DE-LEADING RHODE ISLAND:
Assessing the Health Benefits of Lead Hazard Remediation in the State

by

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Thesis

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Executive Summary

Despite recent gains in reducing the incidence of childhood lead poisoning throughout the United States – a result due in large part to the removal of lead from gasoline, canned goods, and paints[1] – lead poisoning remains one of the foremost environmental health risks to children under six.[2] Estimated to affect nearly 2.2% of children ages 1-5 years in the United States, lead poisoning affects a much higher proportion of children in many states throughout the Northeast, including Rhode Island, where children's blood lead levels are at least four times the national average.[3] Additionally, over 300,000 homes in Rhode Island are reported to contain lead-based paint hazards, and 30,000, mostly low-income homes, present a high risk of lead poisoning and are in immediate need of remediation.[4] In the past year alone, nearly 3,000 children under six years of age were diagnosed as lead poisoned in Rhode Island.[5,6]

Although some studies find the remediation of lead hazards is an effective tool to reduce the blood lead levels (BLLs) of children who have been chronically exposed to lead, other studies report conflicting results. One study, in particular, examining the effects of

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[1] Lanphear BP, Dietrich KN, and Berger O. *Prevention of Lead Toxicity in U.S. Children.* Ambulatory Pediatrics. 2003, Jan-Feb. 3(1): 27-36.

[2] *Ibid*.

[3] Over 8% of children, ages 1-5, have BLLs >10µg/dL. *Lead Poisoning in Rhode Island: The Numbers (2002)*. Providence, RI: Rhode Island Department of Health.

[4] Rhode Island Childhood Lead Poisoning Prevention Program. Housing: Best Practices. Available at http://www.healthri.org/family/lead/housing.htm Accessed on 03/05/03.

[5] Rhode Island Kids Count. *Issue Brief: Childhood Lead Poisoning*. February 2003.

[6] Lead poisoning is defined by the Center for Disease Control (CDC) as a BLL over 10 µg/dL – the CDC's standard of concern.

remediation on children's BLLs, indicates a significant difference amongst intervention and control groups when BLLs are 30 µg/dL,[7] while another study, examining the same effects, reports BLLs increasing after the removal of lead hazards.[8]

Given that results on the effects of remediation are divided, and since lead data for Rhode Island are prolific in comparison to the data used in other studies, this thesis assesses the effectiveness of Rhode Island's current lead hazard remediation program.

Using Microsoft Access, Excel, and SPSS as the primary tools to assist in the manipulation and analysis of data from the Rhode Island Department of Health's (DoH) Childhood Lead Poisoning Prevention Program (CLPPP), three groups of cases that have been closed by the DoH were used to gauge the efficacy of Rhode Island's current lead hazard remediation program in reducing the BLLs of poisoned children. The three groups include cases that have been closed:

(1.) Due to the remediation of lead-based paint hazards (HA);

(2.) Due to the refusal of DoH inspections (REF) by home-occupants, and;

(3.) Due to the parent of a poisoned child being the owner of the home where the poisoning occurred. (PO)[9]

[7] Staes C, Matte T, Copley CG, Flanders D, Binder S. *Retrospective Study of the Impact of Lead-Based Paint Hazard Remediation on Children's Blood Lead Levels in St. Louis, Missouri.* American Journal of Epidemiology. May 15, 1994. 139(10): 1016-1026.

[8] Lanphear, BP. *The Paradox of Lead Poisoning Prevention.* Science. 1998, Sept. 11. 281(5383): 1617-18.

[9] Only the first group (HA) knowingly remediated lead hazards and subsequently met DoH lead-safe standards. The REF and PO groups may have remediated hazards without DoH assistance.

Using the REF and the PO groups as ‘controls,’ against which to compare the group of cases that are closed due to the remediation of lead hazards (as the ‘cases’) [10], a series of three approaches were used to determine whether the BLLs of poisoned children are reduced by Rhode Island's current lead hazard remediation program. Specifically, I examined and compared:

1.) The BLLs of poisoned children in the case and control groups at various periods after cases were opened.

2.) The BLLs of poisoned children in the case group who move from remediated addresses to addresses that do not have a record of remediation, versus those who remain in remediated addresses.

3.) The BLLs of poisoned and non-poisoned children residing at the addresses of the case and control groups three years before and after cases were opened.

The last analysis assessed whether Rhode Island's current lead hazard remediation program causes property-owners to engage in practices that deny housing to families with children under six. Specifically, it examined and compared:

4.) The number of children residing in HA and REF homes before and after inspections were offered to these homes.

The results show that cases and controls, with mean BLLs 20 µg/dL, take over two years for their BLLs to drop below 10 µg/dL. These findings parallel the results of

[10] 'Case group' refers to the children that have received intervention by residing in homes that have been remediated, while 'control group' refers to the children who reside in homes that have not had lead hazards remediated.

studies examining the natural rate at which lead decays in children who are removed from sources of lead exposure.[11]

Results also provide strong evidence that Rhode Island's current lead hazard remediation program does not benefit children. Specifically, the results show that the BLLs of children in the cases do not statistically differ from the BLLs of children in the controls after they cases were opened by the DoH. In periods where significant differences do exist, the directions of the differences are unexpected, with the results showing the controls with lower BLLs than the cases.

The movement of children from remediated homes was not found to adversely affect the BLLs of children. Although children who remain in remediated homes show lower BLLs than those who move, the difference in BLLs is not a result of mobility.

Results of this thesis also show that the some property-owners in the HA and REF groups deny rental housing to families with young children. Both groups report the presence of children at addresses (as detected by blood lead tests at these addresses) before the remediation of lead hazards and the refusal of inspections, but do not report blood lead tests at these same addresses after such interventions – a likely indication of housing discrimination. Specifically, 9% of homes that undergo remediation and 22% of homes that refuse DoH inspections are presumed to have property-owners that engage in housing discrimination.

[11] Manton WI, Angle CR, Stanek KL, Reese YR, Kuehnemann TJ. *Acquisition and Retention of Lead by Young Children.* Environmental Research. 2000. 82: 60-80.

Since research indicates that chelation therapy does not improve children's scores on cognitive, behavioral, and neuropsychological tests, and moreover because the results clearly indicate that remediation does not benefit children's health by significantly lowering children's BLLs, the most logical step is for the State to shift its emphasis away from the treatment of children with significantly elevated BLLs to preventing lead poisonings from occurring in the first place via a primary prevention strategy that includes among other measures, the complete removal of lead from homes.

Additionally, whether implicit or explicit, the message that the remediation of lead hazards benefits children must be corrected. It is essential for State agencies and lead advocacy groups, like the DoH and Childhood Lead Action Project (CLAP), as well as for the families of poisoned children, to recognize that remediation does little for children. This recognition would provide a powerful incentive for the State to begin cracking down on the worst homes (homes that have the highest risk for lead exposure) without further delay Bringing these homes into compliance with DoH lead-free standards assures that they are removed from the housing market and future occupants will not be poisoned at these homes.

Based on the results, I also caution the Housing Resource Commission (HRC) and the DoH who have been granted the responsibility of implementing the portion of the 2002 Lead Hazard Mitigation Act that refers families to housing that is lead-safe, lead hazard mitigated, or abated. Instead, these bodies should direct families with young children to the homes that are lead-free or low-risk, and not the homes that have been remediated.

Other recommendations involve: advising families on homes that are lead-free or have no record of poisoning, rather than the homes that have been remediated; investigating those homes and their property-owners that are suspected be engaging in housing discrimination; and conducting further research on the effects of lead hazard remediation to discriminate amongst the effects from different types of remediation.

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List of Acronyms

ADHD – Attention Deficit Hyper-activity Disorder

BLL – Blood Lead Level

CDC – Centers for Disease Control and Prevention

CLPPP – Childhood Lead Poisoning Prevention Program

EPA – Environmental Protection Agency

HA – Hazards Abated (Case/Intervention Group)

HIP – Home Improvement

HUD – U.S. Department of Housing and Urban Development

HRC – Housing Resource Commission

ID – Identification

IQ – Intelligence Quotient

µg/dL – Micrograms per Deciliter (micrograms of lead per deciliter of whole blood)

NOV – Notice of Violation

NHaNES – National Health and Nutrition Examination Survey

NHS – National Health Service

PO – Parent Owner (Control Group)

REF – Refusal (Control Group)

RIFHMC – Rhode Island Housing and Mortgage Financing Company

DoH – Rhode Island Department of Health

Introduction

Nationwide, nearly one million children under the age of six[12] suffer from an environmentally induced disease that lowers intelligence and induces behavioral problems that can eventually lead to delinquency and criminality.[13] These same children may develop learning and attention deficit disorders, and consequently suffer from losses in earning potential as they age. This disease is not genetically rooted, nor are the parents of these children necessarily negligent. Rather, these children have been poisoned by lead,[14, 15] an ubiquitous heavy metal – having no known human physiological or nutritional value – that was used extensively in industrial processes and residential house paints prior to 1978, when the federal government banned its use as an additive in paint.[16] Despite this ban, a large body of evidence indicates that lead-based paint hazards in deteriorating homes and buildings constructed prior to 1978,[17] and the contaminated dust these hazards generate, remain the primary source of indirect lead exposure in children

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[12] CDC Update: Blood Lead Levels – United States, 1991-1994. Morbidity and Mortality Weekly Report. 1997. 46: 146-7.

[13] Wakefield, J. "The Lead Effect?" Environmental Health Perspectives. 2002 Oct. 110(10): A575-580.

[14] MacRoy, P. *In Search of Safe Housing: Blood Lead Levels as an Indicator of Present Lead Safety*. (Master's Thesis – web version) Brown University Center for Environmental Studies. 2001. Available at http://envstudies.brown.edu/Thesis/2001/MacRoy/PatMac_Soup_Sem_files/frame.htm. Accessed on 02/27/03.

[15] In more technical settings, lead poisoning is referred to as plumbism. Centers for Disease Control and Prevention. *Preventing Lead Poisoning in Young Children: A Statement by the Centers for Disease Control and Prevention*. 1991.

16 C.F.R Title 16. § 1313. 1977 ed. Ban of Lead-Containing Paint and Certain Consumer Products Bearing Lead-Containing Paint.

[17] Estimates indicate that pre-1980 American housing stock contains more than 3,000,000 tons of lead in the form of lead-based paint, with the vast majority of homes built before 1950 containing substantial amounts of lead-based paint. Housing and Community Development Act (Residential Lead-Based Paint Hazards Reduction Act) of 1992. Title X. § 1002 (3).

under the age of six.[18] The painted surfaces within these structures, particularly those surfaces exposed to frictional forces – including door frames, window sashes, and stair treads[19] – are in poor condition, resulting in the generation of lead-contaminated dust which creates hazardous conditions for children that engage in hand-to-mouth behaviors.[20]

One way to effectively limit children's exposure to lead, and consequently reduce their risk of being lead poisoned, is to house children[21] less than six years of age in lead-free environments. The sizeable constraints[22] involved in such an undertaking, however, make the execution of this goal impractical. More pragmatic options, as suggested by State and Federal regulatory agencies like the U.S. Environmental Protection Agency (EPA) and the Rhode Island Department of Health (DoH) include primary and secondary lead poisoning prevention practices, such as: (1.) The basic maintenance and cleaning of homes to prevent both the deterioration of lead-based paint and the subsequent accumulation of lead-contaminated dust;[23] (2.) Outreach and education efforts intended

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[18] Lanphear BP, Matte TD, Rogers J, Clickner RP, Dietz B, Bornschein RL, et al. *The Contribution of Lead Contaminated Dust and Residential Soil to Children's Blood Lead Levels: A Pooled Analysis of 12 Epidemiological Studies.* Environmental Research. 1998. 79: 51-68.

[19] *Eliminating Childhood Lead Poisoning: A Federal Strategy Targeting Lead Paint Hazards.* President's Task Force on Environmental Health and Safety Risks to Children. 2000 Feb: 29-33.

[20] Lourie, RS. *Pica and Poisoning.* American Journal of Orthopsychiatry. 1971 Jul. 41(4): 697-9.

[21] Those children who are at the highest risk for lead exposure include urban, minority populations residing in pre-1980 housing. These individuals have lower incomes, and consequently cannot keep children's environments effectively lead-free, by containing the paint with regular maintenance. Harold Ward. Personal Correspondence. 04/26/03.

[22] Constraints include costs of tenant relocation, inspections, and moreover, lead removal and remediation - of which will be discussed in the ensuing text.

[23] Rhode Island Childhood Lead Poisoning Prevention Program (CLPPP). Housing: Best Practices. Available at http://www.healthri.org/family/lead/housing.htm. Accessed on 03/04/03.

for families with children at a high risk for future incidents of lead poisoning; (3.) Increased measures to identify and remediate[24] lead hazards; and lastly, (4.) Universal lead screening of children less than six years of age to identify poisoned children and the hazards that caused these poisonings.[25]

My research is primarily designed to examine the efficacy of the third-mentioned practice that seeks to identify and remediate homes containing lead-based paint hazards that have resulted in the poisoning of children under six. More specifically, my thesis will focus on the evaluation of remediation strategies that are currently being practiced in the State of Rhode Island. In order to gauge the effect that remediation services have had on making Rhode Island's rental homes lead-safe, and subsequently, in lowering the amount of lead in children's blood, I have analyzed data obtained from the DoH's Childhood Lead Poisoning Prevention Program (CLPPP). To accomplish this goal, I examined three groups of cases previously closed by the DoH. The cases used in this analysis include cases that have been closed:

1.) *Due to the remediation of lead hazards (HA);*

2.) *Due to the refusal of DoH services (REF); and*

3.) *Due to the parent of a poisoned child being the owner of the home where the poisoning occurred (PO)*

[24] For purposes of this research, the term abatement shall be synonymous with remediation. A more detailed definition of remediation, however, will be provided in the *Background* section.

[25] *Eliminating Childhood Lead Poisoning: A Federal Strategy Targeting Lead Paint Hazards.* President's Task Force on Environmental Health and Safety Risks to Children. 2000 Feb: 29-33.

