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# Impact of Case Management on Childhood Lead Exposure in Marion County, Indiana

Maliki Yacouba
*Walden University*

# Walden University

College of Health Professions

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Maliki Yacouba

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Dr. David Anderson, Committee Chairperson, Public Health Faculty
Dr. Montrece Ransom, Committee Member, Public Health Faculty
Dr. Mehdi Agha, University Reviewer, Public Health Faculty

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Sue Subocz, Ph.D.

Walden University
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Abstract

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MS, Georgetown University, 2010

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Dissertation Submitted in Partial Fulfillment

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# Abstract

The Centers for Disease Control and Prevention recently declared that no amount of childhood blood lead level (BLL) is safe. The purpose of this quantitative study with a retrospective cohort design was to evaluate the effectiveness of case management intervention on children diagnosed with elevated BLL (EBLL; $\geq 5$ µg/dL) in Marion, County, Indiana. The health belief model was used as the theoretical foundation for the study. A data set of 160 lead exposure case management records was analyzed to find whether: (a) BLL at post-case-management time significantly differ from BLL at baseline (b) BLL at post-case-management time is affected by race, poverty, zip code and, severity of BLL at baseline. Results indicated that case management had a significant ($X^2 = 147.62$, $df = 4$, $p < 0.0001$) effect on children's BLL. The geometric mean BLL dropped from 7.4 µg/dL at baseline to 3.0 µg/dL at post-case-management time. The highest (6.6 µg/dL) and lowest (5.3 µg/dL) mean BLL occurred in Latino and Asian children, respectively. Mean BLL in White (6.1 µg/dL) and Black (5.8 µg/dL) children were not statistically different. High risk zip codes showed the highest mean BLL (6.2 µg/dL). Low risk zip codes showed the lowest mean BLL (5.4 µg/dL). Medicaid eligible children showed a significantly higher reduction (34.31%) in their BLLs than non-Medicaid-eligible (24.67%) children. The severity of lead exposure at baseline had a significant effect on the outcome of the case management ($f = 3.15$, $df = 3$, $p < 0.02$). The higher the severity at baseline, the longer the time to recovery from EBLL. Public health authorities may use these findings to target the most affected communities for effective lead exposure prevention.

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# Chapter 1: Introduction to the Study

Lead is a naturally occurring toxic metal, and widespread use has resulted in extensive environmental contamination and public health problems around the world. According to the World Health Organization (WHO, 2019), in 2016 lead exposure accounted for 63.2% of the global burden of idiopathic developmental intellectual disability, 10.3% of hypertensive heart disease, 5.6% of ischemic heart disease, and 6.2% of stroke. The WHO added that in 2017 lead exposure was associated with 1.06 million deaths and 24.4 million years of healthy life lost worldwide.

The highest burden of childhood lead exposure has been reported in low- and middle-income countries. For example, in South Africa, Barnes (2017) reported that over 1,400 deaths in children were associated with lead poisoning annually. In Nigeria, a 2010 outbreak of acute lead poisoning killed more than 400 children under the age of 5 years and left more than 2,000 children with permanent disabilities (Kaufman et al., 2016). It is estimated that about 90% of children diagnosed with blood lead reside in developing countries (Schultz, 2016). Childhood lead poisoning continues to be a public health problem in industrialized countries as well. For instance, Hauptman et al. (2017) reported that more than half a million children in the United States had elevated blood lead level (EBLL) or blood lead level (BLL) above the reference level of 5 micrograms per deciliter (µg/dL) in 2017.

Lead has no biological role in the body, and any detectable BLL is abnormal (Mayans, 2019). There is evidence that a BLL as low as 5 µg/dL in children cans cause many health and developmental problems including decreased intelligence, behavioral difficulties, and learning problems (Delgado et al., 2018; Mayans, 2019). There is also evidence that as BLL increases, the range of symptoms, severity, and effects on children's health also increases. Many researchers have reported that blood lead level as high as ≥ 70 µg/dL may cause severe neurologic problems including seizures, comas, and death (American Academy of Pediatrics Council on Environmental Health, 2016; Raymond & Brown, 2017).

In addition to those health problems, childhood lead poisoning has also been associated with significant societal financial and economic costs. The Centers for Disease Control and Prevention (CDC, 2019a) stated that a federal investment of $80 billion would be needed to prevent all U.S. children born in 2018 from having any detectable levels of lead in their blood. Major risk factors of childhood lead exposure include lead-based paint in older houses and lead in drinking water. Evidence suggested that about 70% of childhood lead exposure can be attributed to lead-based paint and the remaining 30% to lead-contaminated drinking water and imported goods such as candies, spices, pottery, and herbal remedies (Mayans, 2019). Childhood lead exposure has also been associated with socioeconomic, racial, and ethnic factors. According to the CDC (2019a), children living at or below the federal poverty level and children living in older housing are at greater risk of lead exposure, and that being non-Hispanic African American put a child at greatest risk of lead exposure.

