1)	3	44	3.9 (2.1-5.2)	7	5.0 (3.0-6.8)		259	3.5 (2.2-5.3)

p = The p-values shown indicate significant differences between the children who scored below and above spring benchmarks, within each fall benchmark group, based on t-tests.

1 = $p \leq 0.001$
2 = $p \leq 0.01$
3 = $p \leq 0.05$
4 = $p < 0.08$ borderline

**race – Asians make up 92% of "Other" * **child language – Asian languages make up 80% of "Other" Data as of Sept. 15, 2009, November 13, 2009, December 18, 2009

Table 5.2: Means of Spring PALS-K Total Scores by Study Population Characteristics (N= 3406)

Variable	Below Fall Benchmark Group			Above Fall Benchmark Group		
	N	Score (SD)	% > Spring B-mark	N	Score (SD)	% > Spring B-mark
Entire Group	1193	75.1 (19.8)	53	2213	93.9 (7.7)	94
Blood Lead Categories		p=0.0007			p=0.0080	
BLL <5 μg/dL	668	77.0 (19.5)	58	1423	94.2 (7.3)	94
BLL 5-9 μg/dL	415	73.4 (19.0)	46	683	93.1 (8.3)	93
BLL 10+ μg/dL	110	70.8 (22.8)	45	107	93.5 (7.2)	93
Individual Child Characteristics						
Gender		p=0.0013			p=0.0046	
Female	535	77.2 (17.8)	56	1144	94.3 (7.2)	95
Male	658	73.5 (21.1)	50	1069	93.4 (8.1)	93
Age at Start of Kindergarten		p=0.0033			p=0.12	
<5 years 3 months	372	76.0 (18.6)	53	529	93.3 (7.8)	94
5 years + 3 to <6 months	323	76.2 (19.8)	56	558	93.7 (7.6)	93
5 years + 6 to <9 months	275	76.3 (19.2)	58	613	94.1 (7.4)	95
5 years + 9 months +	223	70.7 (21.7)	40	513	94.4 (7.9)	94
Race		p=0.12			p=0.0015	
White	100	73.7 (21.5)	50	342	94.6 (8.0)	93
Black	174	72.2 (20.9)	44	533	92.8 (8.4)	92
Hispanic	835	76.0 (19.4)	55	1186	94.0 (7.2)	95
Other*	84	74.7 (18.9)	50	152	94.7 (7.0)	97
Child Language		p=0.85			p=0.56	
English	570	74.8 (19.8)	51	1504	93.8 (7.9)	94
Spanish	565	75.4 (19.8)	54	654	94.0 (7.2)	95
Other**	53	75.3 (20.4)	53	45	94.9 (5.2)	100
Missing	5	83.8 (13.4)	80	10	89.2 (9.4)	80
Birthplace		p=0.34			p=0.46	
Rhode Island	937	75.2 (20.0)	53	1859	93.9 (7.6)	94
US = not Rhode Island	173	73.5 (20.0)	51	251	94.0 (7.8)	94
Central/South America	51	78.6 (14.7)	57	49	92.6 (8.4)	92
Other	23	78.3 (21.2)	70	34	92.4 (8.9)	88
Missing	9	72.3 (15.4)	33	20	92.4 (8.4`)	90
School Characteristics						
Kindergarten Year		p=0.38			p=0.0237	
2004/2005	350	76.4 (18.9)	54	520	93.2 (7.7)	93
2005/2006	439	74.8 (20.0)	52	833	93.7 (7.8)	94
2006/2007	404	74.4 (20.3)	52	860	94.4 (7.5)	95
Kindergarten Program		p=0.0872			p=0.45	
Dual Language	43	81.6 (13.6)	63	72	94.8 (5.8)	97
English as a 2nd Lang.	354	74.6 (20.4)	55	214	93.5 (6.7)	95
Regular	796	75.0 (19.7)	51	1927	93.9 (7.8)	94
Reading First School		p=0.0357			p<0.0001	
Yes	304	77.2 (19.3)	59	587	95.3 (6.1)	97
No	889	74.4 (19.9)	51	1626	93.3 (8.1)	93
Socioeconomic Status						
Free/Reduced Lunch Status		p=0.71			p<0.0001	
Free	1026	75.0 (19.7)	51	1687	93.4 (7.8)	93
Reduced	97	76.5 (19.0)	58	260	95.0 (7.4)	97
Pay	70	76.0 (22.8)	63	266	95.8 (6.6)	97

*race – Asians make up 92% of "other" **child language – Asian languages make up 80% of "other" Data as of September 15, 2009 & December 18, 2009 The p-values shown for each category are the result of test differences across categories using t-tests for 2-category variables and t-tests with Bonferroni adjustments for variables with more than 2 categories.

Table 5.3: Means of Fall-Spring Change in PALS-K Total Score by Study Population Characteristics and Fall Benchmark Status (N=3406)

Variable	Below Fall Benchmark Group			Above Fall Benchmark Group		
	N	Change in Score (SD)	% > Spring B-mark	N	Change in Score (SD)	% > Spring B-mark
Entire Group	1193	59.5 (17.7)	53	2213	38.8 (15.5)	94
Blood Lead Categories		p=0.0021			p=0.55	
BLL <5 μg/dL	668	61.0 (17.8)	58	1423	38.6 (15.5)	94
BLL 5-9 μg/dL	415	58.0 (16.7)	46	683	38.9 (15.6)	93
BLL 10+ μg/dL	110	55.8 (20.4)	45	107	40.3 (16.0)	93
Individual Child Characteristics						
Gender		p=0.0010			p=0.0699	
Female	535	61.3 (15.9)	56	1144	39.4 (15.4)	95
Male	658	57.9 (19.0)	50	1069	38.2 (15.7)	93
Age at Start of Kindergarten		p=0.0019			p<0.0001	
<5 years 3 months	372	60.3 (16.9)	53	529	41.2 (15.1)	94
5 years + 3 to <6 months	323	60.7 (17.7)	56	558	40.0 (15.4)	93
5 years + 6 to <9 months	275	60.2 (17.4)	58	613	38.1 (15.2)	95
5 years + 9 months +	223	55.4 (19.1)	40	513	36.0 (16.0)	94
Race		p=0.0021			p<0.0001	
White	100	58.0 (19.4)	50	342	34.1 (15.7)	93
Black	174	55.1 (18.2)	44	533	36.2 (14.8)	92
Hispanic	835	60.6 (17.4)	55	1186	41.3 (15.3)	95
Other*	84	59.1 (16.9)	50	152	39.5 (15.6)	97
Child Language		p=0.11			p<0.0001	
English	570	58.3 (17.6)	51	1504	36.6 (15.3)	94
Spanish	565	60.5 (17.8)	54	654	43.7 (14.9)	95
Other**	53	59.8 (18.7)	53	45	43.3 (15.3)	100
Missing	5	64.0 (11.5)	80	10	34.1 (13.2)	80
Birthplace		p=0.20			p=0.0714	
Rhode Island	937	59.5 (17.9)	53	1859	38.7 (15.4)	94
US = not Rhode Island	173	58.0 (17.5)	51	251	38.6 (16.7)	94
Central/South America	51	63.4 (15.1)	57	49	44.6 (16.3)	92
Other	23	63.1 (18.6)	70	34	38.3 (14.9)	88
Missing	9	56.1 (13.1)	33	20	35.8 (13.3)	90
School Characteristics						
Kindergarten Year		p=0.62			p=0.0029	
2004/2005	350	60.2 (17.0)	54	520	40.7 (14.9)	93
2005/2006	439	58.9 (18.1)	52	833	37.8 (15.8)	94
2006/2007	404	59.4 (18.0)	52	860	38.6 (15.5)	95
Kindergarten Program		p=0.0752			p<0.0001	
Dual Language	43	63.5 (11.8)	63	72	47.8 (12.3)	97
Eng as 2nd Lang	354	60.6 (17.9)	55	214	49.6 (12.8)	95
Regular	796	58.7 (17.9)	51	1927	37.3 (15.3)	94
Reading First School		p=0.0622			P<0.0001	
Yes	304	61.1 (16.5)	59	587	41.6 (14.5)	97
No	889	58.9 (18.1)	51	1626	37.8 (15.8)	93
Socioeconomic Status						
Free/Reduced Lunch Status		p=0.70			p<0.0001	
Free	1026	59.4 (17.6)	51	1687	39.6 (15.2)	93
Reduced	97	60.9 (17.8)	58	260	38.3 (16.3)	97
Pay	70	59.1 (19.7)	63	266	34.3 (15.8)	97

*race – Asians make up 92% of "other" **child language – Asian languages make up 80% of "other" Data as of September 15, 2009 and December 18, 2009. The p-values shown for each category are the result of test differences across categories using t-tests for 2-category variables and t-tests with Bonferroni adjustments for variables with more than 2 categories.