Using the blood lead levels (BLLs), measured as micrograms of lead per deciliter of whole blood (μg/dL),[26] of poisoned children, and the BLLs of all children residing at the original addresses that were offered inspections in the groups, the effect that remediation services have had on children's BLLs can be measured. The effect of mobility on children's BLLs, among other confounders, will also be explored.

Before exploring the themes discussed in the previous text, additional information pertaining to lead poisoning, as well as the mitigatory efforts currently being performed in Rhode Island, will be provided to establish a more thorough understanding of the areas that will be explored throughout this thesis.

[26] *Lead Poisoning in Rhode Island: The Numbers (2002)*. Providence, RI: Rhode Island Department of Health.

Background

Despite recent gains in reducing the incidence of childhood lead poisoning throughout the United States[27] – a result due in large part to the removal of lead from gasoline, canned goods, and paints[28] – lead poisoning remains one of the foremost environmental health risks to children under six.[29] Of particular concern, however, are children who reside in disadvantaged urban communities throughout the Northeastern United States. This includes several communities in the State of Rhode Island – where some of the nation's oldest wood-frame housing stock exists.[30]

The Effects of Lead Poisoning

The adverse health effects from lead exposure are well documented, especially those manifesting at higher levels.[31,32] However, lead poisoning is not a signature disease. Its symptoms are often indistinguishable from other maladies and therefore difficult to

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[27] The most recent National Health and Nutritional Examination Survey (NHaNES) reports that the percentage of U.S. children, ages 1-5, having BLLs ≥ 10 µg/dL decreased from 88.2% to 2.2%. It further reports that the decrease in overall mean BLL for the general U.S. population was from 14.6 µg/dL in 1976-1981 to 2.2 µg/dL in 1999-2001. Nonetheless, 434,000 (189,000-846,000) children are still estimated to have BLLs ≥ 10 µg/dL. National Health and Nutritional Examination Survey. Available at http://www.cdc.gov/nceh/lead/research/kidsBLLhtm#National%20surveys. Accessed on 5/4/02.

[28] Lanphear BP, Dietrich KN, Berger O. *Prevention of Lead Toxicity in U.S. Children.* Ambulatory Pediatrics. 2003, Jan-Feb. 3(1): 27-36.

[29] *Ibid*.

[30] It is estimated that nearly 70% of Rhode Island's housing stock was built prior to 1978, when lead was banned from paint. Further lead poisoning information specific to the State of Rhode Island will be provided in the ensuing section entitled *Lead Poisoning and Rhode Island*. RICLPPP. Housing: Best Practices. Available at http://www.healthri.org/family/lead/housing.htm. Accessed on 03/05/03.

[31] Needleman HL, Gunnoe C, Leviton A, et al. Deficits in Psychologic and Classroom Performance in Children with Elevated Dentine Lead Levels. New England Journal of Medicine. 1979. 300: 584-695.

[32] Needleman HL, Gastonsis CA. *Low-level Lead Exposure and the IQ of Children*. Journal of the American Medical Association. 1990(263): 673-8.

diagnose. This is particularly relevant in cases of chronic lead poisoning – or, the gradual accumulation of lead in the body[33] – where poisonings are often detected during the latter stages of exposure when the effects of lead poisoning are relatively irreversible.

The adverse effects resulting from chronic lead exposure have been confirmed as leading to memory loss, hearing and speech impairments, stunting of growth, kidney dysfunctions, and reduced intelligence quotient (IQ) levels.[34] In fact, several studies have reported an evidentiary link between lead exposure and deficits in academic and cognitive performance. One study in particular, concluded that on average, a child whose BLL increases from 10 to 20 μg/dL will suffer a loss of approximately two IQ points.[35,36] Another study examining lead's effects on cognition found that an increase of 4 μg/dL of lead in the blood would result in the loss of almost one IQ point.[37] Most recently, a study conducted by Cornell University, Cincinnati Children's Hospital Medical Center, and the University of Rochester School of Medicine found that the IQ scores of children who had BLLs of 10 μg/dL were about 7 points lower than for children with levels of 1 μg/dL. At

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[33] National Health Service (NHS) Direct Online Health Encyclopedia. Lead Poisoning. Available at http://www.nhsdirect.nhs.uk/nhsdoheso/print.asp?sTopic=Leadpoisoning. Accessed on 03/05/03.

[34] *Ibid*.

[35] Bellinger DC, Stiles KM, Needleman HL. *Low-Level Lead Exposure, Intelligence, and Academic Achievement: A Long Term Follow-up Study*. Pediatrics. 1992. 90: 855-61.

[36] World Health Organization. Environmental Health Criteria 165: Inorganic Lead. Geneva, Switzerland: World Health Organization. 1995. As seen in, Brown, MJ. *Costs and Benefits of Enforcing Housing Policies to Prevent Childhood Lead Poisoning*. Medical Decision Making. 2002 Nov/Dec: 482-92.

[37] Daniel Swartz, Executive Director of the Children's Environmental Health Network. Lecture in Environmental Studies 171: Environmental Health Policy. Brown University, fall 2002.

the same time, the study found that an increase in BLL from 10 to 30 μg/dL is associated with only a small additional decline in IQ.[38]

Although losses of a few IQ points may go unnoticed in some cases, it is important to understand how IQ loss in the general populace affects the distribution of IQ. Figure 1, for example, shows that a shift in the mean 'normal' IQ of a population will impact the size of the distribution's tails. This meaning that the number of children in the 'impaired' range will increase significantly if the population mean shifts to the left (Figure 1).

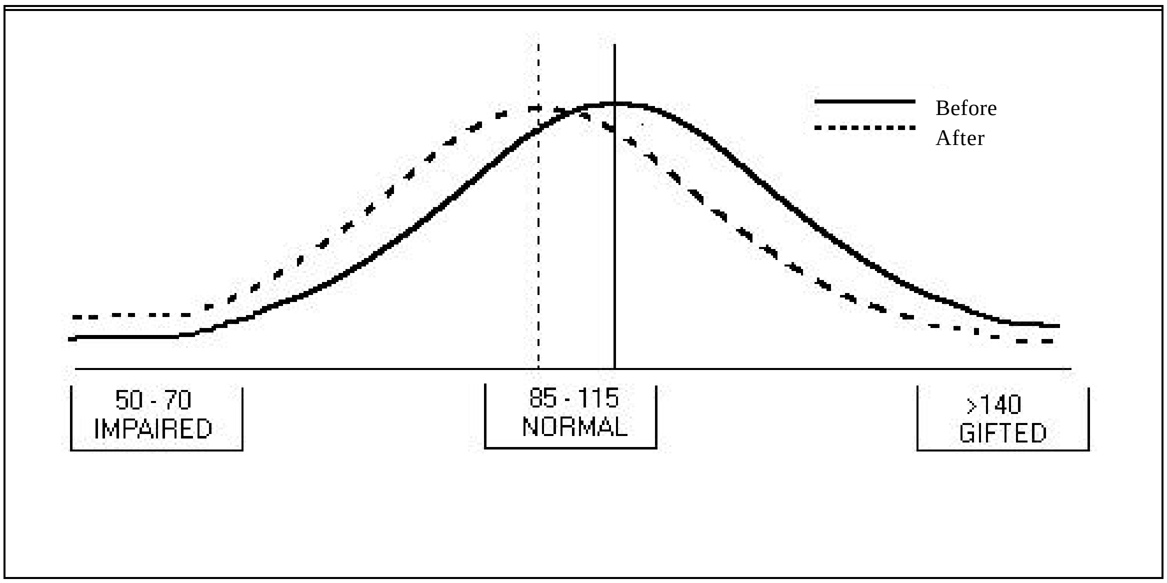

Figure 1: Distribution of IQ in a Population Before and After a Minimal Reduction in IQ Points.

[38] Canfield RL, Henderson CR, Cory-Slechta DA, Cox C, Jusko TA, Lanphear BP. Intellectual Impairment in Children with Blood Lead Concentrations Below 10 μg/dL The New England Journal of Medicine. 348(16): 1517-1526.

Acute lead poisoning, fortunately now rare, differs from chronic lead poisoning because it occurs when copious amounts of lead are ingested or inhaled into the body during shorter time periods – often attributed to occupational lead exposures.[39] The effects of acute lead exposure are more severe than chronic poisoning and include, among other effects: anemia, immune deficits, speech and hearing disabilities, organ failure, and finally, death.[40]

The duration of poisoning after exposure is removed varies depending on whether children have been chronically or acutely exposed to lead.[41] One study reports a half-life of lead in the body for children who have been chronically exposed, and present high BLLs, to be between 20 and 38 months, while for children who have been acutely exposed to lead, the same study indicates a half-life of 10 months.[42] Researchers conclude that these variations are largely due to the uptake and leaching characteristics of children's bones.[43] Early in childhood, lead in bone and blood are labile because of a high turnover rate – meaning that lead is more easily absorbed and released from children's bones. Once returned to circulation, lead can either be reabsorbed by the bone,

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[39] Some industries at risk for occupational lead exposure include those involved in the production and smelting of lead, lead soldering, and the manufacturing and recycling of batteries. MacRoy, P. *In Search of Safe Housing: Blood Lead Levels of Past Occupants as an Indicator of Present Lead Safety*. Master's Thesis. Brown University Center for Environmental Studies. 2001.

[40] National Health Service (NHS) Direct Online Health Encyclopedia. Lead Poisoning. Available at http://www.nhsdirect.nhs.uk/nhsdoheso/print.asp?sTopic=Leadpoisoning. Accessed on 03/05/03.

[41] Mushak, P. *Lead Remediation and Changes in Human Lead Exposure: Some Physiological and Biokinetic Dimensions.* The Science of the Total Environment. 2003. 303: 35-50.

[42] Manton WI, Angle CR, Stanek KL, Reese YR, Kuehnemann TJ. *Acquisition and Retention of Lead by Young Children.* Environmental Research. 2000. 82: 60-80.

[43] O'Flaherty, EJ. Physiologically *Based Models for Bone-Seeking Elements. V. Kinetics of Lead Deposition in Humans.* Toxicological Applied Pharmacology. 1995. 131: 16-29.

or excreted from the body.[44] However, once children reach adolescence, the rate of bone turnover begins to decrease, and bones become a reservoir for lead.[45] Another study, examining the amount of time required for children's BLLs to drop below 10 µg/dL,[46] found that children with BLLs between 25-29, 20-24, 15-19, and 10-14 µg/dL, required 24, 20.9, 14.3, and 9.2 months, respectively, to present BLLs below 10 µg/dL.[47,48] The study also concluded that the mean time for BLLs to decline was directly proportional to the peak BLL of children, but the time for 50% of the BLLs in children to decline to less than 10 µg/dL was not linear, and varied according to children's peak BLLs.

Both studies report rates of lead decay as a function of the degree of the exposure. Their research shows that children presenting BLLs above 20 µg/dL may take up to two years to exhibit BLLs that fall below the Center for Disease Control's (CDC) level of concern. One researcher concluded that because of this slow decay, lead remediation benefits have a greater benefit for future children that have not been exposed to lead.[49]

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[44] *Ibid.*

[45] *Ibid.*

[46] This is the current lead poisoning 'threshold – known as the Center for Disease Control's (CDC) level of concern. According to the CDC, a child with a BLL ≥ 10 µg/dL is lead poisoned.

[47] As a caveat, these children were also enrolled in case management services. Roberts JR, Riegart JR, Ebeling M, Hulsey TC. *Time Required for Blood Lead Levels to Decrease in Non-chelated Children.* Journal of Toxicology – Clinical Toxicology. 2001. 39(2): 153-60.

[48] Important to note is that 438 of 1148 children were excluded in this study because their BLLs had not dropped below 10 µg/dL, either due to a short-follow up time or a slow decline in BLL. Had these children been included in the analysis, the number of days required for BLLs to fall below 10 µg/dL would likely differ. *Ibid.*

[49] Mushak, P. *Lead Remediation and Changes in Human Lead Exposure: Some Physiological and Biokinetic Dimensions.* The Science of the Total Environment. 2003. 303: 35-50.

Though lead is a confirmed neurotoxicant, with high exposure levels inversely correlated with cognitive functioning, the absolute lowest levels of blood lead concentration, associated with deficits in cognition and academic achievement have yet to be adequately defined.[50] In the 1960's, lead toxicity was defined as a BLL of 60 μg/dL – a level that now is treated by chelation.[51] Since then, a continued exploration into the effects of lead poisoning on children's environmental health has resulted in the periodic lowering of the acceptable BLL in children (Figure 2).[52] The CDC's most recent reduction in 1991 redefined the level as 10 μg/dL. This reduction was based on epidemiological studies and models that indicated BLLs between 10 and 20 μg/dL could have adverse effects on the neurological development of children.[53,54,55] However, recent evidence indicates that lead remains toxic to children at even lower levels. Therefore, child advocates are

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[50] Lanphear, BP. *The Paradox of Lead Poisoning Prevention.* Science. 1998, Sept. 11. 281(5383): 1617-18.

[51] Chelation is a type of chemical treatment for children with severely high BLLs. The chemicals in the substance bind with lead in the body to increase the urinary excretion of lead in the blood and decrease total body burden. Available at http://www.hsph.harvard.edu/Organizations/DDIL/chelation.html. Accessed on 04/15/03.

[52] Landrigan, PJ. *Pediatric Lead Poisoning: Is There a Threshold?* (commentary on Lanphear, BP, Dietrich K, Auginer P, Cox X. C*ognitive Deficits Associated With Blood Lead Concentrations <10mg/dL in U.S. Children and Adolescents*. Public Health Reports. 2000 Nov/Dec. 115(6):521-9). Public Health Reports. 2000 Nov/Dec. 115: 530-1.