The definition of EBLL for children is not consistent across the United States. A recent report indicated that 36 states and the District of Columbia use a blood lead content of ≥ 5 µg/dL as the cutoff for EBLL; four states use a blood lead content of ≥ 10 µg/dL as the cutoff, one state uses a blood lead content of ≥ 3µg/dL as the cutoff, and three states do not specify a cutoff limit. This inconsistency has been observed in certain cities within different states as well. For example, New York City, New York; Philadelphia, Pennsylvania; and Marion County, Indiana all use ≥ 5 µg/dL as the cutoff limit for EBLL while the states of New York, Pennsylvania, and Indiana use ≥ 10 µg/dL as the cutoff for EBLL (Michel et al., 2020; Robert et al., 2017).

In Chapter 1, I first provide background information about childhood lead exposure in the United States and Marion County, Indiana. I then state the problem and the purpose of this study followed by the research questions and hypotheses that were tested. These sections are followed by the theoretical framework and the nature of the study. I then provide definitions of important keywords and phrases frequently used in this study. The definitions section is followed by the assumptions, limitations, and significance sections of the study. I close this chapter with a summary of the main ideas discussed.

## Background

The need to eliminate lead in the environment and to prevent childhood lead poisoning in the United States has been recognized as a public health priority since the early 1970s. This has been evidenced by several federal-level policies including the Lead-Based Paint Prevention Act of 1971 and the ban of lead-based paint for residential use in 1978 and plumbing works in 1986. These policies have contributed to a significant decrease the median childhood BLL in the United States (American Academy of Pediatrics Council on Environmental Health, 2016). The percentage of children under 6 years old who were diagnosed with EBLL fell from 7.6% in 1997 to 0.6% in 2013 (Child Trends Data Bank, 2015; Raymond & Brown, 2016).

Despite this general decline in childhood lead poisoning indicators at the national level, childhood lead exposure continues to be a public health issue in many communities across the United States as evidenced by the 2015 Flint, Michigan water crisis. In Flint, lead-contaminated public drinking water supply source caused an additional 561 children with EBLL, with a conservative estimate of social costs of $65 million (Zahran et al., 2017). Across the United States, a recent report indicated that an annual average of 1,558 emergency department visits were associated with lead exposure and that about 55% of these emergency department visits involved young people below the age of 18 years (Hauptman et al., 2017).

Screening for blood lead has been widely accepted as the best approach to prevent adverse health and developmental effect of lead in children. Starting in 1978, the CDC recommended universal screening of all children between the ages of 9 months and 6 years (Ettinger, Leonard, & Mason, 2019). However, by 1997 the CDC recognized that the risk for lead exposure varied by geographic location, and therefore encouraged states to look at risk patterns and develop targeted screening strategies (Ettinger, Leonard, & Mason, 2019).

Presently there is a patchwork of childhood lead poisoning prevention and screening policies across the United States (Dickman, 2017). For example, the Marion County Public Health Department (MCPHD, n.d.) adopted universal screening for childhood lead poisoning prevention while the Indiana State Department of Health

(ISDH, 2016) recommended targeted screening. The CDC is currently funding childhood blood lead surveillance in many communities across the United States (Ettinger, Leonard, & Mason). However, operational activities on the ground are regulated by state and local statutes (Ettinger, Leonard, & Mason, 2019). In Marion County, Indiana, blood lead surveillance data reporting, monitoring, and preventive measures are regulated by Chapter 29 of the 2007 Indiana State Administrative Code (Indiana Administrative Code, 2007).

In terms of reporting, the statute requires that the results of a childhood blood test be reported to ISDH no later than 1 week after carrying out the test. Also, the rule requires that the name, address, and telephone number of the person who carried out the blood test as well as the physician, hospital, or clinic that submitted the blood specimen be reported to ISDH (Indiana Administrative Code, 2007; ISDH, 2016, 2018). In terms of case management and follow-up services for children with EBLL, the statute requires the local health department do the following: (a) notify the child’s primary medical provider within 10 working days of receipt of test results, (b) provide educational materials to the parents or family of the child regarding prevention of lead poisoning, and (c) take any additional actions that may assist the family in preventing the child’s BLL from increasing (Indiana Administrative Code, 2007; ISDH, 2016, 2018). In terms of childhood lead exposure prevention, the statute gives guidance on when a local health officer can inspect a private property to identify potential lead hazards in the property. Also, the statute provides guidance for the health officer to order reasonable and necessary actions to prevent or to remediate lead hazards in the property (Indiana Administrative Code, 2007; ISDH, 2016, 2018).