Table 5.4: PALS-K Spring Scores (95% Confidence Intervals) by Blood Lead Level Categories, for children who scored below PALS-K Benchmark in the fall (N=1193)

	Number		Model 1[a]	Model 2[b]	Model 3[c]	Model 4[d]	Model 5[e]
	Below Spring BM	Above Spring BM					
Geometric Mean Blood Lead (μg/dL) Total N= 1194	565	628					
0-4μg/dL	279	389	Reference	Reference	Reference	Reference	Reference
5-9μg/dL	225	190	-3.6 (-6.0, -1.2)	-3.4 (-5.8, -0.9)	-3.4 (-5.8, -0.9)	-3.3 (-5.8, -0.9)	-2.1 (-4.3, 0.09)[1]
10+μg/dL	61	49	-6.2 (-10.2, -2.2)	-5.1 (-9.2, -1.1)	-5.1 (-9.2, -1.0)	-5.0 (-9.0, -0.9)	-3.6 (-7.2, 0.04)[2]
p-trend			<0.001	0.001	0.001	0.001	0.009
r^2			0.0121	0.0344	0.0346	0.0397	0.2411

[1] = borderline p=0.060 [2] = borderline p=0.053 Source: December 17, 2009

[a]Model 1 – lead only
[b]Model 2 – further adjusted for age at kindergarten, sex, year, race, child language
[c]Model 3 – further adjusted for free/reduced lunch status
[d]Model 4 – further adjusted for kindergarten program and Reading First school
[e]Model 5 – further adjusted for **fall PALS-K score**

Table 5.5: Association of model covariates with PALS-K Spring Summary Scores for children below PALS-K benchmark in fall (N=1193), before/after adjusting for lead

Covariates	Differences in Spring PALS-K Summary Score (95% CI)	Differences in **Spring** PALS-K Summary Score (95% CI)
	Before adjusting for lead[a]	After adjusting for lead
GM BLL 0-4µg/dL		Reference
GM BLL 5-9µg/dL		**-2.11[4] (-4.30, 0.09)**
GM BLL 10+µg/dL		**-3.59[5] (-7.21, 0.04)**
Female	Reference	Reference
Male	-3.22 (-5.23, -1.20)	**-3.25[1] (-5.27. -1.23)**
Year 2004-2005	Reference	Reference
Year 2005-2006	0.05 (-2.55, 2.45)	0.08 (-2.43, 2.57)
Year 2006-2007	0.74 (-1.83, 3.30)	0.87 (-1.69, 3.44)
Age group 5-5¼ years	Reference	Reference
Age group 5¼ - 5½ years	0.13 (-2.49, 2.75)	-0.95 (-2.52, 2.71)
Age group 5½ - 5¾ years	-0.57 (-3.31, 2.18)	-0.58 (-3.32, 2.16)
Age group 5¾ years and older	**-4.92[1] (-7.89, -1.95)**	**-4.66[2] (-7.64, -1.69)**
Race Hispanic	Reference	Reference
Race White	-1.89 (-5.88, 2.11)	-1.62 (-5.62, 2.38)
Race Black	**-5.24[2] (-8.59, -1.88)**	**-4.78[2] (-8.15, -1.41)**
Race Other	-2.06 (-7.00, 2.89	-1.75 (-6.69, 3.20)
Race White	Reference	Reference
Race Black	-3.35 (-7.67, 0.97)	-3.15 (-7.47, 1.16)
Race Hispanic	1.89 (-2.11, 5.88)	1.62 (-2.38, 5.62)
Race Other	-0.17 (-5.68, 5.35)	-0.17 (-5.63, 5.38)
Language English	Reference	Reference
Language Spanish	-0.77 (-3.56, 2.03)	-0.96 (-3.76, 1.84)
Language Other	1.82 (-3.99, 7.62)	2.21 (-3.60, 8.01)
Pay for lunch	Reference	Reference
Reduced lunch	1.67 (-3.73, 7.07)	1.38 (-4.02, 6.77)
Free lunch	0.37 (-3.87, 4.62)	0.54 (-3.71, 4.78)
Fall score (linear)	**1.35[1] (1.20, 1.50)**	**1.34[1] (1.19, 1.48)**
Dual Language Program	Reference	Reference
English as a Second Language Program	0.14 (-5.76, 6.04)	0.31 (-5.59, 6.21)
Regular program	-1.74 (-7.53, 4.04)	-1.65 (-7.43, 4.12)
Not Reading First School	Reference	Reference
Reading First School	1.64 (-0.81, 4.08)	1.66 (-0.79, 4.10)
Constant	**61.38[1] (52.56, 70.19)**	**62.28[1] (53.40, 71.16)**
R^2	.2374	.2411

[a] This model was adjusted for: sex, year, age at time of test, race, child language, free/reduced lunch status, kindergarten program, Reading First School and fall score.
Source: November 25, 2009 **Note:** Significant associations are **bolded.**
[1] = statistically significant at p=0.001 [2] = statistically significant at p=0.01
[3] = statistically significant at p=0.05 [4] = borderline, p=0.060 [5] = borderline, p=0.053

Table 5.6: Odds Ratio of Scoring Below PALS-K Spring Benchmark (95% Confidence Intervals) by Blood Lead Categories & Log2 Blood Lead

	Number		Model 1[a]	Model 2[b]	Model 3[c]	Model 4[d]	Model 5[e]
	Below Spring BM	Above Spring BM					
Blood Lead Category Logistic Model							
Below Fall Benchmark							
Geometric Mean Blood Lead (μg/dL) Total N= 1,193	565	628					
0-4μg/dL	279	389	Reference	Reference	Reference	Reference	Reference
5-9μg/dL	225	190	1.65 (1.29, 2.11)[1]	1.60 (1.24, 2.06)[1]	1.59 (1.23, 2.05)[1]	1.58 (1.23, 2.04)[1]	1.52 (1.15, 2.01)[2]
10+μg/dL	61	49	1.74 (1.16, 2.61)[2]	1.56 (1.03, 2.38)[3]	1.53 (1.00, 2.34)[3]	1.55 (1.01, 2.37)[3]	1.48 (0.93, 2.35)[4]
p-trend			<0.001	<0.001	0.001	0.001	0.004
Above Fall Benchmark							
Geometric Mean Blood Lead (μg/dL) Total N= 2,213	133	2080					
0-4μg/dL	79	1344	Reference	Reference	Reference	Reference	Reference
5-9μg/dL	47	636	1.26 (0.87, 1.83)*	1.27 (0.87, 1.86)*	1.25 (0.85, 1.84)*	1.25 (0.85 1.84)*	1.12 (0.75, 1.67)*
10+μg/dL	7	100	1.19 (0.54, 2.65)*	1.20 (0.53, 2.70)*	1.10 (0.49, 2.49)*	1.13 (0.50, 2.55)*	1.03 (0.44, 2.40)*
p-trend			0.276	0.269	0.394	0.298	0.592
Log2 Blood Lead Logistic Model							
Below Fall Benchmark							
Log2 GM BLL Total N= 1,193	565	628	1.34 (1.17, 1.54)	1.31 (1.14, 1.50)	1.29 (1.12, 1.48)	1.29 (1.12, 1.49)	1.28 (1.10, 1.49)
p-value			<0.001	<0.001	<0.001	<0.001	0.002
Above Fall Benchmark							
Log2 GM BLL Total N= 2,213	133	2080	1.17 (0.95, 1.45)*	1.17 (0.94, 1.46)*	1.12 (0.90, 1.40)*	1.13 (0.90, 1.41)*	1.05 (0.84, 1.33)*
p-value			0.149	0.160	0.308	0.263	0.539

*= not statistically significant at p=0.05

[1]= statistically significant at p = 0.001 [2]= statistically significant at p = 0.01 [3]= statistically significant at p = 0.05 [4] = marginal significance at p=0.096

[a]Model 1 – lead only

[b]Model 2 – further adjusted for age at kindergarten, sex, year, race and child language

[c]Model 3 – further adjusted for free/reduced lunch status

[c]Model 4 – further adjusted for kindergarten program and Reading First school

[c]Model 5 – further adjusted for **PALS-K fall score** September 24, 2009, November 3-4, 2009, December 17, 2009

Table 5.7: Odds Ratios (95% CI) of Scoring Below Spring Benchmark, for model covariates, before and after adjusting for lead