[53] Lanphear BP, Dietrich K, Auginer P, Cox X. *Cognitive Deficits Associated With Blood Lead Concentrations <10mg/dL in U.S. Children and Adolescents*. Public Health Reports. 2000 Nov/Dec. 115(6): 521-9. Public Health Reports. 2000 Nov/Dec. 115: 530-1

[54] Schwartz, J. *Low-level Lead Exposure and Children's IQ: A Meta-Analysis and Search for a Threshold*. Environmental Research. 1994. 65: 42-55.

[55] Needleman HL, Gastonsis CA. *Low-level Lead Exposure and the IQ of Children*. JAMA 1990(263): 673-8; and Lanphear BP, Dietrich K, Auinger P, Cox C. *Cognitive Deficits Associated With Blood Lead Concentrations <10 μg/dl in US Children and Adolescents*. Public Health Reports. 2000 Nov/Dec. 115(6): 521-9.

recommending that the CDC lower its level of concern from 10 μg/dL to 5 μg/dL, if not even lower. [56]

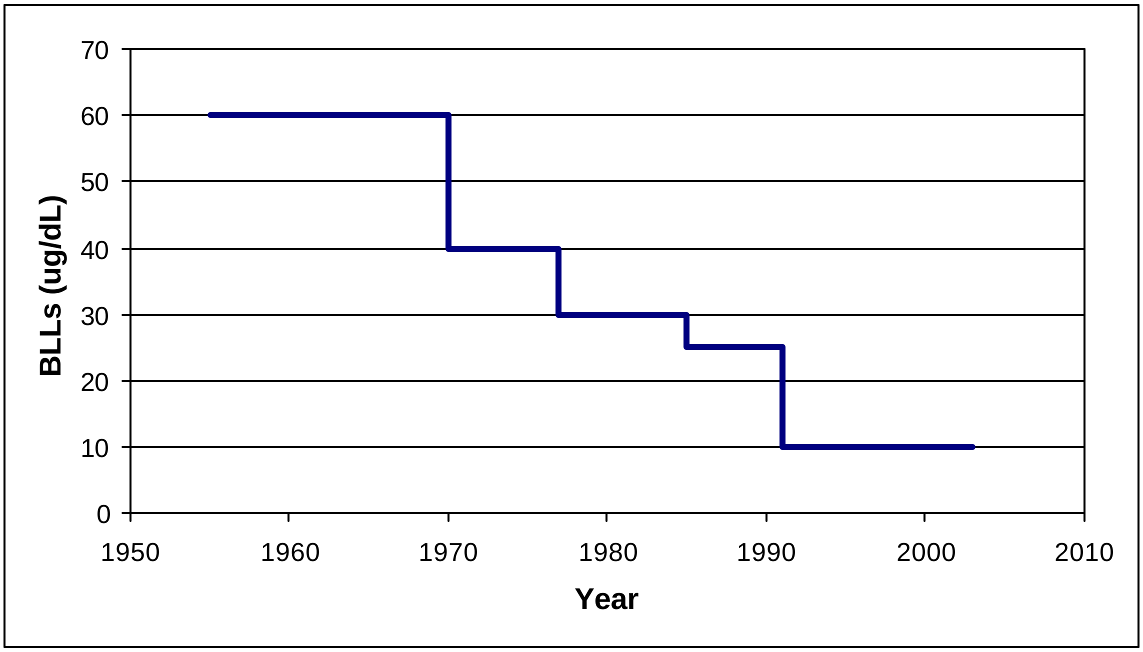

Figure 2: Evolution of Children's BLLs Considered to be Poisoned by the CDC.[57]

Lead exposure also interferes with social adjustability and may lead to impulsive behavior. Once anecdotal, recent studies are finding an evidentiary link between low-level lead exposure and behavioral disorders, including Attention Deficit Hyper-activity Disorder (ADHD) and criminality.[58] A study conducted in 1996 examined bone lead concentrations in children ages 12-18, and discovered, after controlling for confounders, significantly higher bone lead concentrations in children who were convicted of

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[56] *Ibid.*

[57] Adapted from Preventing Lead Poisoning in Young Children. Atlanta: Centers for Disease Control. 1991. As seen in Rogan, WJ and Ware, JH. Perspective: *Exposure to Lead in Children – How Low is Low Enough?* New England Journal of Medicine. April 17, 2003. 348(16): 1515-16.

[58] Wakefield, J. "The Lead Effect?" Environmental Health Perspectives. 2002 Oct. 110(10): A575-580.

delinquency than in those devoid of such convictions.[59] Similarly, past crime rate fluctuations highly correlate with periods of lead exposures in the past. For example, researchers believe that the decrease in crime rates during the 1990's might be a reflection of the sharp decline in the number of childhood lead poisonings that occurred during previous periods.[60] Although these studies are controversial, they are particularly noteworthy since the societal and individual costs of lead poisoning might be severely underestimated.[61]

Given the critical impacts of lead poisoning, perhaps the most tragic issue surrounding this disease involves urban and minority children who are already facing enormous societal disadvantages and have the highest risk for lead exposure. The areas in which these populations reside are more likely to have deteriorating homes constructed prior to 1978, creating an exceptionally high risk for lead exposure. Even more troubling is that these same children are likely to have other risk factors, such as inadequate nutrition and

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[59] *Ibid*.

[60] *Ibid*.

[61] One estimate indicates a $9,600 societal loss for each IQ point lost due to lead poisoning (translated from a future loss in earning potential). Daniel Swartz, Executive Director of the Children's Environmental Health Network. Lecture in Environmental Studies 171: Environmental Health Policy. Brown University, fall 2002. Other estimates indicate a loss of $10,569 per year in special education costs. Brown, MJ. *Costs and Benefits of Enforcing Housing Policies to Prevent Childhood Lead Poisoning*. Medical Decision Making. 2002 Nov/Dec: 482-92. These estimates do not include costs of medical treatment, remediation, relocation, and inspection, and more importantly, they do not include costs attributed to delinquency and criminality.

anemia,[62] which further increases their susceptibility to lead poisoning and its adverse effects.[63]

Lead Poisoning and Rhode Island

Of the many areas in the nation plagued by high rates of lead poisoning, few are worse than those situated in the Northeastern portion of the United States, including the State of Rhode Island, where childhood lead poisoning rates have reached epidemic proportions. Recent estimates indicate that Rhode Island has a lead poisoning rate almost four times the national rate of childhood lead poisoning.[64] According to the U.S. Department of Housing and Urban Development (HUD), approximately 39 million homes, or 40% of the nation's housing stock, contains leaded paint.[65] Some estimates indicate that 50-80% of Rhode Island homes have lead paint covering their surfaces.[66] Of these homes, further estimates are that nearly 30,000, mostly low-income housing units,[67] present a high risk of lead poisoning and have a pressing need for remediation.[68] In 2002 alone, nearly

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[62] The effects of lead poisoning and anemia are reported to be synergistic and devastating. Poor nutrition, on the other hand, prevents the intake of specific minerals that can help increase the uptake rate of lead.

[63] Rhode Island Kids Count. *Issue Brief: Childhood Lead Poisoning*. February 2003. p 3.

[64] *Lead Poisoning in Rhode Island: The Numbers (2002)*. Providence, RI: Rhode Island Department of Health.

[65] Wakefield, J. *The Lead Effect?* Environmental Health Perspectives. October 2002. 110 (10): A575-580.

[66] Rhode Island Childhood Lead Poisoning Prevention Program (CLPPP). Housing: Best Practices. Available at http://www.healthri.org/family/lead/housing.htm. Accessed on 03/05/03.

[67] A housing unit will be defined as any room or group of rooms located within a dwelling and forming a single habitable unit with facilities which are used, or intended to be used for living, sleeping, cooking, and eating. State of Rhode Island and Providence Plantations Department of Health. Rules and Regulations for Lead Poisoning Prevention [R23-24.6-PB]. February 1992, as amended January 2002.

[68] Rhode Island Childhood Lead Poisoning Prevention Program. Housing: Best Practices. Available at http://www.healthri.org/family/lead/housing.htm. Accessed on 03/05/03.

2,500 children under the age of six in the State were diagnosed as having a BLL greater than 10 μg/dL, of whom hundreds having significantly elevated levels (BLLs ≥ 20 μg/dL).[69] Of these children, those with the greatest risk for lead exposure, as discussed in the aforementioned section, include poor, minority, and urban children. In 2001, the DoH reported that Black, Asian, and Hispanic children were two to three times as likely to have elevated BLLs as were White children in the State.[70]

Rhode Island's Lead Poisoning Prevention Policies

The CLPPP is the DoH program that is largely responsible for the creation and coordination of a comprehensive program for the prevention of childhood lead poisoning, including, but not limited to: the screening and detection of lead in children, the education about lead and its effects on children, lead hazard reduction efforts, and the enforcement of its policies.[71] State regulations require that all children under six be screened annually for lead[72] – one of the most comprehensive testing requirements in the country.[73] Once children are screened, the samples are sent to the State laboratory or to one of two State approved hospitals for processing.[74] Test results are immediately

[69] Rhode Island Kids Count. *Issue Brief: Childhood Lead Poisoning*. February 2003. p 1.

[70] *Ibid.*

[71] Rhode Island Lead Poisoning Prevention Act. § 23-24.6-5: Environmental Lead Program.

[72] *Ibid*. § 23-24.6-7: Screening by Health Care Providers.

[73] Rhode Island's current lead screening rate is nearly 80%. *Lead Poisoning in Rhode Island: The Numbers (2002)*. Providence, RI: Rhode Island Department of Health.

[74] *Ibid*.

reported to the CLPPP, where state licensed certified inspectors[75] are dispatched to the homes of children whose tests report elevated BLLs (BLLs ≥ 20 μg/dL, or persistent BLLs between 15 and 19 μg/dL[76,77]) to conduct comprehensive environmental lead inspections.[78] If a resident grants the inspector permission to conduct an inspection, the inspector performs several tests to verify the presence of lead hazards.[79] In the event that lead hazards are discovered during the inspection, the property owner is issued a notice of violation (NOV) that requires the remediation of identified lead hazards within 90 days after the NOV was issued.[80] The actual method of remediation that a homeowner must undergo for their home to be considered safe for re-occupancy, however, is loosely defined.[81] The DoH describes remediation as:

> . . . Any activity that reduces the risk of human exposure to lead-based paint through environmental modification. Activities include, but are not limited to:

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[75] Rhode Island Lead Poisoning Prevention Act § 23-24.6-20: Licensure or Certification of Environmental Lead Inspectors and Lead Contractors, Supervisors, and Workers.

[76] Inspectors are sent to homes when a child presents a BLL between 15-19 µg/dL for two tests (venous or capillary) at least 90 days, but less than 365 days apart. A single BLL of 15 µg/dL, however, will be referred for case management. If the home does not meet the DoH inspection criteria, then the case management agency will perform an environmental inspection that will not be enforced by the DoH. Patrick MacRoy. Personal Correspondence. 04/18/2003.

[77] An important note is the discrepancy between the DoH intervention threshold and the CDC level of concern. The DoH intervention level is much higher due to resource constraints. If the DoH were to use the CDC's level of concern for its intervention level, the number of children poisoned in the state would substantially increase.

[78] A comprehensive environmental lead inspection is a surface-by-surface investigation for the presence of current, or potential future, lead hazards in paint, dust, soil, and water, conducted by a certified lead inspector. State of Rhode Island and Providence Plantations Department of Health. Rules and Regulations for Lead Poisoning Prevention [R23-24.6-PB]. February 1992, as amended January 2002.

[79] Tests include a visual inspection of exposed surfaces, dust-wipe tests, XRF (X-ray fluorescence) tests, and if needed, soil and water tests. *Ibid.*

[80] *Ibid.*

[81] Each option in the ensuing text presents specific guidelines that have to be followed in order to meet lead-safe standard. However, the term loosely defined implies that multiple methods can be used to meet the DoH standards.

> repair, enclosure, encapsulation, removal, and/or replacement of lead based paint or painted surfaces, material, or components in a building or structure. It shall also include any measures that reduce the concentration of lead in lead contaminated dust, soil, or drinking water.[82]

Once the homeowner corrects the cited violations, the inspector conducts a post-remediation lead clearance test to assure that the property has achieved compliance in accordance to the DoH's lead-safe requirements.[83] Upon satisfying the requirements, a lead-safe certificate is issued for the home.[84]

This process, however, does not always occur in the manner depicted above. Instead, it is commonly hindered by residents within the homes. For example, tenants will often refuse to allow the inspectors into their homes to conduct a comprehensive environmental lead inspection – preventing the detection of lead hazards, and more importantly, the remediation process. Although state inspectors can obtain a court order directing tenants to comply with inspection requirements[85] (upon a showing of probable cause for conducting the inspection) this practice is rarely conducted because of the DoH's fear

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[82] *Ibid.*

[83] A post-remediation clearance inspection shall determine that: all painted surfaces (of concern), as well as samples of soil and water, are not above permitted levels of lead. They will also assure that no visible dust or paint chips remain in the home. A lead-free environment is defined as a level of lead < 20 μg/sq. ft. on any surface, whilst a lead-safe environment is defined as a level of lead between 40-400 μg/sq. ft., depending on the surface. *Ibid.* §§ *4.2-6.2*.

[84] A lead-safe certificate implies that at the time of certification, the regulated environment did not contain any significant lead hazards (see above footnote), and would not be expected to pose a significant health threat to children under six. More importantly, a lead-safe certification does not require the complete removal of lead (lead-safe ≠ lead-free), but it does require routine maintenance and annual reinspection. *Ibid.*

[85] Rhode Island Lead Poisoning Prevention Act. § 23-24.6-13: State Inspectors.

that the presence of a sheriff's deputy and a court order at people's doors will make parents reluctant to getting their children tested for lead.[86]

Inspection is also avoided when the owner of the home where the child has been poisoned is the parent or guardian of that child. Here, the DoH will conduct an inspection, assuming the parent or guardian has granted permission, but violations are not enforced.[87] To help explain this process, the hierarchical chart in Figure 3**[88]** illustrates the flow of all cases in 2001 that were referred for comprehensive environmental lead inspections.[89]

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[86]Additionally, the State of Rhode Island has a minimal number of inspectors and cannot afford to allocate scarce resources obtaining court orders when they could be inspecting other homes suspected of lead-based paint hazards. Patrick MacRoy. Personal correspondence. May 2003.