## Problem Statement

Risk factors of childhood lead exposure are relatively common in Marion County, Indiana. According to the U.S. Census Bureau (2019), about 29% of the population in Marion County is African American; 45% to 65% of the houses were built before 1980, and about 32% of children under the age of 5 years were below the federal poverty level. In addition, the 2018 Census Tract Map showed that seven of the 37 zip codes in the county were high-risk areas when considering childhood lead exposure (MCPHD, n.d.). In 2018, about 1.10% of children in Marion County, Indiana, had been diagnosed with EBLL (ISDH, 2018).

## Purpose of the Study

In Marion County, Indiana, EBLL occurs when a venous blood test produces a lead content of ≥ 5 µg/dL, or when two consecutive capillary blood tests within 2 weeks of each other show a blood lead content of ≥ 5 µg/dL (Indiana Administrative Code, 2007). Children diagnosed with EBLL have been provided with case management and follow-up services including (a) home inspections by a state-certified lead inspector following the U.S. Department of Housing and Urban Development (HUD) guidelines; (b) parents and guardians education such as awareness of potential lead hazards, symptoms and behaviors when a child is exposed to lead poisoning, and importance of good nutrition for the prevention and treatment of lead exposure; and (c) referring children to social programs such as Head Start and Women Infant & Children (WIC) programs for good nutrition and cognitive development (Delgado et al., 2018, Michel et al., 2020). However, no study had addressed the effectiveness of these services in bringing children's BLL below the reference level of 5 µg/dL in Marion County, Indiana. The purpose of this study was to fill that gap.

## Research Questions and Hypotheses

RQ1: Is there a difference between blood lead level at baseline and blood lead level at post-case-management time?

$H_o1$: The difference between blood lead level at baseline and blood lead level at post-case-management time is not statistically significant at alpha = 0.05 probability level.

$H_a1$: The difference between blood lead level at baseline and blood lead level at post-case-management time is statistically significant at alpha = 0.05 probability level.

RQ2: Is there a difference between blood lead level at baseline and blood lead level at post-case-management time that may be modifiable by race, education, income, and zip code levels?

$H_o2$: There is no modification of the difference between blood lead level at baseline and blood lead level at post-case-management time by race, education, income, and zip code levels.

$H_a2$: There is a modification of the difference between blood lead level at baseline and blood lead level at post-case-management time by race, education, income, and zip code levels.

RQ3: Can the difference between baseline and post-case-management be modified by the severity of the baseline blood lead level?

$H_o$3: There is no modification of the difference between blood lead level at baseline and blood lead level at post-case-management time by the severity of baseline blood lead level.

$H_a$3: There is a modification of the difference between blood lead level at baseline and blood lead level at post-case-management time by the severity of baseline blood lead level.

## Theoretical Framework

The theoretical base of this study was the health belief model (HBM; Glanz et al., 2008). The HBM posits that people are more likely to take health promotion or risk prevention action if they believe that they are susceptible to a disease (perceived susceptibility), if they believe that the disease may cause serious health consequences (perceived severity), if they believe that taking an action would reduce the susceptibility or severity or may lead to positive outcomes (perceived benefits), and if they perceive few negative attributes are associated with that action (perceived barriers; Jones et al., 2015; Salari & Filus, 2017). In addition to these original four constructs, researchers have added two other constructs including self-efficacy and cues to action. Self-efficacy is the belief that a person can complete the behavior of interest despite the perceived barriers while cues to action include factors in an individual's environment such as experiencing the symptoms of the disease (Jones et al., 2015; Salari & Filus, 2017).

The HBM has been widely used to explain people’s behaviors and uptakes of vaccinations and screenings in many health conditions. Fall et al. (2018) found that perceived susceptibility and benefits were significant independent predictors of vaccination intention while perceived barriers had a negative tendential effect on the intention to get a vaccination. In addition, Fall et al. found that perceived self-efficacy and perceived benefit significantly predicted vaccination behavior 1 year after they interviewed study subjects.

Parents and guardians of children exposed to EBLL do not see the urgency of lead screening because there is a delay or absence of symptoms and health effects. HBM constructs may therefore provide a theoretical framework to understand the thinking of parents and guardians when they decide to screen their children for lead exposure. Lead poisoning is often asymptomatic even at higher blood lead levels of 45 μg/dL or greater (Hauptman et al., 2017; Mayans, 2019). Therefore, this study was conducted to evaluate parents’ and guardians’ behaviors toward case management and follow-up recommendations using these constructs. For instance, a high level of parental compliance to case management and follow-up recommendations may be explained by the perception that exposure to lead constitutes a substantial threat to their children’s health and success.