	Below Fall Benchmark Model		**Above Fall Benchmark Model**	
	Before adjusting for lead	**After** adjusting for lead	**Before** adjusting for lead	**After** adjusting for lead
Covariates	Odds of Scoring Below Spring B-mark (95% CI)	Odds of Scoring Below Spring B-mark (95% CI)	Odds of Scoring Below Spring B-mark (95% CI)	95% CI
GM BLL 0-4µg/dL		Reference		Reference
GM BLL 5-9 µg/dL		**1.52[2](1.15, 2.01)**		1.12 (0.75, 1.67)
GM BLL 10+ µg/dL		1.48 (0.93, 2.35)		1.03 (0.44, 2.40)
Female	Reference	Reference	Reference	Reference
Male	1.24 (0.96, 1.61)	**1.26[5] (0.97, 1.63)**	**1.51[3] (1.04, 2.19)**	**1.50[3] (1.03, 2.19)**
Year 2004-2005	Reference	Reference	Reference	Reference
Year 2005-2006	0.96 (0.70, 1.32)	0.95 (0.69, 1.30)	0.93 (0.58, 1.49)	0.93 (0.58, 1.49)
Year 2006-2007	0.82 (0.59, 1.14)	0.80 (0.58, 1.12)	0.74 (0.45, 1.20)	0.73 (0.45, 1.20)
Age group 5-5¼ years	Reference	Reference	Reference	Reference
Age group 5¼ - 5½ years	0.85 (0.61, 1.18)	0.85 (0.61, 1.18)	1.13 (0.68, 1.88)	1.12 (0.68, 1.87)
Age group 5½ - 5¾ years	0.85 (0.60, 1.19)	0.84 (0.59, 1.19)	0.99 (0.58, 1.67)	0.98 (0.58, 1.67)
Age group 5¾ years and older	**1.80[2] (1.23, 2.62)**	**1.73[2] (1.18, 2.54)**	1.43 (0.82, 2.47)	1.40 (0.81, 2.45)
Race Hispanic	Reference	Reference	Reference	Reference
Race White	1.20 (0.72, 1.98)	1.17 (0.70, 1.94)	1.51 (0.83, 2.73)	1.49 (0.82, 2.71)
Race Black	**2.00[2] (1.29, 3.08)**	**1.90[2] (1.22, 2.94)**	1.28 (0.76, 2.14)	1.25 (0.74, 2.11)
Race Other	1.53 (0.82, 2.89)	1.48 (0.79, 2.79)	0.89 (0.32, 2.47)	0.89 (0.32, 2.47)
Race White	Reference	Reference	Reference	Reference
Race Black	**1.67[4] (0.96, 2.90)**	**1.62[5] (0.93, 2.83)**	0.85 (0.78, 1.50)	0.84 (0.47, 1.49)
Race Hispanic	0.84 (0.51, 1.38)	0.86 (0.52, 1.42)	0.66 (0.37, 1.21)	0.67 (0.37, 1.22)
Race Other	1.28 (0.64, 2.58)	1.27 (0.63, 2.55)	0.59 (0.21, 1.68)	0.60 (0.21, 1.70)
Language English	Reference	Reference	Reference	Reference

Language Spanish	1.16 (0.82, 1.66)	1.21 (0.85, 1.74)	0.89 (0.51, 1.55)	0.88 (0.50, 1.54)
Language Other	0.81 (0.39, 1.72)	0.76 (0.36, 1.61)	*	*
Pay for lunch	Reference	Reference	Reference	Reference
Reduced lunch	1.13 (0.56, 2.27)	1.19 (0.59, 2.40)	1.07 (0.36, 3.21)	1.08 (0.36, 3.23)
Free lunch	1.52 (0.87, 2.66)	1.49 (0.85, 2.61)	**2.43[3] (1.08, 5.48)**	**2.44[3] (1.08, 5.52)**
Fall score (linear)	**0.87[1] (0.85, 0.89)**	**0.87[1] (0.85, 0.89)**	**0.93[1] (0.92, 0.95)**	**0.93[1] (0.92, 0.95)**
Dual Language Program	Reference	Reference	Reference	Reference
English as a Second Lang. Program	0.63 (0.30, 1.34)	0.62 (0.29, 1.33)	0.58 (0.11, 3.04)	0.58 (0.11, 3.05)
Regular program	0.99 (0.47, 2.08)	0.99 (0.47, 2.08)	1.38 (0.30, 6.35)	1.37 (0.30, 6.34)
Not Reading First School	Reference	Reference	Reference	Reference
Reading First School	**0.75[4] (0.55, 1.02)**	**0.75[4] (0.55, 1.02)**	**0.38[1] (0.22, 0.67)**	**0.38[1] (0.22, 0.67)**

Final model was adjusted for GM BLL category, sex, year, age at time of test, race, child language, free/reduced lunch status, kindergarten program, attending a Reading First school and fall score.

Note: significant associations are **bolded.**

[1] = statistically significant at $p \leq 0.001$

[2] = statistically significant at $p \leq 0.01$

[3] = statistically significant at $p \leq 0.05$

[4] = borderline significant at $p \leq 0.070$

[5] = borderline significant at $p \leq 0.090$

* Language Other predicted failure perfectly and was dropped from the model (all children with language = other in above benchmark group scored above spring benchmark

Source: September 24, 2009 (spring models), November 3, 2009, November 4, 2009B, November 25, 2009

Chapter Six - Discussion

6.1 Overall Findings

This is the first study of the association between childhood lead exposure and reading readiness at the start of kindergarten. It was conducted in a similar manner as Miranda's study of blood lead levels (BLLs) and performance on grade end-of-grade reading and math scores in 3rd and 4th grades, in a population of North Carolina school children [5]. Our models demonstrate a clear dose-response effect between exposure to lead in early childhood, measured by GM BLLs, and reading readiness at the beginning of kindergarten, measured by the total PALS-K score. The negative impact of BLLs on kindergarten reading readiness is statistically significant and consistent across all levels of adjustment. Importantly, these effects are seen at BLLs below 10μg/dL. The doubling model suggests a log-linear relationship, with larger effect sizes at lower BLLs. Similar to Miranda's observations of end of grade test scores [5], the magnitude of the change in fall PALS-K score associated with lead exposure in this study is similar to the change associated with eligibility for free and reduced lunch, a measure of low SES. The results of the refined categories of BLL model suggest that the largest population decline in fall PALS-K scores, 8.2 out of 13 points, occurred prior to GM BLL of 6μg/dL.

This is also the first study of the longitudinal association of childhood lead exposure and reading readiness during kindergarten. During the course of kindergarten, the overall proportion of children who achieved PALS-K benchmarks increased by about 15% from 65% in the fall to about 80% in the spring. However, stratifying by BLL, we saw that BLLs were associated with both achievement of benchmark status and with the proportion of children who improved during kindergarten.

Between fall and spring, children with BLLs <5, 5-9 and 10+μg/dL improved 47%, 34% and 40% respectively. Stratifying by fall benchmark status, we observed that 93-94% of the children who achieved benchmark in the fall also achieved benchmark in the spring, compared to 45-58% of the children who did not achieve benchmark in the fall.

Clearly although BLLs impact readiness in the spring, the difference in impact is much greater between children who did and did not achieve benchmark in the fall. Children who entered kindergarten with reading readiness levels below national PALS-K benchmark standards and a history of elevated BLLs above 5μg/dL experienced a 2-3.6 point decline in spring scores and were 50% more likely to fail in the spring compared to their counterparts with lower BLLs, i.e. <5μg/dL. This decline in score associated with lead accounts for 10-18% of one standard deviation in spring score. Children whose reading readiness levels were above national benchmark standards in the fall of kindergarten and who had BLLs above 5μg/dL showed evidence of a decrease in spring reading readiness scores of about one point, compared to children with lower BLLs (e.g. 0-4μg/dL) and were less able to achieve a perfect score, but were not at higher risk for failure to achieve national reading readiness benchmarks in the spring of kindergarten. Over-all, children who performed well in the spring had lower average BLLs than children who did not, particularly for the children who scored below BM in the fall where many differences across individual characteristics were significant, as seen in Table 5.1. Achieving benchmark PALS-K standards in the fall may reflect some measure of a child's prior enriched environment or the result of earlier childhood education which could potentially influence how lead affects cognitive outcomes during kindergarten and early elementary school, similarly to the changes reported in animal models [77].

Walpole reported that a child's initial literacy level alone, among a variety of literacy, language and social adjustment variables examined in a group of low-income children, was consistently associated with increases in literacy during kindergarten and to later literacy success [109]. Due to the limitations of this dataset, we were unable to examine the effect of early childhood education, quality of the home environment, or additional socioeconomic factors which might help to explain these results.

6.2 Additional Findings for the Fall

About half of the students with BLL in the highest category (GM>=10μg/dL) scored above benchmark standards when they entered kindergarten in the fall. Since we do not have information on early childhood education, the quality of the home environment, or more informative measures of socioeconomic status for these children, it is difficult to conjecture what other factors may have accounted for this achievement of higher levels of reading readiness. It will be important in future studies to examine the effect of these factors on reading readiness.

Despite their higher levels of failure to achieve PALS-K benchmarks in the fall of kindergarten (35% in Providence compared to 20% in Virginia during a similar time period) [113], the differences in success are likely associated with the differences in population demographics, including the large proportion of Hispanic children enrolled in Providence (60%) compared to an average of about 9% for Virginia for the 2004-2005 and 2005-2006 school years [125], and the high proportion of Providence children classified as recipients of free and reduced lunch (90%). The rates of failure by race/ethnicity and free lunch status seen in this study compare favorably with similar rates for children attending Virginia public schools in 2005-2006 [125].

6.3 Additional Findings for the Spring

In the spring of kindergarten, higher BLLs continued to be associated with lower PALS-K scores, as seen in both the bi-variate tables and the linear regression models. However, we were unable to discriminate differences in improvement between sub-groups in the above-fall benchmark group because of the "ceiling effect." Nearly 11% of children in this group achieved the highest possible spring PALS-K test result (score = 102), and the proportion of children who achieved perfect spring scores followed a dose-response relationship with BLLs. But, we were unable to determine whether these children might have scored higher if their score was not already the highest measured! We observed a dose response pattern in the relationship between BLLs and spring score, with significant differences observed for the 5-9μg/dL BLL category. The below-fall benchmark group was not affected by the "ceiling effect" because only one child from this group achieved a perfect PALS-K spring score.