[87] The DoH assumes that the parent or guardian of the poisoned child will assume responsibility for mitigating the suspected lead hazards.

[88] Data obtained from the DoH's CLPPP. Chart developed by the author.

[89] Data included in the chart appears different than the 2001 data in *Lead Poisoning in Rhode Island: The Numbers (2002)*. Providence, RI: Rhode Island Department of Health, because the status of cases are continually changing, and some cases are grouped together.

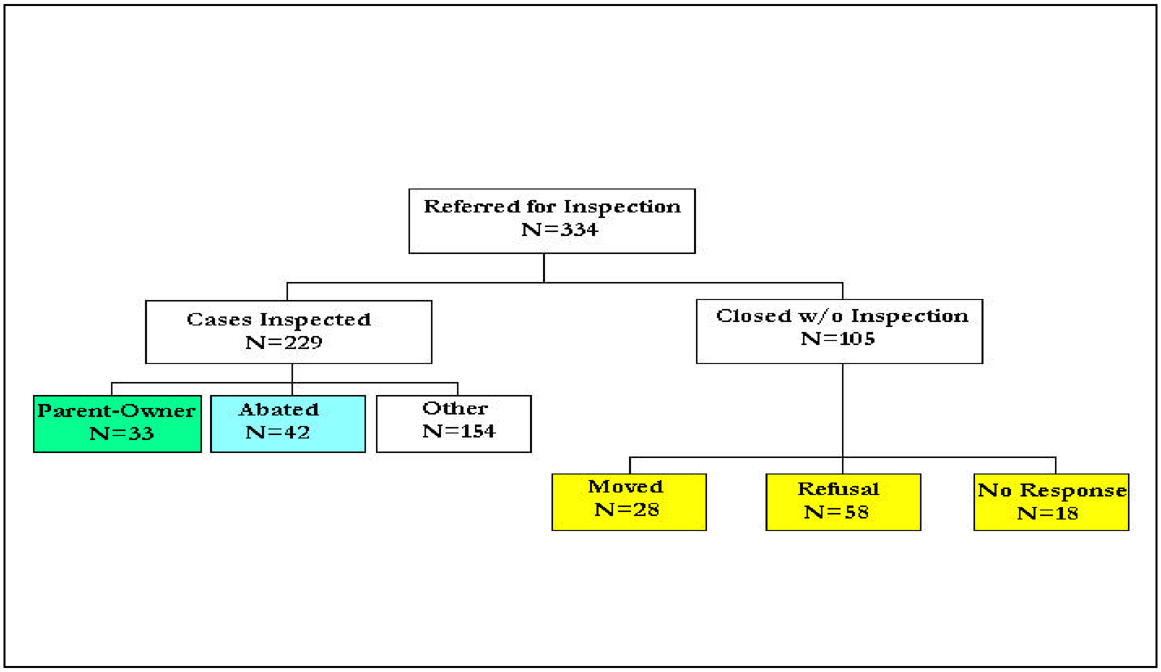

Figure 3: Hierarchical Chart for all Cases Referred for a Comprehensive Environmental Lead Inspection by the DoH, 2001.

The chart illustrates that 105 cases, or 30% of the total cases referred in 2001, refused the DoH's comprehensive environmental lead inspections.[90] Figure 2 also indicates that approximately 10% of the cases referred for inspection were parent homeowner cases. This meaning that the cases were referred for a comprehensive environmental lead inspection, but violations were never enforced. Together, these figures indicate that in just 2001 alone, 40% of the referred cases were never enforced by the DoH. Even more troubling is that the number of tenants who refused comprehensive environmental lead inspections in the past three years has increased substantially.[91] With the average cost of

[90] The chart actually indicates 58 cases refusing inspections, however, for research purposes; the three groups (moved, refused, and no response) are categorized as all having refused DoH services. The "Other" category includes cases that are in various stages of compliance (i.e., first or second NOV has been sent and the DoH is awaiting compliance, or cases have been sent to the Attorney General for further prosecution).

[91] In 1999, 19% of the total cases referred for inspection resulted in a tenant refusing services. In 2000, that number increased to 22%, and in 2001 it was 30%. Meanwhile, the parent-owner cases have remained

remediation roughly $6,000 per unit, and $16,000 per building,[92] it is believed that some landlords are pressuring their tenants to refuse remediation services, or alternatively, face eviction. As a result, these tenants, when faced with the threat of retaliatory eviction and the pressure of locating a home in a tight market for safe, affordable housing choices, are likely opting to continue to live in homes that contain lead-based paint hazards.[93]

Question Formulation

Despite Rhode Island's comprehensive lead prevention polices intended to decrease the incidence of childhood lead poisoning, this disease continues to threaten children's health and welfare throughout the State. Based on the figures presented throughout the introduction and background sections of this thesis, the efficacy of Rhode Island's current lead hazard remediation program is questioned.

An examination of the literature on the effects of remediation on children's BLLs reveals a range of conclusions. One study measured the impact of lead-based paint hazard remediation on children's BLLs in St. Louis, Missouri, and discovered that remediation

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relatively static – representing 10-20% of the total cases referred for inspection between 1999-2001. *Lead Poisoning in Rhode Island: The Numbers (2002)*. Providence, RI: Rhode Island Department of Health.

[92] Brown, MJ. *Costs and Benefits of Enforcing Housing Policies to Prevent Childhood Lead Poisoning*. Medical Decision Making. 2002, Nov/Dec. 482-92.

[93] Rhode Island Housing estimated in 2000 that 17,867 families were living below the poverty level, and 37,337 low-income, non-elderly, renter families were in search of housing, but only 12,745 units existed for low and moderate-income families. Rhode Island Housing. *State of Rhode Island Consolidated Plan. 2000-2005*. January. 2000. As seen in: Tobin-Tyler, E. *Safe and Secure: Enforcing the Rights of Low-income Tenants and their Children to Lead-Safe Housing*. Brief for Children's Friends & Service and the HELP Lead Safe Center. June 2002.

efforts were effective in lowering children's BLLs that were initially above 34 μg/dL.[94] The St. Louis study was a retrospective analysis, using St. Louis, Missouri, City Health Department records, to analyze both the changes in BLLs of poisoned children who were residing in homes that underwent remediation, and the changes in BLLs of children living in dwellings that did not undergo lead hazard remediation. Of the 185 children who met the selection criteria,[95] only 71 children had a blood lead test in the period 10-14 months after the initial diagnosis. In this period, the BLLs of the cases and the controls were significantly different. Specifically, the mean BLL of children residing in homes that underwent remediation dropped from 34.9 μg/dL to 26.7 μg/dL (a 23% decrease from the starting BLL (95% CI: -30 to -16)), compared with a drop from 35.1 μg/dL to 30.9 μg/dL (95% CI: -18 to -5) for children living in homes that did not undergo lead hazard remediation (t-test, p = 0.07). Together, these estimates indicate that the effect of remediation is a 13% decline (95% CI: -25 to 1; p = 0.07) in BLLs. However, after adjusting for confounders, the study suggested an effect of remediation closer to -16% (95% CI: -25 to -7; p = 0.002). The St. Louis study also reported that the BLLs of children in both groups were above the CDC's level of concern 10-14 months after diagnosis, and little benefit was evident in children with initial BLLs between 25 and 34 μg/dL (-13%, 95% CI: -19 to -6; p = 0.02). Although the St. Louis study reports differences amongst the cases and controls (t-test, p = 0.07), the control group also presents a drop in mean BLL in the 10-14 month follow-up period. The researchers posit

[94] Staes C, Matte T, Copley CG, Flanders D, Binder S. *Retrospective Study of the Impact of Lead-Based Paint Hazard Remediation on Children's Blood Lead Levels in St. Louis, Missouri*. American Journal of Epidemiology. May 15, 1994. 139(10): 1016-1026.

[95] Most of the children that did not meet their selection criteria moved from their homes before the 10-14 month blood lead measurement. *Ibid*.

that this might be due to secular trends, the education of parents, aging of their subject, or some combination of factors, and therefore, "the change in BLLs after remediation cannot be attributed solely to the remediation, and control populations must be used to assess fully the impact of remediation on children's BLLs."[96]

Another study attempting to assess the effects of remediation on BLLs, and determine if declines can be attributed to other factors besides remediation, estimated the natural rate of BLL decline via a meta-analysis of several control populations used in different studies.[97] The meta-analysis of controls estimated the one-year change in BLLs for populations that had not experienced any intervention efforts to reduce exposure to lead-based paint hazards, and concluded that an average 9% decline in BLLs during the first year after remediation could be attributed to 'natural' factors unrelated to intervention (i.e., age and season), and a 16% decline in BLLs could be attributed to 'unnatural' intervention strategies like lead remediation. Together, these results indicate that children would be expected to exhibit a 25% decline in BLLs during a period of one-year after intervention that is due to both 'natural' and 'unnatural' factors. These findings support the observations in the St. Louis study that show BLLs in the cases falling for reasons both related and unrelated to the effects of intervention, and BLLs in the controls falling for reasons unrelated to intervention.[98]

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[96] *Ibid.*

[97] Niemuth NA, Wood BJ, Schultz BD. *Estimated Change in Blood Lead Concentrations in Control Populations*. November/December 2001. 56(6): 542-51.

[98] Once again, the initial BLLs of children will impact these reductions significantly.

A study by Taha et. al., examining the effects of environmental and educational intervention on children with BLLs between 25 and 44 μg/dL,[99] is consistent with the findings in the above studies, showing a significant difference ($p < 0.05$) in the decline of BLLs between the case and control groups. Specifically, the mean decline of case children's BLLs is 6 μg/dL, or -18%, of the initial BLLs for the period 1-6 months after intervention (95% CI: -29.3 to -14.6). The control group BLLs, on the other hand, declines 1.6 μg/dL, or -1.8% (95% CI: -4.3 to 5.1), of the starting BLLs, for the same period. The researchers note that the findings for the intervention change in BLLs is consistent with the percentage changes in the St. Louis study, while the percent decline in the control group is less than that in the retrospective St. Louis study.[100]

In contrast, other studies present results that are contrary to the St. Louis and Taha et. al. studies. An examination of the BLLs of poisoned children in Toronto in 1990 following remediation strategies,[101] observed that children's BLLs, like those in the above studies, decreased in both the case (-6.4 μg/dL; 95% CI: -5.9 to -6.9) and control (-4.2 μg/dL; 95% CI: -3.8 to -4.6) groups, but concluded that their results could neither strongly support, nor refute, the beneficial effects of lead remediation.[102] In other studies, investigations into the effects of lead dust control measures on children's BLLs, found

[99] Taha T, Kanarek MS, Schultz BD, Murphy A. *Low-Cost Household Paint Abatement to Reduce Children's Blood Lead Levels.* Environmental Research. 1999. Section A. 81: 334-38.

[100] *Ibid.*

[101] Strategies of remediation in the study included soil replacement and professional housecleaning for lead removal. Langlois P, Smith L, Gould R, Goel V, and Gibson B. *Blood Lead Levels in Toronto Children and Abatement of Lead Contaminated Soil and House Dust.* Archives of Environmental Health. 1996. Jan.-Feb. 51(1): 59-67.

[102] *Ibid.*

that an intervention consisting solely of providing cleaning supplies and educational methods to tenants is not effective in reducing the BLLs of poisoned children.[103,104]

Perhaps even more relevant to this research are studies that use Rhode Island data to examine the effectiveness of intervention, and report no significant differences amongst case and control groups. A study by the DoH, examining the effects of case management services on children's BLLs, reports no significant differences in the BLLs amongst those receiving and completing case management services, versus those receiving partial, or no case management services.[105]

Knowing that conclusions on the effects of remediation in reducing poisoned children's BLLs are divided, I have analyzed the DoH lead data, as previously discussed, to assess the efficacy of Rhode Island's lead hazard remediation program. It is important to recognize that the previous studies, including the St. Louis and Taha, et. al. studies, used relatively small numbers of children within their case and control groups. In contrast, a wealth of data exists for Rhode Island, which can help to better portray the efficacy of lead remediation in reducing poisoned children's BLLs, and moreover, produce results that have more statistical power than those in the literature. Figure 3 outlines the differences amongst the data used in these studies.

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[103] Lanphear BP, Winter NL, Apetz L, Eberly S, Weitzman M. *A Randomized Trial of the Effectiveness of Children's Blood Lead Levels.* Pediatrics. 1996. 98(1): 35-40.

[104] Tohn ER, Dixon, LR, Wilson JL, Galke WA, Clark, SC. *An Evaluation of One-Time Professional Cleaning in Homes with Lead-Based Paint Hazards.* Journal of Applied and Occupational Hygiene. 2003. 18 (2): 138-43.

[105] MacRoy, P. *Evaluation of Case Management for Lead Poisoning in Rhode Island*. Rhode Island Department of Health's Childhood Lead Poisoning Prevention Program. 2003.

Study Statistic	St. Louis study[106]	Taha, et. al. study	Present Study
Size of Case Group	**49**	**37**	**862**
Size of Control Group	**22**	**65**	**590**
Study Type	**Retrospective**	**Retrospective**	**Retrospective**
Covariates	**Age, Season**	**Age, Season**	**None**

Table 1: Comparison of Case and Control Groups in Three Studies Assessing the Effects of Lead Hazard Remediation on Children's BLLs.

Data Source

Data for this study were derived from two sources obtained from the DoH's CLPPP: The Statewide Blood Lead Level Database ('SWBLL'), and the Comprehensive Environmental Lead Inspection Database ('Pb Inspect'). The first source – the SWBLL database – contains, among other fields: 'BLL,' 'Sample Type,'[107] 'Birth Date,' 'Gender,' 'Sample Obtained Date,' and a unique child identification number – 'Child ID' – for all children screened between January 1993 and October 2002. The second source –

[106] These numbers include the number of children that met specific selection criteria, including a follw-up test a year after cases were opened. In comparison, this study has 451 children in the case group and 257 in the controls a year after cases were opened.