## Nature of the Study

This was a quantitative study with a retrospective cohort design using data from case management and follow-up charts of children exposed to EBLL in Marion County, Indiana, between January 2018 and December 2019. A convenience sampling technique was used to sample study subjects with the following selection criteria: (a) children of age 6 or younger, (b) children diagnosed with EBLL, and (c) children enrolled in case management and follow-up. A paired *t* test was used to answer Research Question 1 because the measurements of BLLs were carried out on the same individual. Multiple regressions were used to answer Research Question 2. The analysis of variance (ANOVA) method was used to answer Research Question 3 (see Daniel & Cross, 2013; McDonald, 2014).

## Definitions

*410-IAC-29*: Designation of Chapter 29 of the 2007 Indiana Administrative Code that regulates the reporting, monitoring, and preventive procedures for lead poisoning (Indiana Administrative Code, 2007).

*Blood lead test*: Any blood lead draw (capillary, venous, or unknown sample type) on a child that is analyzed by a CLIA-certified facility or an approved CLIA-waived portable device and produces a quantifiable result (CDC, 2019b).

*Case management*: The process of providing, overseeing, and coordinating lead poisoning services, including but not limited to the following:

- outreach and identification of children with EBLLs
- child case management service planning and resource identification
- child case management service implementation and coordination
- monitoring of child case management service delivery, program advocacy, and program evaluation (Indiana Administrative Code, 2007).

*Children at risk*: Children who have any or combination of the following conditions:

- lives in or regularly visits a house or other structure built before 1978
- has a sibling or playmate who has been lead poisoned
- has frequent contact with an adult who works in an industry or has a hobby that uses lead
- is an immigrant or refugee or has recently lived abroad
- is a member of a minority group
- is a Medicaid recipient
- uses medicines or cosmetics containing lead
- lives in a geographic area that increases the child's probability of exposure to lead (Indiana Administrative Code, 2007).

*CLIA*: A Clinical Laboratory Improvement Amendments (CLIA)-certified facility (CDC, 2019b).

*CLIA waived*: A Clinical Laboratory Improvement Amendments (CLIA)-waived facility (CDC, 2019b).

*Confirmed EBLL*: A child with one venous blood test ≥ 5 μg/dL or two capillary blood tests ≥ 5 μg/dL drawn within 2 weeks of each other (Indiana Administrative Code, 2007).

*Elevated blood lead level (EBLL)*: A single blood lead test (capillary or venous) at or above the reference value of 5 μg/dL (CDC, 2019b; Indiana Administrative Code, 2007).

*Percentage of children tested*: The number of children less than 72 months of age tested for blood lead divided by the total number of children less than 72 months of age within a geographic unit (i.e., county or state) based on annual intercensal estimates for the most recent U.S. Census data, multiplied by 100 (CDC, 2019b).

*Percentage of children with EBLLs*: The number of children less than 72 months of age with an elevated blood lead level ≥ 5 µg/dL divided by the number of children less than 72 months of age tested for blood lead, multiplied by 100 (CDC, 2019b).

*Screening test*: A blood lead test for a child age < 72 months who previously did not have a confirmed elevated BLL (CDC, 2019b).

*Test type*: A blood lead test that may be conducted for screening, confirmation, or follow-up (CDC, 2019b).

## Assumptions

I used secondary data from a CDC-funded childhood lead poisoning prevention surveillance data set, which was collected by the Healthy Home and Senior Care Department of the MCPHD. I made the following assumptions. First, I assumed that the primary data had been collected using valid instruments and by adhering to ethical and quality standards required by the Indiana Administrative Code 410-IAC-29. Second, I assumed that parents and guardians who consented to screen their children for lead exposure behaved in the framework of the HBM constructs including perceived susceptibility, severity, benefits, and barriers of childhood lead poisoning condition (see Jones et al., 2015; Salari & Filus, 2017). Finally, I assumed that the data set was representative of the county population in terms of ethnic, racial, and socioeconomic characteristics. These assumptions were essential for the generalizability of the findings of this study.

## Scope and Limitations of the Study

I analyzed the BLLs of young children between the ages of 0 and 72 months. Therefore, the findings and interpretations of the results of this study may not apply to the adult population because the effect of lead in children is different from that in adults (see Mayans, 2019). Also, this study was designed as a retrospective cohort study; therefore, selection bias due to loss to follow-up and information bias due to misclassification were limitations (see Howe et al., 2016). In addition, I used a convenience sampling method that limited the generalizability of the results (see Jager et al., 2017).