The magnitudes of the associations of lead with spring PALS-K scores were larger for children who scored below the benchmark in the fall compared to those who scored above the benchmark, supporting Miranda's observation that deficits associated with lead exposure may be greater at lower levels of school performance [6].

The oldest group of kindergarten children had the lowest spring scores and the lowest fall to spring change compared to children of other ages, which could be associated with their significantly higher BLLs. Some of the children in this group were the oldest in their age cohort, but some are children who may have been held back from starting kindergarten in an earlier year when they were among the youngest in their age cohort. These results suggest that holding younger children back, particularly when their BLLs have been elevated, may be detrimental to progress during kindergarten. However, there may well be other factors we do not know about that make this group different from the kindergarten population as a whole.

In the fall of kindergarten, differences by SES, measured by free/reduced lunch status, were large and equal in size to differences associated with elevated BLLs. However, SES differences were no longer significant in the spring for children who scored below the benchmark in the fall. These unexpected findings may have been due to reduced statistical power associated with the small numbers of children who paid for their lunch (six percent) and/or the effect of the environment of kindergarten along with the additional in-classroom time focused on reading skills. The latter is suggested because for children who scored above the benchmark in the fall, the association of PALS-K spring scores with SES was still apparent, evidenced by a high odds of spring failure of 2.44 for children who received a free school lunch compared to children who paid for their lunch.

We observed minimal differences in improvement throughout kindergarten based on school programs, but they were not significant in the adjusted linear or logistic models, suggesting that children made similar progress in all three of the programs included in our study.

The additional instruction received in Reading First schools, adjusted for other factors, did appear to be beneficial, particularly for those children who scored above benchmark in the fall, who enjoyed significant improvement in score and an increased likelihood of achieving the spring benchmark. Improvement for their below benchmark counterparts was of lower magnitude with most results of borderline significance. This supports the value of programs like Reading First to all students, particularly those at risk of poor school outcomes.

6.4 Race and Language

The student populations of urban school districts such as Providence are very diverse, with white students often in the minority and a large number of students who speak languages other than English. This diversity, coupled with poverty, creates unique challenges for educators who wish to narrow the gap in educational performance. Most educational researchers have focused attention on differences between Black and White children without examining the size of the achievement gap for other racial or ethnic groups, notably Hispanic or Asian children [126]. The relationship between race and language in the US is complex. Children may grow up speaking English as their primary language even though another language is spoken in the home. English may be spoken in the home even though it is not the primary language of the child. For example, among Hispanic students in this study who spoke English as their primary language (40% of all Hispanic students), half did not speak Spanish in their homes. Likewise, among Hispanic students whose primary language was Spanish (the remaining 60% of Hispanic students), 40% spoke English as well as Spanish in their homes. We had reliable information about both race and language and were thus able to examine the effect of lead on reading readiness while controlling for language. Because race and language are important determinants of reading and reading readiness in the US, it is important to include Hispanic children and children of other racial/ethnic groups in population level analyses such as these, along with adjustment for language.

Findings by race suggest that Hispanic children and children of Asian descent enrolled in Providence public schools made substantial improvement in reading readiness during kindergarten, possibly in part as a result of improving their fluency in English, while Black children failed to make similar improvements in reading readiness. Part of this racial disparity may be explained by lower BLLs observed for Hispanic children compared to the higher BLLs observed for Black children, but lead may not fully account for the large difference in scores seen in children who scored below the benchmark in the fall. The higher spring scores and the 100% success in achieving spring benchmark for the above benchmark children whose race was categorized as "other" may reflect a cultural emphasis on education seen in many Asian nationalities.

Results stratified by child language suggest that by the end of kindergarten, disparities in reading readiness observed in the fall for children who spoke a language other than English (40%) had largely been eliminated. Based on PALS-K research reported elsewhere, we would have expected English speakers to out-perform Spanish speakers in both the fall and the spring [116,125]. Overall, our findings suggest that Providence children who spoke English may not have experienced the same degree of educational progress as Hispanic and Asian immigrant groups, possibly due to overall gains in English proficiency in the latter groups.

6.5 Population Estimates of Blood Lead Exposure

To the best of our knowledge, this is the first time that a prevalence estimate has been calculated for a population of urban school children and suggests that national population estimates may seriously underestimate the lead problem in urban schools. The proportion of children attending Providence public schools who have had at least one elevated BLL (e.g. greater than or equal to 10μg/dL), 20% or one in five children, is more than 14 times higher than national estimates of US children aged 1-5 reported by NHANES during the same period of time [14].

Unlike national population estimates [14], children who spoke Spanish and were classified as Hispanic or were reported by their parents to have been born in Central or South America had the lowest BLLs in our study. There is no evidence to suspect that Hispanics in Providence were living in newer housing, but anecdotal evidence that housekeeping in the homes of many Spanish-speaking immigrant families in Rhode Island is excellent may be associated with this finding.

6.6 Comments on the Success of the Below Benchmark Group

The intensive reading readiness intervention provided to below fall benchmark children during kindergarten in Providence could also be considered to be an "enriched environment" intervention that might improve outcomes for lead-exposed children. Based on the results of similar approaches in other research studies of children with reading disabilities [128,129], it is reasonable to believe that the intensive intervention provided to the below fall benchmark group might be sufficient to affect patterns of neural circuitry in the brain. Therefore, the changes in reading readiness during kindergarten that we observed for the below benchmark group are likely to have been positively influenced by the additional reading interventions provided by their teachers and undoubtedly underestimate the true association with lead in absence of these interventions. The evidence of a positive effect of the additional interventions was also supported by the closure of the gap in readiness during the kindergarten year between the above and below benchmark groups.

Additionally, although our study was not designed to evaluate the success of the intervention program for children who scored below benchmark standards in the fall, there were differences in overall group performance for 2002-2003, the year before the program was put into place, and for the same three years as our study (2004, 2005 and 2006 school years), although the data were not matched by child from fall to spring. Obtaining data for the 2002-2003 school year would have enabled us to also conduct a pre-post program evaluation to examine the success of intervention program.

6.7 Potential Next Steps

These findings and the rich evidence in the early childhood education literature [92,133] also suggest that earlier educational opportunities prior to kindergarten may be of benefit to children with average BLLs above 4μg/dL, particularly those with multiple risk factors for poor educational outcomes. The results of these studies suggest the need to evaluate the current screening approaches for early intervention in Providence to determine whether adding a history of an elevated BLL to the program qualifying criteria might improve targeting of children who are at-risk for school failure but are not presently being captured in that system. As a general first step, localities could evaluate the effectiveness of their existing early intervention programs to provide adequate assistance to children with a history of elevated BLLs who are at risk for failure to achieve benchmarks in the fall of kindergarten.

It would be feasible to target children based on their history of one elevated venous BLL or on the basis of an average measure of two or more BLLs, such as a simple mean BLL or the GM BLL used for our study. Based on assumptions described in Chapter Five, such an approach could identify between 6.5% and 67% of Providence children, although the estimate could be lower if other factors for high-risk were part of the targeting criteria. In 2009, more than 20% of children aged 0-3 residing in Providence already receive placement into early childhood programs, through early intervention programs [130] and full or partial child care subsidy, available to families with incomes up to 180% of Federal Poverty Level [130]. However, identification or eligibility for these programs is made without any systematic examination of BLL testing results. Resources are an issue for poor children in Providence because Rhode Island is one of a dozen states without a state pre-kindergarten program [131].

However, if schools and early intervention providers are willing to make early educational opportunities available based on a history of BLL elevation, public health departments could devise strategies to appropriately identify and refer children, possibly using the existing case management system for children with elevated BLLs

Using a similar approach (linking BLL and test outcome data) to evaluate the success of at-risk children currently placed in reading intervention programs in later grades could help identify the best approaches for children already enrolled in school who have a history of elevated BLLs.

An additional approach, using geographic information systems (GIS), could help identify neighborhood factors that help or hinder the development of reading readiness prior to kindergarten. The geo-mapping of neighborhoods where a high percentage of children failed to achieve benchmarks in both the fall and the spring provides a clearer picture of the locations where reading readiness is a problem and may also coincide with areas where the population is poor and living in older, deteriorated housing. The additional mapping of existing community literacy assets (i.e. libraries, schools, early childhood education programs, community-based organizations, home visiting programs, and parenting programs) would inform a discussion of possible next steps. These might include targeting additional community literacy assets to areas identified as high-risk, developing strategies to improve utilization of existing community resources, or securing additional slots for early education programs for individual children who live in identified neighborhoods.

Success in school is dependent on a variety of factors. Educational research in Virginia suggests that PALS-K scores are predictive of success in reading achievement, measured at the end of third grade [113]. An evaluation of student performance on end of grade reading tests later in elementary school (3^{rd} and 4^{th} grades) using longitudinal analytical approaches in this diverse cohort could help shed light on the long-term educational impacts of both kindergarten reading readiness (a possible marker of early enrichment) and childhood lead exposure on reading performance. Securing additional information on the quality and extent of each child's exposure to early childhood education, the quality of their home environment, and additional socioeconomic measures, such as parental education and family strengths may also help to explain these results or the results of future studies.