[107] 'Sample Type' refers to the different methods of blood lead sample collection: a capillary ("fingerstick") test and a venous test. Venous tests generally provide a more accurate measure than capillary tests because they can limit any 'noise' that could accompany the sampling process.

the Pb Inspect database – contains fields that depict: the current status of all cases, the dates that cases were opened by the DoH, and where applicable, the dates that cases were closed by the DoH, for all comprehensive environmental lead inspections offered between January 1993 and October 2002.[108] Using Microsoft Access, Excel, and SPSS, for manipulation and analysis purposes, these sources were used as data in the analyses of this thesis.

Overview of Study Design

An essential goal of lead hazard remediation is to lower the rate of childhood lead poisoning as much as possible. One of the few measures to gauge such success is to analyze children's BLLs over time. Therefore, this research will use children's BLLs as an indicator of past and present lead safety – akin to the method developed in a Master's thesis by Patrick MacRoy that used BLLs of past occupants – children as indicators of present lead safety.[109] Like the limitations in using BLLs as an indicator of lead safety discussed in MacRoy's thesis, the same limitations will apply here. For example, BLLs are apt to change according to the age of a child and the season of the year, producing results that are actually attributed to natural processes, as opposed to any real changes in a child's physical environment.[110,111] Recognizing these limitations, BLLs remain the

[108] Databases provided to Brown University for these research purposes spanned January 1993 to October 2002. The CLPPP's versions, however, are continually updated and include present data.

[109] MacRoy, P. *In Search of Safe Housing: Blood Lead Levels of Past Occupants as an Indicator of Present Lead Safety*. Master's Thesis. Brown University Center for Environmental Studies. 2001.

[110] As children age they are less likely to engage in hand-to-mouth behaviors, consequently limiting the ingestion of lead-contaminated dust. Studies have also indicated that BLLs are highest during warmer months, perhaps the result of shutting windows during colder months and limiting the area of contamination and dispersal of lead from wind and fans. *Ibid*.

most accessible measurement of the success of Rhode Island's current lead hazard remediation system.[112]

Approaches to Answer the Primary Question

As discussed in the aforementioned text, current DoH policy requires that cases be closed when an inspection is refused, or when the parent of a poisoned child is established to be the homeowner. These cases can be used as control groups against which to compare the group of cases that are closed by the DoH due to the successful remediation of lead hazards.

Using the refusal (REFs) and the parent home owner (POs) groups as the 'controls,' and the group that accepts DoH lead hazard remediation services, and remediates lead hazards (HA) as the 'cases,[113]' a series of four approaches are used to test whether decreases in children's BLLs are statistically different amongst the cases and controls, thereby providing a measure of the effectiveness of Rhode Island's lead hazard remediation program. Three approaches in this thesis will examine and compare:

1.) The BLLs of poisoned children in the case and control groups at various periods after cases were opened.

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[111] Yiin LM, Rhoads GG, Lioy PJ. S*easonal Influences on Childhood Lead Exposure*. Environmental Health Perspectives. 2000 Feb; 108(2): 177-82.

[112] Ideally, continual comprehensive environmental lead inspections in homes of poisoned children are the most accurate indicators of present lead safety, and moreover, the effectiveness of the current lead hazard remediation system. However, resources obviously constrain such measures.

[113] In epidemiology, a case group is also known as an intervention group.

2.) The BLLs of poisoned children in the case group who move from remediated addresses to addresses that do not have a record of remediation, versus those who remain at remediated addresses.

3.) The BLLs of children in the case and control groups, residing at the initial addresses of the case and control groups three years before and after cases were opened.

The fourth analysis differs from the previous approaches in that it assesses whether the current lead hazard remediation program causes property-owners to engage in practices that deny housing to families with children under six years of age. Specifically, it examined:

4.) The number of children residing in HA and REF homes before and after inspections were offered to these homes.

Approach 4 tests the hypothesis that some landlords, having just experienced, or been threatened with an expensive remediation process, will be likely to discriminate against future tenants with children under six, for fear that their property may once again poison a child, consequently requiring compliance with costly lead-safe standards, or even worse, prosecution.[114]

The four analyses are discussed below. Each section includes; the goal, methodology, results, and the discussion for the four approaches.

[114] The recently amended lead poisoning prevention act considers the repeated poisoning of a child after a property-owner has refused to comply with DoH requirements a felony.

Approach 1

Approach 1 – Goal

In approach 1, I analyzed the BLLs of children in the case and control groups sampled during five periods after which cases were opened by the DoH. Specifically, these periods were: 0-60 days, 61-120 days, 121-365 days, 366-730 days, and >730 days. This approach tests whether accepting DoH services at some homes (or alternatively, refusing services, or failing to enforce the remediation of hazards at others) has a significant effect on the BLLs of children.

More specifically, this approach tests with more statistical power than the St. Louis and Taha, et. al. studies, if Rhode Island's lead hazard remediation program has a beneficial effect on poisoned children that can be statistically validated. According to the literature, if a lead hazard remediation program benefits the health of poisoned children, then I can expect to see significantly different BLLs in the cases when compared to the controls during the five periods after which cases were opened by the DoH. More importantly, I expect the direction of the differences to show that BLLs in the cases are significantly higher than they are in the controls.

Approach 1 – Methodology

Since the 'Pb Inspect' database contains multiple records per case, the first step of approach 1 involved extracting all 'new' case records occurring between January 1993[115] and October 2002[116] – identified in the Pb Inspect database by having a “02,” or alternatively, a “C” in the ‘Inspection Type’ field.[117] Upon identifying the 'new' cases, any child that resided at a HA, REF, or PO addresses at the time they were closed by the DoH – identified according to the status of their last inspection – were extracted from the above query, and isolated into separate tables. Cases that were closed due to the remediation of lead hazards (HA) and PO status were identified by a “03” and a “10” in the ‘last address status’ field respectively, while the presence of a “04,” “05,” or “06,” in the 'last address status' field identified cases that were closed due to tenants refusing DoH services.

This method of extraction and isolation created a table for each group that included, among other fields: ‘Child ID,’ Case Open Date,’ ‘DoH Inspection Date,’ and where appropriate, ‘DoH Close Date.’[118] These tables were then linked to the 'SWBLL' database, via matching 'child ID' fields, to obtain the BLLs of each child sampled after the dates at which the DoH had opened their cases. Once extracted, the BLLs were

[115] The universal screening law was passed in late 1991 and it took time to set-up the basic surveillance system, so 1993 is the first full calendar year of data. Patrick MacRoy. Personal Correspondence. 04/26/03.

[116] Records are established in the Pb Inspect database each time an inspector visits a home undergoing intervention. By extracting all new cases from 1993-2002, the data becomes much easier to manipulate.

[117] "02" and "C" are the codes for the initial inspection for a poisoned child. Other codes in the subsequent text are follow-up codes. Patrick MacRoy. Personal Correspondence. 04/27/03.

[118] The control cases (REF and PO) rarely contain case closed dates since their dates of inspection are generally the same as the dates they were closed by the DoH.

further partitioned into periods according to the dates that the respective BLLs were obtained: 0-60 days, 61-120 days, 121-365 days, 366-730 days, and > 730 days, after cases were opened by the DoH. In cases where children had multiple blood lead tests per time period, their respective levels for said period were averaged together to create a mean BLL per child.[119] The mean BLLs per child were then averaged together to produce a group mean BLL for each of the time periods. These values were then compared using an Independent t-test ($p < .05$).

To provide further analysis of BLL decline amongst the cases and controls, the percentage of BLL decline, per group, per period, were also determined. The first step used to calculate the percentage of BLL decline similarly involved extracting the three groups (HA, REF, and PO) from the 'Pb Inspect' database. These groups were then linked to the 'SWBLL' database via the 'Child ID' field to obtain all the BLLs per child – having a sample type of "2" – that were sampled: 0-60 days, 61-120 days, 121-365 days, 366-730, and >730 days after cases were opened by the DoH. From this query, all BLLs per child, occurring within the particular periods, were averaged to produce a 'BLL Table' containing the single mean BLL per child, per time period. The starting BLLs were then obtained from a series of queries involving both the 'SWBLL' and 'Pb Inspect' databases and placed in separate tables. The BLL for each child was then linked to the 'BLL table' – via 'Child ID' – and an expression was generated that calculated the percentage of BLL decline in children sampled during the five periods from the original

[119] If the results of capillary tests are above 20 µg/dL, a venous test is often conducted to confirm the result that was obtained from the capillary test. Therefore, in cases where the query reported several tests per child per time period, only the venous tests were averaged together. The venous tests are distinguished in the database by a "2"in the Sample Type Field, while the capillary test has a "1" in the same field.

elevated BLL.[120] These values were then averaged to produce a single percentage of BLL decline per group, per period. Statistical comparisons were then conducted on the means of the groups using t-tests ($p < .05$).

Approach 1 – Results

The results of approach 1 indicate that mean BLLs of children in both the cases and controls decline throughout all follow-up periods (Table 2).[121] The mean percentages of BLL decline amongst the groups support this finding, but also show that the largest percentage of BLL decline occurs in the first sixty-day period for all groups. Table 4, for example, shows that BLLs drop 9.6% for the HA group in the first period, and then only another 3.1% in the second sixty-day period. The REF and PO groups show similar results; respectively showing percent declines of 24% and 21% in the first period, and then another 5% and 9.1% in the second period. The latter periods also show large percent declines, but their time intervals are not standardized (they are larger than 60 days) and are therefore expected to show large percent declines.

The findings of this analysis also show that mean BLLs of the cases and controls remain above the CDC's level of concern for over two years after cases were opened by the DoH. These results, including the number of children tested in each group and their

[120] The BLL that triggered the DoH inspection was divided by the mean BLL per child, per period (i.e. 121-365 days), and the result was again divided by the BLL that triggered the inspection. The result was then multiplied by 100.

[121] BLLs are expected to decline with time due to the natural decay of lead in blood. Further declines in BLL can occur when children age, becoming less likely to crawl on contaminated surfaces and engage in risky hand-to-mouth behaviors.

confidence intervals, are shown in numerical and graphical form in Table 2. The results also show that the mean BLLs of children in the controls are lower than the cases for all five periods – with the REF group presenting the lowest mean BLLs in four out of the five periods (Table 2)

	0-60 days	61-120 days	121-365 days	366-730 days	> 730 days
Hazards Abated	**22.2** (21.3-23.2) (N = 379)	**20.8** (19.9-21.8) (N = 303)	**18.6** (17.8-19.4) (N = 488)	**15.5** (14.8-16.3) (N = 408)	**12.6** (11.9-13.4) (N = 280)
Refusal	**20** (18.5-21.4) (N = 127)	**18.6** (17.1-20.1) (N = 113)	**15.9** (14.9-17) (N = 167)	**13.6** (12.2-14.9) (N = 100)	**10.9** (9.4-12.4) (N = 64)
Parent-Owner	**20.8** (19-22.5) (N = 102)	**18.5** (16.5-20.6) (N = 87)	**16.9** (15.7-18.2) (N = 124)	**14.4** (13-15.8) (N = 85)	**12.2** (10.3-14) (N = 48)

Table 2: Mean BLLs and Confidence Intervals of Poisoned Children in the Case and Control Groups at Various Periods After Cases Were Opened.

	0-60 days	61-120 days	121-365 days	366-730 days	> 730 days
HA v. REF	**.012**	**.016**	**<.001**	**.012**	**.052**
HA v. PO	**.135**	**.036**	**.027**	**.153**	**.644**
REF v. PO	**.519**	**.957**	**.226**	**.399**	**.283**

Table 3: T-tests ($p < .05$) Comparing the Mean BLLs of Poisoned Children in the Case and Control Groups at Various Periods After the Opening of Cases.[122]

[122] The critical vlaue for the HA v. REF groups during the period >730 days is borderline significant andis therefore considered significant.

The t-tests comparing the mean BLLs amongst the case and control groups reveal significant differences, at the .05 alpha-level, in all five periods (Table 4). Specifically, significant differences occur amongst mean BLLs between the HA and REF groups at: 0-60 days, 61-120 days, 121-365 days, 366-730, and >730 days. Significant differences also occur between mean BLLs in the HA and PO groups for tests sampled 61-120 days and 121-265 days after the DoH opened cases. Results also show that no significant differences occur between the mean BLLs of the controls during all five follow-up periods. These comparisons, including the critical values for the t-tests (p < .05), are shown in numerical form in Table 4. The statistical differences are highlighted

	0-60 days	61-120 days	121-365 days	366-730 days	> 730 days
Hazards Abated	**9.6%** (5.6-12) (N = 319)	**12.7%** (7.9-17.5) (N = 256)	**23.5%** (20.2-26.9) (N = 427)	**36.5%** (33.5-39.5) (N = 375)	**49.8%** (46.5-53.1) (N = 256)
Refusal	**24%** (19.9-28.1) (N = 117)	**29%** (24.4-33.5) (N = 105)	**34.8%** (30.2-38.7) (N = 149)	**44.6%** (39.3-49.4) (N = 95)	**57.1%** (51.4-62.8) (N = 62)
Parent-Owner	**21%** (14.8-27.3) (N = 88)	**30.1%** (22.8-37.4) (N = 67)	**38.2%** (32.8-42.1) (N = 102)	**48.1%** (42.8-53.4) (N = 80)	**58%** (52.1-63.9) (N = 46)

Table 4: Percentage of BLL Decline, and Confidence Intervals, for all Children in the Case and Control Groups at Various Periods After Cases Were Opened by the DoH.

	0-60 days	61-120 days	121-365 days	366-730 days	> 730 days
HA v. REF	**<.001**	**<.001**	**.001**	**.009**	**.031**
HA v. PO	**.001**	**<.001**	**<.001**	**<.001**	**.018**
REF v. PO	**.420**	**.789**	**.359**	**.359**	**.815**

Table 5: T-tests ($p < .05$) Comparing the Percentage of BLL decline Amongst the Case and Control Groups at Various Periods after the DoH Opened Cases.

Results on the mean percentages of BLL decline in the groups parallel the results in the above text. Here, the case group shows the lowest mean percent decline amongst the groups in the five periods, while the control groups show similar percent declines. These results, including their confidence intervals are shown in numerical and graphical form in Table 4.

The t-tests examining the percentages of BLL decline amongst the groups show significant differences in four out of the five periods. Specifically, significant differences, at the .05 alpha-level, occur between the case and control groups in the first four periods (Table 5), but not during the period that tests were sampled > 730 days. These comparisons, including their critical values, are shown in numerical form in Table 5. The significant differences are highlighted.

Approach 1 – Discussion

As expected from literature reports on the body burdens of lead, the BLLs in all groups remain above the CDC level of concern for at least two years after cases were opened –

indicating that lead remains in children's bodies for extended periods of time regardless of being in the cases or the controls.

Also expected, the results show that the mean BLLs amongst the cases and control are statistically different. However, the mean BLLs of at least one of the two controls are lower than the case's mean BLLs in four out of the five periods, including the first period of 0-60 days, where BLLs were anticipated to be similar.[123] In this period, one of the controls (the REF group) shows BLLs that are statistically lower than the cases at the .05 alpha-level. Important to note is that children's BLLs in the furthest time category, >730 days, tend to not have as many differences between groups as those BLLs in the earlier categories. One explanation for these results may lie in this bias in who is tested, while other explanations may have to do with children 'aging out,' or the effects of the interventions becoming more apparent.

The results of approach 1 also show that children exhibit similar BLLs when the parent of a poisoned child is the homeowner, when DoH services are refused, or when individuals within the home accept DoH services and have lead hazards remediated. These results, in addition to the results showing that poisoned children's BLLs fall at the same rate at which lead naturally decays in children, indicate that the remediation of lead hazards does not benefit poisoned children.

[123] BLLs were anticipated to be similar to since children are required to have minimal BLLs of 20 µg/dL to be offered a DoH inspection.

One possibility for these unexpected findings is that they are confounded by child mobility. For example, children who are assumed to be in the case group might move to non-remediated homes, where the risk for re-poisoning might be higher – resulting in BLLs for the case group that mirror the BLLs of children in the controls. I tested this possibility in approach 2 – which explores the effects of mobility on children's BLLs. If mobility is not found to increase BLLs in approach 2, then approach 1's results accurately represent the of lead hazard remediation on children's BLLs. On the other hand, if the results indicate that mobility does influence BLLs, then approach 1's results may misrepresent the affect of Rhode Island's lead hazard remediation program.[124]

Approach 2

Approach 2 – Goal

In approach 2, I analyzed whether the BLLs of children who move from remediated addresses to addresses that lack a record of remediation[125] differs from the BLLs of children who remain in remediated addresses. This issue is worth exploring since high rates of mobility have been proven to correlate with higher BLLs.[126] This approach will

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[124] In addition to impacting the mean BLLs of the case (HA) group, mobility may also confound the mean BLLs of the control groups (REF and PO).

[125] The term 'non-remediated' shall be synonymous with 'no record of remediation.' However, the absence of a record of remediation does not imply that remediation measures have not occurred. This limitation is present throughout the research's entirety, and shall be further in the *Uncertainties and Limitations* section of the thesis.

[126] Brown MJ, Gardner J, Sargent JD, Hu H, and Timperi R. *The Effectiveness of Housing Policies in Reducing Children's Lead Exposure.* American Journal of Public Health. 2001. 91(4): 621-24.

also determine whether the movement of children from remediated addresses to non-remediated addresses potentially confounds the results of approach 1.

Since the St. Louis and Taha et. al. studies indicate that groups residing in homes that underwent remediation present BLLs that are statistically lower when compared against controls, I expect that children who move from remediated addresses to addresses with no record of remediation will have BLLs that are significantly higher than those who remain in remediated homes – therefore indicating that mobility influences BLLs and confounds the results of approach 1.

Approach 2 – Methodology

The methodology of approach 2 was three-fold. The first part distinguished between children who moved from, and those who remained in, remediated homes. The second step determined the BLLs of those children, while the third step tested whether starting BLLs were statistically different amongst the groups to ensure that differences in BLLs were not due to factors such as varying socio-economic status.

Unlike the methodology of approach 1, the initial query in approach 2 extracted all children from the 'new case' table – created in approach 1 – that had ever lived at an address where lead hazards were remediated (HA) – again, identified by a "03" in the 'Last Address Status' field. This query, containing the 'Child ID,' 'Case Open Date,' 'Case Closed Date,' and 'Soundex ID'[127] fields, was linked to the SWBLL database, where all blood lead tests, sampled after the last inspection date of an HA property, were extracted. The next step required that the 'Soundex ID' and 'Child ID' fields be grouped[128] to produce unique combinations of 'Soundex' and 'Child' IDs. Once grouped, 'Child IDs' discovered to be listed more than once were identified as children who moved from remediated homes after the remediation process was completed, while 'Child IDs' that were listed only once were identified as children who remained at remediated after the remediation process was completed.

The two groups of children (those who moved, and those who remained) were then placed into separate tables and linked back to the original query containing BLLs – via 'Child ID' – so that the BLLs of the children sampled during the five periods could be extracted. Using the same steps performed in approach 1 to produce a single mean BLL per group, per time period, these levels were averaged. The results were then compared using an Independent t-test ($p < .05$).

In case the comparison revealed significant differences in the mean BLLs of the groups during the first period, an additional analysis (BLLs –60 to 0 days) was conducted to

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[127] A Soundex ID is a generated code that corresponds to the address of a home. It contains information specific to the addresses' city/town code, the street number of the home, the first three letters of the street name, and in rare cases, a unit number. For example, '28135ANG' translates to 135 Angell Street in the City of Providence. Since unit numbers were inconsistent in the data, the unit numbers have not been included in these analyses. In cases where they were present, they were extracted from the ID.

[128] Grouping a field in Microsoft Access produces a unique record if several records in a field are identical. For example, grouping 'Soundex' and 'Child IDs' will yield results that produce unique combinations of the 'Soundex ID' and 'Child ID'. In this case, we'd expect that a 'Child ID' having two or more different 'Soundex IDs' indicates that a child has moved at least two times after remediation.

determine whether the groups had statistically different BLLs before the close date so comparisons could be made amongst the groups.[129]

Approach 2 – Results

Similar to the results of approach 1, the mean BLLs of children in both groups decline as time progresses.[130] The mean BLLs of children who remain in remediated homes are lower than the mean BLLs of children who move from remediated homes in all five periods. These results, including the confidence intervals of the mean BLLs, as well as the number of children tested in the two groups during the five periods, are shown in tabular and graphical form in Table 6.

	-60-0 days	0-60 days	61-120 days	121-365 days	366-730 days	> 730 days
Stayed	**28** (26.8-29.4) (N=255)	**21** (19.5-22.5) (N = 177)	**18.7** (17.4-20) (N = 124)	**17.7** (16.5-18.9) (N = 221)	**14** (13.1-14.9) (N = 168)	**11.4** (10.4-12.4) (N = 103)
Moved	**30** (29.3-32.3) (N=271)	**23.3** (22.1-24.5) (N = 209)	**22.1** (20.8-23.4) (N = 190)	**19.4** (18.4-20.4) (N = 288)	**16.7** (15.7-17.7) (N = 262)	**13** (12-14) (N = 206)

Table 6: Mean BLLs and Confidence Intervals of Children who Remained in and Moved From Remediated Homes at Various Periods After Cases Were Closed by the DoH.

[129] If BLLs of the children in these groups were statistically different at this point, then it could explain why BLLs are different between groups at all periods beyond this date. To obtain this estimate, BLLs of children samp led at dates surrounding the date cases were closed (≥ 60 days and ≤ 60 days) were extracted and compared.

[130] The mean BLLs in approach 2 are lower than mean BLLs in approach 1 because they were derived after cases were closed by the DoH. While, in approach 1, BLLs were obtained after cases were opened by the DoH.

The t-tests of approach 2 show that the mean BLLs of children who remain in remediated homes are statistically different than the mean BLLs of children who move from remediated homes in all five periods. These results are shown in Table 7.

More importantly, the results show that mean BLLs amongst the groups are statistically different before case closed and moved dates (-60 to 0 days)[131] – indicating that differences in BLLs after cases were closed are not due to mobility. These comparisons are also shown in Table 7 with the significant results highlighted.

	-60-0 days	0-60 days	61-120 days	121-365 days	366-730 days	> 730 days
Stayed v. Moved	**.009**	**.009**	**< .001**	**.03**	**< .001**	**.02**

Table 7: T-tests (p < .05) Comparing Mean BLLs of Children who Remained in and Moved From Remediated Homes at Various Periods Before and After Cases Were Closed by the DoH.

Approach 2 – Discussion

The results of approach 2 do not support my expectation that mean BLLs of children who move from remediated homes will be significantly higher than those who remain in remediated homes. Instead, the results show significantly different BLLs amongst the groups before they moved or stayed in remediated homes. This finding suggests that

[131] Equally important is that the movement of children occurred after the closing of cases.

differences in BLLs are not due to remediation, but instead suggests that there are inherent differences between these groups. This finding also indicates that mobility does not confound the results of approach 1, and therefore the results presented in approach 1 accurately portray the effectiveness of Rhode Island's lead hazard remediation program. Together, these findings are consistent with the results of approach 1, which indicate that lead hazard remediation does not benefit poisoned children.

Approach 3

Approach 3 – Goal

Approach 3 further assess the efficacy of the DoH's lead hazard remediation program by analyzing the BLLs of all children residing at the addresses of the case and control groups both three years before and three years after cases were opened by the DoH.[132] More specifically, this approach tests whether significant differences exist amongst BLLs of children residing in the addresses of the cases and controls. If significant differences exist, this approach also determines the direction of the difference.

Based on studies in the literature, I expect, if remediation benefits children's BLLs, that the BLLs of children residing at the 'case addresses' to be significantly lower than the BLLs of children residing at the 'control addresses.'

[132] Performing an address-based analysis includes the BLLs of both poisoned and non-poisoned children into my analysis.

Approach 3 – Methodology

Approach 3 compared the BLLs of children residing in the addresses of the cases and controls three years before and three years after cases were opened by the DoH. The first step in this approach involved extracting HA, REF, and PO addresses from the 'Pb Inspect' database. Next, only the addresses that were opened by the DoH between 1996 and 1999 were obtained.[133] These addresses were then linked to the 'SWBLL' database – via 'Soundex ID' – to obtain the BLLs of children residing at these addresses three years before and after cases were opened. Records were then divided into separate tables, based upon the dates at which samples were drawn. One table contained the BLLs of children residing in the 'case and control addresses' before they were closed (1993 to 1996), while the other contained all blood lead tests sampled after cases were opened at these addresses (1999 to 2002).

Approach 3 – Results

The mean BLLs of the cases and controls, as expected, are significantly lower than those observed in approach 1 since this method incorporates the BLLs of poisoned and non-poisoned children into the same group. Approach 3's results also show that mean BLLs of children residing in the addresses of the cases and controls are lower during the three-

[133] Extracting addresses that were closed due to the remediation of lead hazards, the refusal of inspections, or parent-owner status from 1996-1999 allows me to gauge the BLLs of children at the addresses in these groups both three years before, and three years after the opening of DoH cases (data spans 1993-2002). If I were to look at cases opened from 1996-2000, I do not have three years worth of data after cases were opened closed to compare against three years worth of data before cases were opened.

year period after which cases were opened than they are in the three-year period before (Table 8). The t-tests comparing these levels also show significant declines (Table 8).

The results show the PO group with the highest mean BLL in the three-year period before cases were opened, and the REF group with the lowest mean BLL in the three-year period after cases were opened. Despite the REF group showing the lowest mean BLL after cases were opened, the PO group exhibits the largest difference in BLLs before and after cases were opened (Table 8).

	Three Years Before Open Dates (mg/dL)	Three Years After Open Dates (mg/dL)	Diff. In Mean BLLs (mg/dL)	Critical Value (P = .05)
Hazards Abated	**16.8** (15.9-17.7) (N = 301)	**14.4** (13.5-15.2) (N = 290)	**2.4**	**<.001**
Refusal	**16.7** (15.6-18.1) (N = 157)	**12.8** (11.5-14.1) (N = 137)	**3.9**	**<.001**
Parent-Owner	**18.1** (16.2-20.1) (N = 74)	**13.2** (11.9-15.2) (N = 77)	**4.9**	**<.001**

Table 8: Mean BLLs and Confidence Intervals of Children residing at the Addresses of the Cases and Controls Three Years Before and After They Were Opened, and the results of a t-test comparing the mean BLLs of the groups before and after they were opened ($p < .05$).

	BLLs Three Years Before Cases were Opened	BLLs Three Years After Cases were Opened
HA v. REF	**.958**	**.041**
HA v. PO	**.217**	**.168**
REF v. PO	**.267**	**.609**

Table 9: T-tests comparing the Mean BLLs of the Children residing at the Addresses of the Cases and Controls Three Years Before and After They Were Opened (p < .05).

The results of the t-tests show no significant differences amongst the mean BLLs of children residing at the addresses of the case and control groups in the three-year period before cases were opened by the DoH (Table 9). However, the mean BLLs amongst children residing at the addresses of the HA and REF groups during the three-year period after which cases were opened show a significant difference.

Approach 3 – Discussion

Unexpectedly, the results do not show a significant difference amongst the BLLs of children residing in the 'case and control addresses' three years before and after they were opened by the DoH. This finding indicates that the remediation of lead hazards does not benefit children.

Assuming that remediation benefits children, I would expect the HA group to show a greater decline in mean BLLs than the REF group. Instead, my findings show the opposite. The REF addresses, who I assume have not undergone remediation, show a greater decline in BLLs the HA group. This result, in addition to the result that shows remediation does not benefit poisoned children, indicates that Rhode Island's lead hazard remediation program is broken.