6.8 The Healthy Housing Connection

Exposure to lead in older housing may help to explain some of the disparities in reading readiness seen in populations of at-risk urban children throughout the US. The higher BLLs for Black children and children of other races, primarily Asian, in this study suggest that they were more likely living in lower quality housing, although other exposure factors may have also been present. Children eligible for a free school lunch would have been more likely to live in lower quality housing, compared to children paying for their lunch, so the higher BLLs observed for these children were also consistent. Despite on-going secondary and primary lead poisoning prevention efforts, a very high proportion (20%) of Providence kindergarten children in our study experienced BLLs above 9µg/dL, over 14 times higher than national estimates would predict [14]. Therefore, it may be valuable to determine whether existing programs to remediate lead hazards in the homes of affected children have met with sufficient success, or whether the BLL targets for environmental intervention should be lowered further in an effort to decrease lead exposure for a large proportion of the population of young children in Providence. The results of this study suggest the need to continue to emphasize primary prevention efforts focused on housing and to re-evaluate the effectiveness of current public health measures in protecting young children who live in older housing.

6.9 Why We Were Successful in Conducting This Study

Our data show that 88% of Providence children attending public kindergarten during these three years had been tested for lead at least once, suggesting that children living in Rhode Island have benefitted from the Rhode Island Department of Health's (RIDH) position as a national leader on the issue of blood lead screening. RIDH has also given health care providers on-line access to the state records of lab-reported blood lead testing results for individual children, which may encourage more screening of at-risk children, particularly children who move and change providers with some frequency.

We were able to conduct this study because (1) 88% of Providence kindergarteners had been tested for lead; and (2) on-going relationships and strong cooperation between the state health department, local public schools and a local community data provider made linkage of existing data sets possible. Such relationships can provide opportunities to link existing health and education data sets and to potentially identify critical associations between environmental factors, health, and educational success at potentially lower cost than a clinical trial or other epidemiological study. Although such relationships have long been encouraged [92], at the present time they appear to be the exception rather than the rule.

6.10 Study Strengths and Limitations

Major strengths of this study include the large number of high quality BLL results available for each child, which enabled us to estimate average lead exposure levels rather than relying on a single blood lead measure; the quality of school enrollment and birth data; longitudinal measurements of kindergarten reading readiness for fall and spring;

and high quality linkage of multiple datasets. In addition, our partnership with the Providence Plan and RIDH enabled us to dramatically improve data quality and to benefit from their existing relationships and capacities. However, it is important to acknowledge that data were originally collected for other purposes. As a result, we had limited measures of SES or indicators of the enrichment of the child's early education and home environment which would be important for future studies of this type.

Chapter Seven – Conclusions

As mentioned, this is the first study to use linked kindergarten reading readiness and child health data for a diverse population of school children. Analyses of fall data showed an association between high levels of lead exposure and low levels of kindergarten readiness, occurring at levels below the current CDC level of concern. Further analyses of spring data provided stronger evidence of an effect on learning. This has been the first study to explore longitudinal associations for reading readiness and BLL during kindergarten in the same diverse population of children, demonstrating the feasibility of linking school and child health data to examine even longer term measures of academic progress. We were able to show differences in the effects of BLL on reading readiness in the spring of kindergarten, based on a child's achievement of national benchmark standards for reading readiness in the fall of kindergarten. We found that children who entered kindergarten with high levels of reading readiness were generally able to learn successfully throughout kindergarten and to achieve national benchmark standards for reading readiness at the end of kindergarten. However, their spring scores showed some decrement and achievement of a perfect spring score was associated with BLLs in a dose-response fashion. But children who entered kindergarten with low levels of reading readiness and BLLs of 5µg/dL or higher were less successful during kindergarten and were 50% more likely to fail to achieve national reading readiness standards at the end of kindergarten than children with BLLs below 5µg/dL. This occurred even though these children were routinely provided additional in-class instruction focused on reading skills.

There was some evidence that the educational intervention provided to children who scored below benchmark standards in the fall may have been beneficial. A rigorous evaluation, such as a randomized clinical trial or a pre-post program evaluation would be useful to determine whether such an approach is effective for children with a history of elevated BLLs. The improvements associated with additional efforts to improve reading skills provided in Reading First schools, particularly for children who entered kindergarten with higher levels of reading readiness, suggest that additional enrichment efforts like these should be continued, particularly in populations at high risk for school failure.

This work shows the importance of collaboration between public health and public education agencies and community data providers. This approach serves as a model to other researchers and educators who wish to learn more about lead and school outcomes, including longer term measures of success. Replication of this effort is feasible, given the existence of relationships and on-going partnerships and commitment to improving outcomes for at-risk children.

The high rates of BLL testing made it possible to examine these effects in the population of urban school children rather than in a smaller percent of screened children. Additional advantage came from the existence of data on language, race/ethnicity, and birthplace at the individual child level. This made it possible to make inferences for all groups of children within this diverse population, without exclusion on the basis of race/ethnicity. Additionally, the availability of multiple blood lead tests provided a more accurate estimate of dose, an average measure of lead exposure (GM BLL), rather than a single blood lead value used in previous studies. Use of time-weighted average measures of BLL, better estimates of cumulative lead dose, in future evaluation of school performance may improve our ability to demonstrate associations of lead with educational outcomes.

The findings from both sets of analyses suggest the need to reevaluate current screening approaches that identify children in need of early educational intervention, raising the possibility that knowledge of BLL data may aid that decision. If schools and other providers of early intervention are willing to make additional early educational opportunities available based on a history of BLL elevation, public health departments could devise strategies to appropriately identify and refer children, using the existing case management system for children with elevated blood lead levels. Similar approaches could be used to evaluate the success of at-risk children currently placed in reading intervention programs in later grades, thus helping to identify the best approaches for older children who have a history of elevated BLLs. Mapping of the results of reading readiness evaluations, like this study, by neighborhood, along with community literacy assets could also inform discussions of next steps at the community level.

Perhaps most important, the availability of good blood lead data and these results provide Providence Public Schools with an opportunity (and the impetus!) to serve as a model for the Nation by using linked population health and school performance data to improve school success for all children.

Appendices

Details on Data Linkage for this Study

Our data partner, The Providence Plan, a non-profit community organization with extensive experience working with public and private databases, linked information from the four datasets using a unique identifier (ID) created for each individual child. Providence Plan first joined the PPSD enrollment records with PALS-K records using the unique school ID assigned to each child by PPSD. Discrepancies were resolved by manual examination of the records and by confirmation with PPSD staff to ensure that data quality could be met while reconciling, for example, minor differences in spelling, phonetic similarities, and hyphenation of last name.

Using the PPSD records, Providence Plan staff created two unique identifiers based on the child's name and the date of birth: a "long ID", consisting of first and last names and date of birth, and a "short ID", consisting of the first initial of the first name and the first three letters of the last name, and the date of birth. PPSD records were joined to records from RIDH's KIDSNET "Child" table, which also contained the unique identifiers (first name, last name, date of birth) as well as a unique KIDNET ID, matching first on the long ID, then on the short ID. Once a PPSD student was linked to the KIDSNET Child table, Providence Plan used the KIDSNET ID to obtain lead and birth records. At each step in the process, quality was checked and discrepancies were resolved by manual examination to ensure that data quality could be met while reconciling, for example, minor differences in spelling, phonetic similarities, and hyphenation of last name.

Next, Providence Plan provided the Rhode Island Department of Health (RIDH) with a list of names and dates of birth of enrolled children who could not be linked to the KIDSNET file. RIDH checked each name and date of birth in the RIDH Lead Elimination Surveillance System (LESS) database, which contains all blood lead data reported to the state of Rhode Island since 1992. This step identified 64 additional linkages and RIDH provided the additional blood lead testing information to Providence Plan to add to the linked Enrollment-KIDSNET data file. A child without matched blood lead data from either the KIDSNET or LESS data files was considered as "not tested for lead". A total of 4,596 children, 88% of the three kindergarten cohorts had blood lead information.

As a final step, Providence Plan generated a study ID for each child and provided de-identified data files (absent name and address) for this study. After data cleaning and exploration, we merged the files by study ID into one file for our analyses.