Approach 4

Approach 4 – Goal

Unlike the previous approaches, approach 4 analyzes DoH data for evidence that might be a sign of 'housing discrimination,' or, the practice of property-owners to exclude families with children under six from rental housing. More specifically, this approach examines the validity of anecdotal evidence that property-owners, fearing the costly requirements of remediation, or even worse, prosecution for failing to comply with DoH lead-safe standards, intentionally deny rental housing to families with young children. If property-owners do deny rental housing to families with young children, then I can expect fewer children to reside in HA and REF addresses after the remediation of hazards and the refusal of inspections, than the number of children found to reside in these same addresses before remediation and refusal.

Approach 4 – Methodology

Approach 4 was accomplished by comparing the number of children (tested) residing in homes before remediation and refusal to the number of children residing in the same homes after remediation and refusal. The first step in determining these differences involved extracting cohorts of HA and REF addresses that were opened[134] by the DoH between 1996 and 1999.[135] The cohorts were then linked to the SWBLL database – via 'Soundex ID' – to obtain the dates that blood lead tests were sampled for the above children. Records were then divided into separate tables, based upon the date at which samples were drawn. One table contained all tests before the open date of cases, while another contained all tests made after the open dates of cases. The 'Soundex' and 'Child' IDs were then grouped together to produce records that depicted unique combinations of address ('Soundex ID') and children ('Child ID'), and the number of children per "Soundex' in each table was determined. These tables were then linked – via 'Soundex ID' – and the difference in the number of count of children per 'Soundex ID' was determined and statistically compared with an Independent t-test ($p < .05$).

Approach 4 – Results

Approach 4 reveals a mesokurtic distribution with a slightly negative skew for HA addresses (Figure 4). This means that the majority of differences in children residing in addresses before and after remediation are distributed closely around the median (0) but more negative, than positive, differences exist. Specifically, 87 addresses present an increase of at least one child residing in HA addresses after remediation, while 108 addresses reveal a decrease in the number of children residing in them post-remediation.

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[134] Choosing to look at the opening date of cases, rather than the close date of cases, assumes that property-owners will switch behaviors once they are required to meet lead-safe standards.

[135] Extracting addresses that were opened due to the acceptaince of DoH inspection, or refusal of DoH services from 1996-1999 allows one to gauge the number of children at these addresses both three years before, and three years after the opening of DoH cases (data spans 1993-2002).

The remaining 87 addresses show the same number of children residing in them before and after remediation. Most importantly, however, is the result that reports that only 28 out of 310 addresses (9%) report a presence of children (as detected by blood lead tests) in these addresses before remediation, but none afterwards – a probable sign of 'housing discrimination.'

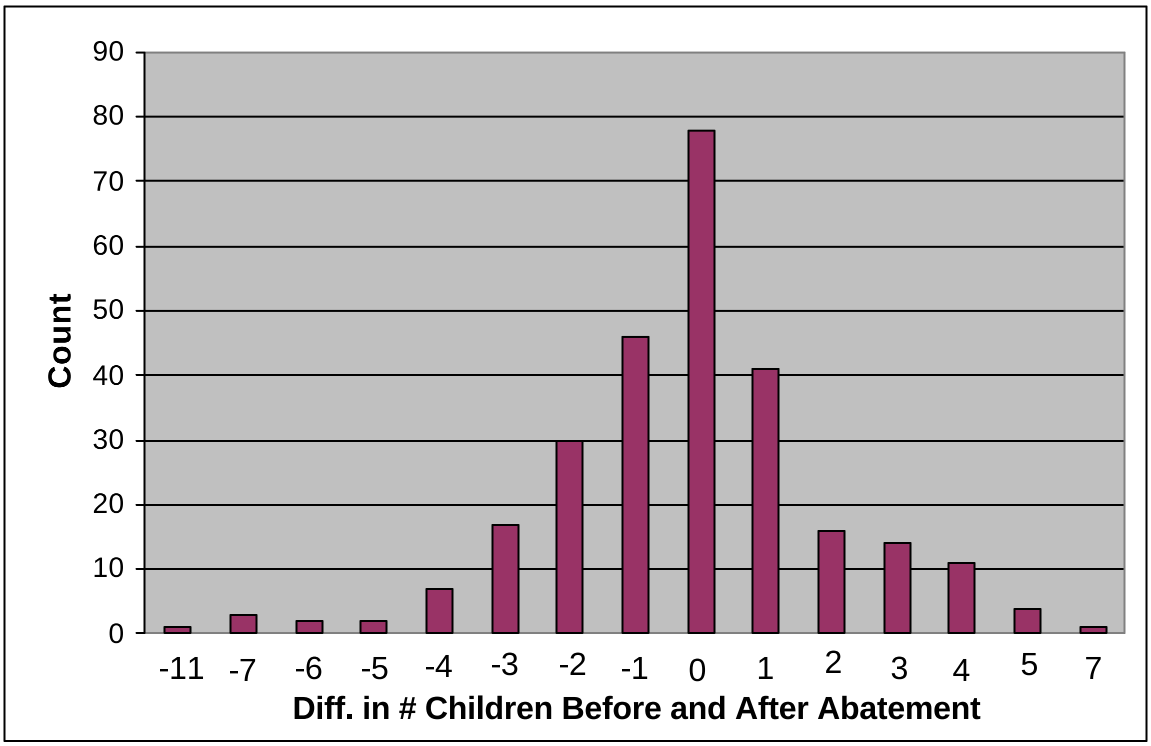

Figure 4: Distribution of Differences in the Number of Children Residing in Addresses Before and After Remediation.

Approach 4 also reveals a mesokurtic distribution with a negative skew for addresses that refused DoH services (Figure 5), again indicating that the majority of differences in children residing in homes before and after refusal are distributed closely around the median of -1. Specifically, 21 addresses show an increase of at least one child residing in addresses after the refusal of services, while another 70 addresses show a decrease in the number of children residing in them post-refusal. The remaining 36 addresses show no difference in the number of children residing in them before and after the refusal of services. Additionally, 36 out of 163 addresses (22%) report the presence of children (as detected by blood lead tests) at these addresses before refusal, but none afterwards – again, a probable sign of 'housing discrimination.'

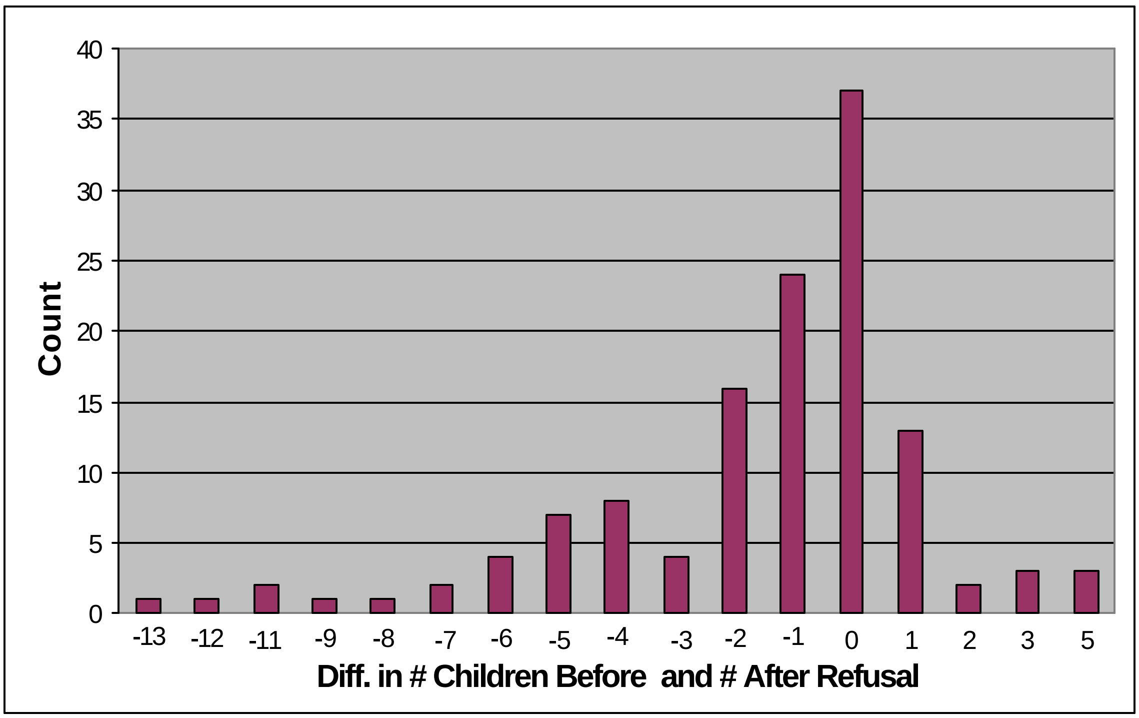

Figure 5: Distribution of Differences in the Number of Children residing in Homes Before and After the Refusal of DoH Inspections.

Approach 4 – Discussion

The results show that the number of children residing in addresses prior to the remediation of lead hazards and the refusal of DoH services is similar to the number of children residing in the same addresses after remediation and refusal. This finding indicates that the majority of property-owners do not exclude young children from rental homes to escape future liability from lead hazards.

These results, however, do not establish that property-owners do not deny rental housing to families with children under six. Instead, property owners of addresses in the tails of the distribution, showing deficits of -13, -11, and –10 children, as well as the 9% of remediated addresses and the 22% of refusal addresses that report children in them before remediation and refusal, but not afterwards, might intentionally exclude housing to young children. Although it is entirely possibly that these homes can no longer provide for the occupancy of children, it is important that these addresses be investigated to assure that 'housing discrimination' is not occurring.

Equally important is the result showing the REF group with over twice the percentage of addresses with children residing at them before intervention, but none afterwards, than the HA group. Although speculative, it is possible that property-owners in the REF group will be more exclusive than the owners in the HA group since they pressure tenants to refuse inspection and therefore assume that hazards remain in their properties. The HA property-owners, on the other hand, will be less likely to deny housing to families with young children, since they do not pressure tenants to refuse and therefore assume that the risk for lead exposure is low having met DoH lead-safe standards.

Uncertainties and Limitations

As with all scientific inquiry, it is important to note the sources of uncertainty involved in one's research. Therefore, the ensuing text will discuss the limitations of my study, as well as the uncertainties that may have entered the analyses of the four approaches.

BLLs as an Indicator of Lead Safety

Since confounders such as age and season easily skew BLLs, the BLLs of children may not be the gold standard to analyze the efficacy of Rhode Island's lead hazard remediation system.[136] Seasonal variations that can raise or lower BLLs make it difficult to distinguish if re-poisonings are due to the presence of lead-based paint hazards, or rather, natural variation.[137] BLLs can also be skewed by the 'regression to the mean' phenomenon – where children with extremely high or low BLLs have follow-up tests that indicate results that are less extreme than their initial measurements.[138] Perhaps a better measurement of lead hazard remediation would be its effects on cognition. However, Despite its flaws, BLLs remain one of the few indicators, aside from continual invasive comprehensive environmental lead inspections, that can provide a realistic window into the safety of homes. Moreover, these potential confounders are present in each of the groups, and therefore would be expected to compensate for each other.

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[136] MacRoy, P. *In Search of Safe Housing: Blood Lead Levels of Past Occupants as an Indicator of Present Lead Safety*. Master's Thesis. Brown University Center for Environmental Studies. 2001.

[137] Season may influence BLLs because children are more likely to play indoors during colder months, thereby increasing their risk for exposure. Alternatively, the opening of windows in warmer months may also increase the risk of lead exposure.

[138] Niemuth N, Wood BJ, and Schultz BD. *Estimated Change in Blood Lead Concentration in Control Populations.* Archives of Environmental Health. 2000. Nov/Dec. 56(6): 542-52.

Data Error

Obviously, these results can only be as accurate as the data provided to me by the DoH's CLPPP. Certainly some data errors occurred during the data input processes performed by the DoH's inspectors or by individuals at the DoH laboratories. My research, for example, has revealed address misspellings; the absence of unit numbers for dwellings located in a multi-unit structure; and the lack of inspected and closed dates.

Fortunately, a larger number of errors than those found were limited in part to the 'cleaning' efforts of past researchers who have also analyzed the CLPPP's lead poisoning records. As a result, it is unlikely that these errors will significantly impact the outcome of this study.

Uncertainty in Matching Blood Lead Tests to Dwelling Units

An additional source of uncertainty inherent in the analyses of the approaches involves the difficulty in matching the results of children's blood lead tests to their dwelling units. Current DoH policy only enforces the units where poisoned children reside. The remaining units located at an address may contain lead-based paint hazards.[139] Difficulties arise because the SWBLL database does not include the apartment, unit, or floor number, where a tested child resides, or where a DoH inspection occurred, with any regularity – making the street address the only available identifier.[140] This method of

[139] State law requires that all dwelling units meet lead-safe standards, however only unit where a poisoned children resides, as well as the common areas and exterior of buildings, are enforced. Personal Correspondence. Patrick MacRoy. 05/04/03.

[140] MacRoy, P. *In Search of Safe Housing: Blood Lead Levels of Past Occupants as an Indicator of Present Lead Safety*. Master's Thesis. Brown University Center for Environmental Studies. 2001..

recording, or lack thereof, becomes problematic when multiple units are present in a single structure and units have different risks associated with them.[141] For example, if one unit in a multi-unit structure containing several unsafe units achieves lead-safe requirements, it will appear as if the entire multi-unit structure has met DoH lead-safe requirements.[142] This uncertainty can cause the mean BLLs of groups to be higher and lower than they should be had the databases accurately recorded blood lead tests by the unit-level. Unfortunately, little can be done to correct this uncertainty until recording procedures are changed.