Table A.1: Kindergarten students scoring 101 or 102 on spring PALS-K test, by fall benchmark status and GM BLL group

	Below Fall Benchmark		Above Fall Benchmark	
GM BLL Group	Number with Spring Score of 101 or 102	Percent	Number with Spring Score of 101 or 102	Percent
0-4μg/dL	9	1.3	256	18.0
5-9μg/dL	2	0.5	114	16.7
10+μg/dL	1	0.9	16	15.0
Total	12	1.0	386	17.4

Figure A.1: Fall to spring change in PALS-K total score and spring PALS-K summary score, as functions of fall summary score, for fall scores <50

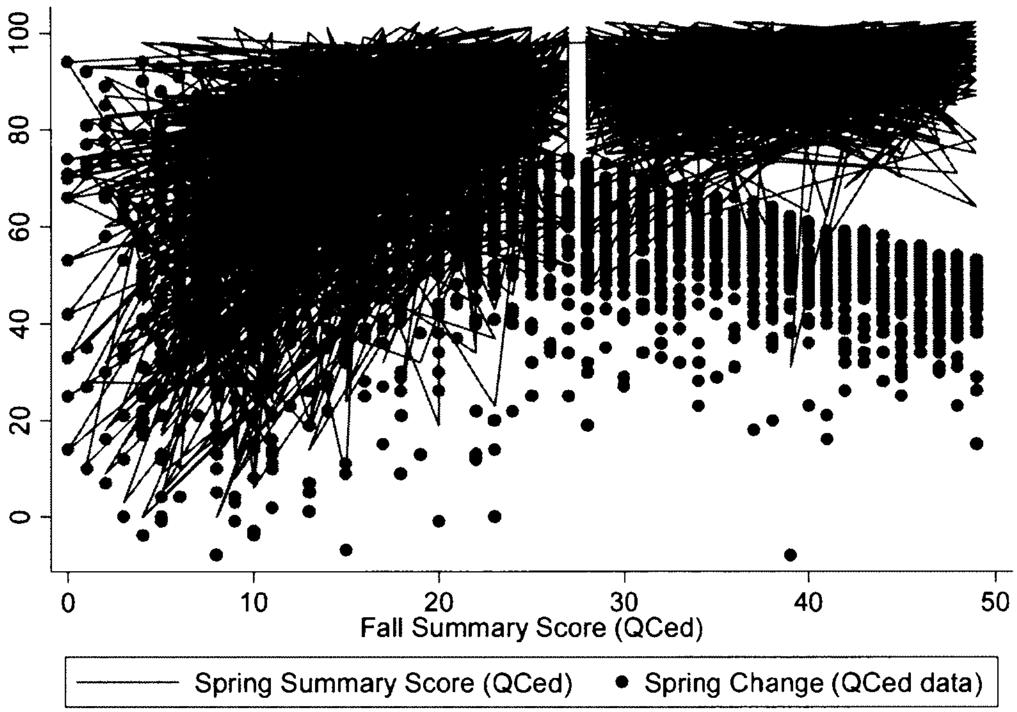

Table A.2: Change in PALS-K Score – Fall to Spring Change (95% Confidence Intervals) by Blood Lead Level Categories

For children scoring below benchmark in the fall (N=1193)

	Number		Model 1[a]	Model 2[b]	Model 3[c]	Model 4[d]	Model 5[e]
	Below Spring BM	Above Spring BM					
Geometric Mean Blood Lead (μg/dL)	565	628					
0-4μg/Dl	279	389	Reference	Reference	Reference	Reference	Reference
5-9μg/dL	225	190	-3.0 (-5.1, -0.8)	-2.5 (-4.7, -0.3)	-2.4 (-4.6, -0.2)	-2.4 (-4.6, -0.2)	-2.1 (-4.3, 0.08)[1]
10+μg/dL	61	49	-5.2 (-8.7, -1.6)	-3.9 (-7.5, -0.3)	-3.9 (-7.5, -0.2)	-3.9 (-7.6, -0.3)	-3.6 (-7.2, 0.04)[2]
p-trend			<0.001	0.004	0.004	0.004	0.009
r^2			0.0103	0.0383	0.0384	0.0416	0.0574

[a]Model 1 – lead only 1= borderline p=0.060 2= borderline p=0.053

[b]Model 2 – further adjusted for age at kindergarten, sex, year, race, child language

[c]Model 3 – further adjusted for free/reduced lunch status

[d]Model 4 – further adjusted for kindergarten program and Reading First school

[e]Model 5 – further adjusted for **fall PALS-K score**

Source: December 18, 2009

Table A.3: Association of model covariates with fall to spring change, for children scoring below PALS-K benchmark in the fall, fully adjusted linear model

	Below Fall Benchmark Model	
Covariates	Fall to Spring Change in Summary Score	95% CI
GM BLL 0-4µg/dL	Reference	Reference
GM BLL 5-9µg/dL	**-2.10[3]**	**-4.29, 0.08**
GM BLL 10+µg/dL	**-3.59[4]**	**-7.21, 0.04**
Female	Reference	Reference
Male	**-3.25[2]**	**-5.26, -1.23**
Year 2004-2005	Reference	Reference
Year 2005-2006	0.07	-2.42, 2.57
Year 2006-2007	0.87	-1.69, 3.44
Age group 5-5¼ years	Reference	Reference
Age group 5¼ - 5½ years	0.09	-2.52, 2.71
Age group 5½ - 5¾ years	-0.58	-3.32, 2.16
Age group 5¾ years and older	**-4.66[2]**	**-7.64, -1.69**
Race Hispanic	Reference	Reference
Race White	-1.62	-5.62, 2.38
Race Black	**-4.78[2]**	**-8.15, -1.41**
Race Other	-1.75	-6.69, 3.20
Race White	Reference	Reference
Race Black	-3.16	-7.48, 1.16
Race Hispanic	1.62	-2.38, 5.62
Race Other	-0.12	-5.63, 5.38
Language English	Reference	Reference
Language Spanish	-0.96	-3.76, 1.84
Language Other	2.21	-3.60, 8.01
Pay for lunch	Reference	Reference
Reduced lunch	1.37	-4.02, 6.77
Free lunch	0.54	-3.71, 4.78
Fall score (linear)	**0.34[1]**	**0.19, 0.48**
Dual Language Program	Reference	Reference
English as a Second Language Program	0.31	-5.59, 6.21
Regular program	-1.65	-7.43, 4.12
Not Reading First School	Reference	Reference
Reading First School	1.66	-0.79, 4.10
Constant	**62.28[1]**	**53.40, 71.16**
R^2	0.0574	

Final model was adjusted for GM blood lead level category, sex, year, age at time of test, race, child language, free/reduced lunch status, kindergarten program, attending a Reading First school and fall score.
Source: December 18, 2009 Significant findings are **bolded.**
[1] = statistically significant at p = 0.001 [2] = statistically significant at p = 0.01
[3] = borderline significant, p=0.060 [4] = statistically significant at p=0.053

TableA.4: Association of model covariates with odds of scoring below PALS-K spring benchmark, in fully adjusted log2 logistic model

	Below Fall Benchmark Model		Above Fall Benchmark Model	
Covariates	Odds of Scoring Below Spring B-mark	95% CI	Odds of Scoring Below Spring B-mark	95% CI
	Reference	Reference	Reference	Reference
Log2 GM BLL	**1.28²**	**1.09, 1.49**	1.05	0.84, 1.33
Female	Reference	Reference	Reference	Reference
Male	1.25	0.97, 1.62	**1.50³**	**1.03, 2.19**
Year 2004-2005	Reference	Reference	Reference	Reference
Year 2005-2006	0.94	0.69, 1.30	0.93	0.58, 1.49
Year 2006-2007	0.81	0.58, 1.13	0.74	0.45, 1.20
Age group 5-5¼ yrs	Reference	Reference	Reference	Reference
Age group 5¼ - 5½ yrs	0.85	0.61, 1.18	1.13	0.68, 1.88
Age group 5½ - 5¾ yrs	0.85	0.60, 1.21	0.98	0.58, 1.67
Age group 5¾ yrs+	**1.74²**	**1.19, 2.54**	1.41	0.81, 2.45
Race Hispanic	Reference	Reference	Reference	Reference
Race White	1.16	0.70, 1.93	1.49	0.82, 2.71
Race Black	**1.92²**	**1.24, 2.97**	1.25	0.74, 2.12
Race Other	1.44	0.77, 2.71	0.89	0.32, 2.46
Race White	Reference	Reference	Reference	Reference
Race Black	**1.65⁴**	**0.95, 2.87**	0.84	0.47, 1.49
Race Hispanic	0.86	0.52, 1.43	0.67	0.37, 1.22
Race Other	1.24	0.62, 2.50	0.60	0.21, 1.69
Language English	Reference	Reference	Reference	Reference
Language Spanish	1.22	0.85, 1.74	0.88	0.50, 1.55
Language Other	0.78	0.37, 1.64	*	*
Pay for lunch	Reference	Reference	Reference	Reference
Reduced lunch	1.16	0.58, 2.35	1.06	0.36, 3.19
Free lunch	1.43	0.81, 2.50	**2.40³**	**1.06, 5.43**
Fall score (linear)	**0.87¹**	**0.85, 0.89**	**0.93¹**	**0.92, 0.95**
Dual Lang. Program	Reference	Reference	Reference	Reference
English as a 2nd Lang.	0.60	0.28, 1.27	0.59	0.11, 3.09
Regular program	0.97	0.46, 2.03	1.35	0.30, 6.45
Not Reading First School	Reference	Reference	Reference	Reference
Reading First School	**0.74⁵**	**0.54, 1.01**	**0.38²**	**0.22, 0.67**

Final model was adjusted for GM blood lead level category, sex, year, age at time of test, race, child language, free/reduced lunch status, kindergarten program, attending a Reading First school and fall score.
Source: -December 18, 2009
¹ = statistically significant at $p = 0.001$ ² = statistically significant at $p = 0.01$
³ = statistically significant at $p = 0.05$ ⁴ = borderline significant at $p = 0.077$
⁵ = borderline significant at $p = 0.057$ * language "other" predicted failure perfectly and was dropped from the model (all children with language = other in above benchmark group scored above spring benchmark)

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CURRICULUM VITAE

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EDUCATION:

Doctor of Public Health, 2010	The Johns Hopkins Bloomberg School of Public Health, Baltimore, MD. Department of Environmental Health Sciences. Dissertation Title: The association between Elevated Blood Lead Levels and Reading Readiness in Kindergarten Children
Master of Public Health, 1987	The Johns Hopkins School of Hygiene and Public Health, Baltimore, MD. Concentration in Occupational Health.
Bachelor of Science in Nursing, 1981	Frances Payne Bolton School of Nursing, Case Western Reserve University, Cleveland, Ohio Senior clinical emphasis: Community Health.