Uncertainty Amongst the Case Group and Control Groups

Although the case group is the only group of that is known to have had lead-based paint hazards remediated, the assumption that the controls do not remediate lead hazards may be erroneous. PO cases, for example, are given the results of the inspection but the hazards are not enforced, however, the parents will often do some of the work that is needed to address the hazards.[143] Other forms of 'unrecorded' intervention, such as physician intervention and educational outreach, may also help to lower the BLLs of the controls. On the other hand, the remediation of lead hazards does not establish that

[141] *Ibid.*

[142] Alternatively, a tenant refusing DoH inspections in a structure composed of multiple units will present results that indicate that the entire address has refused DoH inspections.

[143] Some PO cases are given the PO ("10") status, but upon meeting lead-safe requirements, their 'last address status' in the Pb Inspect database is changed to a "03," – where they'd then be grouped into the HA cohort.

hazards are non-existent in the case group,[144] or as previously discussed, non-existent in the remainder of a structure.[145] Another limitation is the possibility that fundamental differences exist amongst those who refuse and accept inspections. For example, those that refuse inspections may actually be in a better position to address the problem themselves and make some substantial improvements, while those who accept services may do so because they are not capable of addressing lead hazards in their homes. In an effort to limit this uncertainty, some basic comparisons amongst the demographics of the different groups were conducted. The results are shown in Table 10 and show minimal differences amongst the groups in regards to ages and location of poisonings.

Group Statistics	**HA**	**REF**	**PO**
Mean Age at Open Date (years)	**2.45**	**2.6**	**2.18**
% Children with Elevated BLLs in RI's Cities	**62% Providence 7% Central Falls 10% Pawtucket 5% Woonsocket 16% Other**	**68% Providence 5% Central Falls 8% Pawtucket 6% Woonsocket 13% Other**	**51% Providence 2% Central Falls 8% Pawtucket 5% Woonsocket 34% Other**

Table 10: Comparison of Mean Age of Children in Case and Control Groups and the Percentage of Elevated BLLs in the State's Core Cities.

[144] Remediation efforts may have consisted solely of keeping paint intact, and in the days following the remediation of hazards, damage may have occurred to the surface, increasing the risk for lead exposure.

[145] See previous section in the Uncertainties and Limitations portion of the thesis entitled, *Uncertainty in Matching Blood Lead Tests to Dwelling Units.*

Behavioral Uncertainties

As discussed, another form of uncertainty may be the result of behavioral changes that might occur in tenants once they are offered inspections by the DoH. For example, merely offering inspections may be a catalyst which causes tenants in the REF and PO groups to engage in lead hazard reduction measures that help to decrease the risk of lead exposure and subsequently, lower the BLLs of poisoned children. Alternatively, those in the HA group who believe that children in their homes are at a lower risk for lead exposure, may engage in behaviors that continue to place children at risk. These parents may be less likely to keep us basic risk reduction measures.

One method to address these uncertainties is to create another group of poisoned children that are denied all intervention services and not offered inspections. Practical and ethical reasons, however, prevent the denial of interventions that may reduce children's exposure to lead, and more importantly, their BLLs.

Uncertainty in Approach 3

Limitations are also evident in analyzing the average BLLs of all the residents of the group's addresses before and after cases were opened. In approach 3, for example, I neglected to determine if the BLLs were from the same child or multiple children before and after cases were closed. Additionally, there also may be problem in measuring BLLs that might have come from other places. Although it most likely does not happen as much as it should, one can make an argument that some poisoned children are going to be seeking out lead-safe houses. Therefore, the lack of decline amongst the HA addresses may be a factor of the house being lead-safe and having children poisoned elsewhere seeking it out. To show the benefit or not of remediation on future children, I would need to identify populations of children moving into the HA and REF houses who either had no record of a BLL in the past, or whose past BLLs were all <10, and then see the relative change in BLL amongst these children.[146]

Uncertainty in locating Evidence of Housing Discrimination

Although the distribution of differences in the figures in approach 4 exhibit slightly negative skews by showing large negative tails, this observation may also be due to uncertainty that has entered the analysis. For example, tenants who reside in remediated homes and believe that their children are at a lower risk for lead exposure may neglect to have their child screened for lead as frequently, consequently resulting in a negative difference of tests – thereby creating the illusion that families with children under six are excluded rental housing. It is also possible that the children in these homes have aged enough so that they are not required to be screened for lead, again creating the false appearance that families with children under six are excluded housing at this property. Lastly, in addition to the remediation of lead hazards, other investments may have been made at these properties, resulting in the 'marketing out' of families with young children.

[146] Patrick MacRoy. Personal Correspondence. 05/03/03.

Conclusions

The results show that cases and controls, with mean BLLs 20 µg/dL, take over two years for BLLs to drop below 10 µg/dL. These findings parallel the results of studies examining the natural rate at which lead decays in children who are removed from sources of lead exposure. However, since recent studies suggest that BLLs remain toxic at levels much lower than the CDC's level of concern and the Rhode Island action level,[147,148] more extensive BLL reduction measures are needed to help children who have already been poisoned.[149]

Secondly, with relatively few exceptions, the analyses indicate that the mean BLLs of the cases do not statistically differ from the mean BLLs of the controls for all periods after which the DoH opened cases. In the follow-up periods where significant differences do exist, the directions of the differences are unexpected, with the controls exhibiting BLLs that are lower when compared to the cases. Although it is possible that BLL reductions are confounded by a number of factors, there is no definitive explanation as to why cases exhibit similar (and often higher) BLLs than the controls. One possibility for these findings is that children in the case group are exposed to lead for longer periods, reside in riskier-neighborhoods, have worse nutrition, or come from poorer families than those in

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[147] Schwartz, J. *Low-level Lead Exposure and Children's IQ: A Meta-Analysis and Search for a Threshold*. Environmental Research. 1994. 65: 42-55.

[148] Canfield RL, Henderson CR, Cory-Slechta DA, Cox C, Jusko TA, Lanphear BP. Intellectual Impairment in Children with Blood Lead Concentrations Below 10 µg/dL The New England Journal of Medicine. 348(16): 1517-1526.

[149] These measures will be discussed in the ensuing *Recommendations* section.

the controls – consequently creating BLLs that mirror the BLLs of children in the control groups.

Another conceivable theory is that remediation occurs in both the cases and controls. Parents in the controls, for example, knowing that their children are lead poisoned and the homes in which they reside are hazardous, may opt to receive case management services or physician intervention to ensure the health and safety of their children. Alternatively, the acceptance or refusal of DoH services, as previously discussed, may alter the behavior of parents, which can either protect or jeopardize the health of their children. Parents in the control group, for example, not having lead hazards enforced within their homes, may comply with proper housekeeping and nutritional recommendations to help lower their children's risks for lead exposure. On the other hand, parents who accept DoH inspections and reside in homes that have met DoH lead-safe standards, believing that their children have low risks for lead exposure, may engage in behaviors that can increase BLLs or slow the rates at which they decline. Although conceivable, these theories are purely speculative and do not provide any real explanation for my findings. Moreover, they are unlikely to explain the entirety of my results.

Therefore, despite the above confounders, the lack of significant differences amongst the cases and controls in approaches 1 and 3 indicates that Rhode Island's lead hazard remediation program does not benefit poisoned and non-poisoned children. If current lead hazard remediation efforts were to benefit children's health, then I would expect to see – assuming that controls do not remediate lead hazards – children in the case group with BLLs that are significantly lower than those of in the control groups. Instead, the results show otherwise.

Although these results conflict with studies that show health benefits from lead hazard remediation, it is important to recognize that many of these studies show benefits in subjects with severely high or low BLLs. Alternatively, the small sample sizes within these studies do not provide a realistic window into the relationship between lead hazard remediation and BLLs. While in comparison, the wealth of data on lead poisoning in Rhode Island, as previously discussed, produces results with greater statistical power, which more accurately depict the effects of lead hazard remediation. On the other side, those studies were more controlled in terms of assuring that populations between the various groups were similar.

Other significant findings in this research do not support the anecdotal evidence that mobility adversely affects children's BLLs. Although children who move from remediated homes present higher BLLs than the children who remain in remediated homes, the BLLs differed amongst the groups prior to the case closed dates – indicating that the differences are not likely due to mobility.

Results of this study further indicate that the remediation of lead hazards at some addresses and the refusal of services at others does not readily encourage property-owners to engage in practices that intentionally deny rental housing to families with young children. Instead, the results show that 9% of HA addresses and 22.1% of REF addresses potentially have property-owners that engage in 'housing discrimination.' These addresses were identified by the presence of children before intervention (as detected by blood lead tests at these addresses), but not afterwards.

The remainder of this thesis will provide recommendations that can help take advantage of the results shown in my study.

Recommendations

Based on my finding that Rhode Island's current lead hazard remediation efforts do not reduce the BLLs of poisoned children, I recommend that the State shift its emphasis away from the treatment of children with significantly elevated BLLs to a strategy that can effectively combat Rhode Island's lead burden.[150] Since we know that most cognitive damage in children occurs at concentrations well below the current Rhode Island action level (20 μg/dL), and that once a child has reached this level reducing BLLs does not reduce cognitive damage, the logical strategy is to prevent childhood lead poisonings from occurring in the first place via primary prevention. More rigorous lead hazard remediation standards – perhaps in some cases including the complete removal of lead – may be necessary to address the disproportionate burden that Rhode Island's children face.

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[150] Canfield RL, Henderson CR, Cory-Slechta DA, Cox C, Jusko TA, Lanphear BP. Intellectual Impairment in Children with Blood Lead Concentrations Below 10 μg/dL The New England Journal of Medicine. 348(16): 1517-1526.

A recent study by Canfield et. al., exploring the cognitive effects of lead in children with BLLs less than 10 μg/dL, reports that children's intellectual functioning at 3-5 years of age is inversely associated with BLLs, even when their peak BLLs are below the CDC's level of concern.[151] This study suggests that considerably more children in Rhode Island are adversely affected by lead than previously projected.[152] This study, in addition to research that suggests chelation therapy does not improve children's scores on cognitive, behavioral, and neuropsychological tests[153] supports the recommended shift to primary prevention.

Patrick MacRoy, former DoH epidemiologist, identified the wisdom of a primary prevention strategy in his thesis when he wrote, " . . . several scholars have hypothesized that the prevented increase in BLLs in future occupants . . . would be much greater than the decrease shown by those already poisoned" and therefore "it would clearly be more efficient (than remediation) to practice primary prevention and remediate residences before they result in poisoning."[154]

Additionally, whether implicit or explicit, I recommend that the message that remediation benefits poisoned children be corrected. It is essential that State agencies and lead advocacy groups, like the DoH and Childhood Lead Action Project (CLAP), as well as

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151 *Ibid.*

152 *Ibid.*

153 Rogan WJ, Dietrich KN, Ware JH, et. al. *The Effect of Chelation Therapy with Succimer on Neuropsychological Development in Children Exposed to Lead.* New England Journal of Medicine. 2001. 344 (19): 1421-26.

154 *Ibid.*

families of poisoned children, recognize that current lead hazard remediation efforts do little to benefit children's health. Continuing to accept this misguided assumption risks that individuals will not take the appropriate steps to prevent poisoning from occurring. Additionally, the recognition that current remediation is ineffective in reducing BLLs provides a powerful argument for the State to immediately begin cracking down on the homes with the highest risk for lead exposure. To prevent poisonings from occurring in the first place, it makes the most sense to take the homes with the highest risks for poisoning children out of the market.

Once again, based on my finding that Rhode Island's current lead hazard remediation efforts do not reduce the BLLs of poisoned children, I caution the Housing Resource Commission (HRC) and the DoH who have been granted the responsibility of implementing the portion of the 2002 Lead Hazard Mitigation Act that refers families to housing that is lead-safe, lead hazard mitigated, or abated.[155] Instead, I recommend that these bodies direct families with young children to lead-free and low-risk homes (or, the homes where children have been tested for lead, but none have tested positive for lead poisoning) identified in a thesis by Patrick MacRoy.[156] However, before sending families with young children to these low-risk homes, further study should investigate these homes since the precise reason for their safety remains unknown (and for all we know, the children in these homes may be poisoned, but their levels are below 10 μg/dL).

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[155] The General Laws of Rhode Island. § 42-128.1-6. *Lead Hazard Mitigation Act; Education*.

[156] MacRoy, P. *In Search of Safe Housing: Blood Lead Levels of Past Occupants as an Indicator of Present Lead Safety*. Master's Thesis. Brown University Center for Environmental Studies. 2001.

I also recommend that the State investigate the homes and their respective property-owners that are suspected to be engaging in 'housing discrimination.' This investigation will likely reveal whether homes have been torn down, renovated, or are vacant and can therefore explain why children are no longer residing in these homes, or alternatively, it may also reveal that some property-owners are in fact denying rental housing to families with young children. In the event that this investigation supports my initial suspicions, property-owners who are proven to have engaged in these practices should be heavily prosecuted since federal law prohibits discrimination based on one's family status.

I also recommend for any future remediation that inspectors record the types of remediation that are used in these homes so studies can discriminate amongst the effects of different types of remediation. This recommendation may show that children residing in homes that have windows replaced have significantly lower BLLs than children who reside in homes that have painted over and encapsulated existing lead hazards.

Since this study solely analyzed the effects of remediation on children with initial BLLs in the 'center' of the BLL distribution curve (~20 μg/dL), I further recommend that the effects of remediation in children with severely high and low initial BLLs – children in the 'tails' of the BLL distribution curve – be studied to assess benefits from remediation. Although studies indicate that children with BLLs below 10 μg/dL exhibit cognitive deficits,[157] other studies, as previously discussed, indicate benefits from remediation in children with BLLs ≥30 μg/dL.[158]

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[157] Canfield RL, Henderson CR, Cory-Slechta DA, Cox C, Jusko TA, Lanphear BP. Intellectual Impairment in Children with Blood Lead Concentrations Below 10 μg/dL The New England Journal of Medicine. 348(16): 1517-1526.

[158] Staes C, Matte T, Copley CG, Flanders D, Binder S. *Retrospective Study of the Impact of Lead-Based Paint Hazard Remediation on Children's Blood Lead Levels in St. Louis, Missouri.* American Journal of Epidemiology. May 15, 1994. 139(10): 1016-1026.