LICENSURE:

Registered Nurse: in Ohio 1981 - 1989; in Maryland 1988 to present; in Rhode Island 1999 to 2005.

TEACHING EXPERIENCE:

Teaching Assistant, Johns Hopkins Bloomberg School of Public Health, Department of Environmental Health Sciences, summer 2007
Course: EHS180.601 Environmental Health (MPH core course)
Distributed course materials, proctored exams, graded written assignments and exams.

Clinical Instructor, Johns Hopkins School of Nursing, Community Health Nursing Clinical, January-June 2006, April-June 2007
Set up new clinical sites, oversaw BSN community health clinical, reviewed all written documentation, graded papers, evaluated performance, 7 week rotations, 16 hours/week.

Lead Poisoning Prevention Training Center (sponsored by Centers for Disease Control and Prevention, Lead Poisoning Prevention Branch)

- Primary Prevention Training Track – helped to develop initial course and delivered initial training, 2005
- Case Management Training Track – course faculty, 2005

Lead Case Management Training – coordinated development of two-day national training course for CDC's 2002 Case Management Recommendations, trained trainers, oversaw delivery to more than 400 state and local public health personnel, 2003-2005.

National Lead Training Center, Louisville, KY 2000-2003
Faculty for national training of CDC program managers
Course: Case Management

Clinical oversight for master's level leadership course, 5+ MSN students at Johns Hopkins School of Nursing, 1998-2003.

PROFESSIONAL HONORS:

F.P.B. School of Nursing, Rozella M. Schlotfeldt Alumni Scholarship Award, May 1981.

F.P.B. School of Nursing, Alumni Award for Competence in Clinical Nursing in the Undergraduate Program, May 1981.

Cleveland Health Department, Employee of the Month, November 1983.

Ohio Public Health Association, third place award, poster display contest (Nursing and Communicable Disease), November 1983

Johns Hopkins School of Hygiene and Public Health, NIOSH traineeship, 1986-1987.

Delta Omega, National Honor Society for Public Health, National Merit Award for Outstanding Achievement, October 19, 1987.

Maryland Department of Environment, Toxics, Environmental Science and Health Administration, Employee of the Month, October 1990 and October 1991.

International Society for Environmental Epidemiology, Award for Outstanding Abstract by a Student, 21st Annual Conference, August 25-29, 2009.

OTHER PROFESSIONAL EXPERIENCE:

Consultant (part-time)
September 2006-present
Baltimore City Health Department, Healthy Homes Division. Supported efforts to obtain Maryland Medicaid funding for lead poisoning prevention field services. Helped to develop grant proposal funded by CDC in 2008 to replicate successful asthma home-visiting program in Baltimore, serving as program evaluator and providing technical assistance for research effort.

National Center for Lead Safe Housing
Assistant Director for Program Management, January 1993 - June 2003
Senior Health Advisor, July 2003 –July 2005
Experienced in all areas of environmental research including protocol development, training development and delivery, field oversight, quality control, human subjects protection, data management and data analysis. Served as Co-investigator for CDC-funded clinical trial to evaluate effectiveness of nursing case management and as Principal Investigator for Boston Low Level Soil Demonstration Evaluation (EPA and HUD project). Provided management/field support for other research studies including the National Evaluation of HUD Lead Hazard Control Grant Programs, HUD National Risk Assessment Study, Milwaukee Pilot Ordinance Evaluation, Kennedy Krieger Institute evaluation of effectiveness of moving children into lead-safe housing. Directed evaluation of CDC Quarterly Reports for New England Region, national survey of lead outreach efforts by state and local CLPPPs, and two national surveys of case management and environmental investigation practices by state and local CLPPPs. Helped to develop national training for lead primary prevention efforts and healthy housing. Coordinated lead case management evaluation for a local CLPPP. Coordinated development of national training for CDC's 2002 Case Management recommendations and delivery to more than 400 state and local public health personnel. Coordinated the Center's first year effort to develop a national Healthy Homes Training Center and Network, organized and delivered first training. Coordinated large project to establish web-based lead databases in three cities with public/private sector partners. Managed multi-agency grant from Robert Wood Johnson and provided overall-management for other small evaluation and research projects. Developed technical assistance bulletins, training programs, reports and written guidance materials. Contributing author for 1995 HUD Guidelines. Provided extensive public speaking on lead research and policy issues and healthy housing. Coordinated regular meetings of staff, organized data management team, oversaw efforts to hire new staff. Provided mentoring and fieldwork opportunities for masters students enrolled in Johns Hopkins School of Nursing and School of Public Health. Served as instructor for National Lead Training Center in Louisville, KY, 2000 – 2003.

Maryland Department of the Environment
Division Chief, Lead Poisoning Prevention Program
March 1988 - March 1993

Developed and coordinated comprehensive Lead Poisoning Prevention Program for the State of Maryland. Provided leadership for multi-disciplinary professional team. Secured and managed large CDC Grant funding three agencies. Provided oversight for all program and grant activities including planning, implementation, interagency coordination, evaluation, development and management of budget, and preparation of quarterly reports. Coordinated efforts with state, local, public and private sector organizations; negotiated MOUs with local health departments. Prepared legislative initiatives; oversaw implementation of regulations and development of training certification program. Coordinated work of Governor's Lead Advisory Council and prepared annual reports. Provided consultation to local health departments, health professionals and state housing department. Provided oversight of educational initiatives including design and implementation of statewide educational programs for health care professionals and public health personnel, development of handbook on lead for child health professionals, coordination of annual celebration of Lead Poisoning Prevention Week. Helped to develop a variety of informative pamphlets, materials and displays to support regulations and prevention efforts among target groups and the general public. Provided extensive public speaking on lead issues. Provided oversight of environmental health rotation for students from University of Maryland and Johns Hopkins Schools of Nursing.

Cleveland Board of Education, Cleveland, Ohio
School Nurse, Part-time substitute, October 1987 - February 1988
Provided triage, assessment and treatment of acute and chronic student health complaints with referral/follow-up as needed at the elementary, junior high and high school levels.

Cleveland, Ohio
Occupational Health Consultant
Part-time, October 1987 - December 1987
As a member of a field team delivering screening services to asbestos-exposed members of the Sheetmetal Workers Union, provided pulmonary function testing, scored results.

City of Lakewood, Lakewood, Ohio
Nurse Practitioner, November 1984 - June 1986
Provided health services to city employees, nursing services to city jail, health screening services to parochial schools and generalized public health services to the community (communicable disease, immunizations, etc.). Initiated and coordinated a large-scale program on hand washing for day care centers and kindergartens. Obtained sponsorship and support from public and private sectors, developed program components, delineated work and resource requirements, directed implementation by two public sector agencies, and managed budget. Established employee hypertension screening program. Initiated school-based health education program (Nutrition and Exercise) for middle school students. Assisted with clinical rotations for student nurses from Case Western Reserve University.

City of Cleveland, Cleveland, Ohio
District Public Health Nurse, June 1981 - October 1984

Provided generalized public health nursing services in assigned geographic area. Responsibilities included communicable disease follow-up and prevention; satellite immunization program; home visits to children with chronic disease; home visiting of at-risk individuals and groups for investigative, health education and follow-up purposes [communicable disease control, maternal and child health, and suspected abuse/neglect for children and elderly]; referrals to and coordination with a variety of health and human services agencies. Organized and conducted ten full-scale epidemiological investigations of institutional outbreaks in community settings, primarily day care. Organized and chaired City of Cleveland Interdepartmental Board and Care Task Force, made up of representatives from six City departments, State, county and private agencies. The task force oversaw coordination, joint investigation and problem resolution for unlicensed boarding homes providing services to impaired elderly and other clients. Helped negotiate union contract as chair person of local nurses' collective bargaining unit. Established volunteer program and recruited, trained and supervised four volunteers to assist in clerical work and patient assessment at monthly community-based immunization clinics. Helped create series of written materials on communicable disease and developed protocols for district work. Helped precept clinical rotation for students from CWRU schools of Nursing and Medicine.

International Chemical Workers Union (ICWU) - Cleveland area,
Summer Intern in Occupational Health, Summer-Fall 1979
Worked with two local unions of ICWU as part of multi-disciplinary team. Attended national education and training program. Researched health effects of work place chemicals, obtained occupational health histories, implemented educational programs based on identified risks. Helped to procure local funding.

PROFESSIONAL AFFILIATIONS AND ACTIVITIES

Advisory Committee on Childhood Lead Poisoning Prevention, Centers for Disease Control & Prevention, appointed member - 11/17/93 - 5/31/97, Ex-Officio/liaison member 1998 – July 2005. Chair of Primary Prevention Work Group, March 2003 to August 2004. Member of Educational Workgroup, October 2008 to present.

American Nurses Association, 1981 to present
Chairperson, Nursing Advisory Committee on Practice, Cleveland Health Department, local bargaining unit, 2/83 - 10/84; Chairperson of local bargaining unit, Cleveland Health Department, 8/83 - 10/84.

American Public Health Association, 1979 to present.

Delta Omega, National Honor Society for Public Health, May 1987 to present.

Maryland Lead Commission, December 2002 to present.

Ohio Public Health Association, 1982 - 1987.

Sigma Theta Tau, National Honor Society for Nursing, May 1981 to present.

Periodic peer reviewer for *Environmental Research* since 1996.

PRESENTATIONS (since December 2005)

1. **SCIENTIFIC MEETINGS**

McLaine, Pat, Navas-Acien, Ana, Diener-West, Marie, Simon, Peter, Agnew, Jacqueline; Elevated blood lead levels negatively impacts kindergarten reading readiness; International Society for Environmental Epidemiology, August 25-29, 2009, Dublin, Ireland.

McLaine, Pat, Navas-Acien, Ana, Simon, Peter, Agnew, Jacqueline; Elevated blood lead levels negatively impact kindergarten reading readiness; 2009 National Environmental Public Health Conference, October 27, 2009, Atlanta, Georgia.

McLaine, Pat, Scott, Kate, Shea, Madeleine; Research to practice adaptation: lessons learned in translating effective research to public health; 2009 National Environmental Public Health Conference, October 26, 2009, Atlanta, Georgia.

2. **INVITED PRESENTATIONS**

McLaine, Pat; Elevated blood lead levels negatively impact kindergarten reading readiness in Providence, Rhode Island: how health care providers can help; October 30, 2009, Grand Rounds presentation for doctors and nurses at Hasbro Children's Hospital, Providence, Rhode Island.

McLaine, Pat; Not ready for kindergarten in Providence: new evidence of the negative impact of lead levels on reading readiness; October 29, 2009, to early education, education and health professionals at Meeting Street in Providence, Rhode Island.

McLaine, Pat, Navas-Acien, Ana, Diener-West, Marie, Simon, Peter, Agnew, Jacqueline; Elevated blood lead levels negatively impact kindergarten reading readiness; September 21, 2009, to graduate students and faculty at Johns Hopkins Bloomberg School of Public Health, Occupational and Environmental Health Divisional Seminar.

McLaine, Pat; Elevated blood lead levels negatively impact kindergarten reading readiness; July 23, 2009, to faculty and students of University of Maryland School of Nursing, Baltimore, Maryland.

McLaine, Pat; Association between childhood lead exposure and kindergarten reading readiness, July 14, 2009, presentation to officials from Providence Public Schools District, The Providence Plan and the Rhode Island Department of Health, Providence, Rhode Island.

McLaine, Pat; Lead toxicity issues for infants, children and adults: what rural healthcare providers on the frontline can do about prevention, treatment and policy development; Toxin Risks Healthcare Providers Should Know at Home and Work Conference, April 7, 2009, sponsored by Geissinger Health Systems, Danville, Pennsylvania.

McLaine, Pat; A summary of educational intervention research for dyslexia; CDC Lead Education Work Group meeting, February 12,2009, Atlanta, Georgia.

McLaine, Pat; Childhood lead poisoning – a continuing public health problem, lecture for Public Health Issues course taught by Sara Groves, DrPH, on May 18, 2007 at Johns Hopkins School of Nursing, Baltimore, Maryland.

McLaine, Pat; Childhood lead poisoning – a continuing public health problem, Sara Grove's Public Health Issues Class taught by Sara Groves, DrPH, on February 23, 2007 at Johns Hopkins School of Nursing, Baltimore, Maryland.

McLaine, Pat; Asthma Basics; October 25, 2007; presentation for field staff of Healthy Homes Program, Baltimore City Health Department, Baltimore, Maryland.

McLaine, Pat; Review of journal article: Understanding international crime trends: the legacy of preschool lead exposure, by Rick Nevin; August 21, 2007; lunch-time seminar for Office of Healthy Homes, Baltimore City Health Department.

McLaine, Pat; Testing and inspecting houses: challenges for 2010; presentation to Maryland Summit for 2010, December 5, 2005, organized by the Coalition to End Childhood Lead Poisoning, Baltimore, Maryland.

GRANTS FUNDED

CDC, Task Order 093, to support dissertation research, 2008-2009.

CDC, Reducing Asthma Disparities: Baltimore Initiative, co-investigator, 2008-2011

CDC, Randomized community trial of Nurse Case Management for children with moderately elevated lead levels (15-19μg/dL), co-investigator.

Lead in Soil Project, sub-project of Boston Department of Neighborhood Development, Lead-Safe Boston Program, funded by the Department of Housing and Urban Development, Principal investigator and project coordinator, 1999-2001.

CDC, nurse case management training grant, CDC, trained over 400 state and local public health personnel on CDC's 2002 Lead Case Management recommendations; Project coordinator, 2003-2005.

PUBLICATIONS (in chronological order)

1. **PEER REVIEWED PUBLICATIONS**

Galke, W., Clark, S., Wilson, J., Succop, P., Dixon, S., Bornschein, R., McLaine, P., Chen, M., and D. Jacobs. Evaluation of the HUD Lead Hazard Control Grant Program: early overall findings. *Environmental Research* (June 2001).

Litt, J., Hynes, H. P., Carroll, P., Maxfield, R., McLaine, P., and Kawecki, C. Lead Safe Yards: a program for improving health in urban neighborhoods. *Journal of Urban Technology* Vol.9, No 2: 71-93, 2002.

Clark, S., Chen, M., McLaine, P, Galke, W., Menrath, W., Buncher, R., Succop, P., and Dixon, S. Prevalence and location of teeth marks observed during XRF testing of dwellings in the national evaluation of the HUD Lead-Based Paint Hazard Control Grant Program, *Applied Occupational and Environmental Hygiene* (September 2002).

Clark. S., Grote, J., Wilson, J., Succop, P., Chen, M., Galke, W., and McLaine, P. Occurrence and determinants of increases in blood lead levels in children shortly after lead hazard control activities. *Environmental Research* (October 2004).

Galke, W., Clark, S., McLaine, P., Bornschein, R., Wilson, J., Succop, P., Roda, S., Breysee, J., Jacobs, D., Grote, J., et al. National evaluation of the US Department of Housing and Urban Development Lead-Based Paint Hazard Control Grant Program: study methods. *Environmental Research*, Volume 98, Issue 3, July 2005, pages 315-328.

Brown, MJ, McLaine, P, Dixon, S, Simon, P. A randomized community-based trial of home visiting to reduce blood lead levels in children. *Pediatrics* (January 2006).

McLaine, P., Shields, W., Farfel, M., Chisolm, J. J., Dixon, S. A coordinated relocation strategy for case management of lead poisoned children: outcomes and costs. Journal *of Urban Health*, (January 2006).

Dixon, S., McLaine, P., Kawecki, C., Maxfield, R., Duran, S., Hynes, P., Plant, T. The effectiveness of low-cost soil treatments to reduce soil and dust hazards: the Boston lead safe yards low cost lead in soil treatment, demonstration and evaluation. *Environmental Research*, Volume 102, Issue 1, September 2006, pages 113-124.

Wilson,W., Dixon, S., Galke, W., McLaine, P. An investigation of dust lead sampling locations and children's blood lead levels. *Journal of Exposure Science and Environmental Epidemiology*: 17:2-12, 2007.

2. NON-PEER REVIEWED PUBLICATIONS

McLaine, P. *Lead-Based Paint Hazards and the Comprehensive Affordability Strategy (CHAS) -How to Respond to Title X: Recommendations for Addressing Lead-Based Paint Hazards in Housing to Reduce Childhood Lead Poisoning.* National Center for Lead-Safe Housing, 1993.

Guidelines for the Evaluation and Control of Lead-Based Paint Hazards in Housing, contributing author, U.S. Department of Housing and Urban Development, Washington, DC, 1995.

Guthrie, A. and McLaine, P. *Another Link in the Chain: State Policies and Practices for Case Management and Environmental Investigation for Lead-Poisoned Children.* Alliance to End Childhood Lead Poisoning and National Center for Lead-Safe Housing, 1999.

McLaine, P. and Gaitens, J. *Another Link in the Chain Update*, National Center for Healthy Housing and Alliance to End Childhood Lead Poisoning, 2001.

3. BOOK CHAPTERS

Litt, J., Hynes, H.P., Carroll, P., Maxfield, R., McLaine, P. and Kawecki, C. Chapter 5. A program to improve urban neighborhood health through lead-safe yard interventions, in *Community Research in Environmental Health: Studies in Science, Advocacy and Ethics.* Edited by Brugge, D. and Hynes, H.P. Ashgate. Burlington, VT, 2004.

4. LETTERS

McLaine, P., Brown, M., Simon, P. Home visiting and childhood lead poisoning prevention: In Reply. *Pediatrics* (June 2006)

December 2009