## Significance

This study was conducted to determine whether case management is effective in bringing down the BLL of children diagnosed with EBLL in Marion County, Indiana. Evidence from this study may be critical for the efficient allocation of scarce resources at the MCPHD. Such evidence may also be important for establishing effective intervention plans for subsequent lead surveillance programs in Marion County, Indiana. In addition, the results of this study may be used to create an educational tool kit for childhood lead prevention. Finally, the result of this study may effect social change by indicating which of the management and follow-up services should be considered first when resources are scarce.

## Summary

This chapter included an introduction to the global burden of lead exposure. The introduction indicated that although 90% of childhood lead burden occurs in developing countries, children in developed countries like the United States continue to be exposed to lead poisoning as evidenced by half a million U.S. children diagnosed with EBLL in 2017 (Hauptman et al, 2017). In the background section, I discussed some major U.S. policies that were developed to eliminate lead in the environment and to prevent childhood lead exposure. Examples of such policies included the federal ban of lead-based paints and the adoption of universal and targeted screening policies across states and local jurisdictions (American Academy of Pediatrics Council on Environmental Health, 2016; Dickman, 2017). The background also addressed the Indiana Administrative Code 410-IAC-29, which regulates the reporting, case management, and follow-up services and prevention of childhood lead exposure in Marion County. Also, the background addressed the research gap that this study was conducted to fill. The problem statement and the purpose of the study sections addressed risk factors of childhood lead poisoning and case management services provided to children diagnosed with EBLL in Marion County, Indiana (Indiana Administrative Code, 2007; ISDH, 2018).

I used the HBM as the theoretical basis for the study. The HBM posits that the risk of susceptibility, risk of severity, benefits of the action, barriers to action, self-efficacy, and cues to action drive the probability of an individual to adopt a health promotion and health risk prevention behavior (Jones et al., 2015). The HBM was an appropriate theoretical framework to understand the thinking of parents and guardians when they decide to screen their children for lead exposure (see Salari & Filus, 2017). The nature of the study section addressed the research design and method and the analytical approach. This was followed by a section that provided definitions of important keywords and phrases used throughout this study. This chapter ended with sections that described the assumptions, limitations, and significance of the study, respectively.

# Chapter 2: Literature Review

The problem statement of this study included factors associated with childhood lead exposure, such as risk factors, preventive strategies, EBLL reference limit, follow-up, and case management. In this chapter, I present a synthesis of previous research about those factors to provide a context of the importance of this study. Keywords and phrases used to identify these articles includes *childhood lead exposure*, *childhood lead poisoning, reference level*, *elevated blood lead level, case management*, *follow-up, lead in drinking water*, *risk factors, screening*, and *lead regulations*. I used combinations of these keywords and phrases using “AND” as the connector. The following search engines were used to search these keywords: Thoreau, Cinahl, Medline, and PubMed. These search engines were accessed through the Walden University Library website. The Google search engine was also used to access some of the cited articles. Most of the articles in this review came from peer-reviewed journals. However, this review also included reports and data from federal and state agencies including the CDC, Environmental Protection Agency (EPA), and HUD.

In this review, I first synthesized evidence about the origin, constructs, validity, and rationale of using the HBM (Harrison et al., 1992; Janz & Becker, 1984; Zimmerman & Vernberg, 1994) as the theoretical background for this study. I then synthesized research findings and reports about the properties and utility of lead (EPA, 2020; Wani et al., 2015), its toxicity (Mayans, 2019; Wani et al., 2015), and its negative effects on children’s health and academic performance (He et al., 2019; Yeter et al., 2020). Next, I synthesized the literature on the routes of lead exposure (Carrel et al., 2017; Wani et al., 2015), the sources of lead exposure (Hauptman et al., 2017; Mayans, 2019), and the risk factors of lead childhood lead exposure (CDC, 2020; Hauptman et al., 2017; HUD, 2011) successively. After these sections, I synthesized the prevalence of EBLLs in children in the United States (CDC, 2019a; Hauptman et al., 2017). I then addressed the primary and secondary strategies to prevent childhood lead exposure in the United States. In the last section, I addressed the factors affecting the CDC-funded Childhood Lead Poisoning Prevention Program (CLPPP) in Indiana (CDC, 2020b; ISDH, 2016, 2018).

## Theoretical Foundation

### Origin and Constructs of the Health Belief Model

I used the HBM (see Janz & Becker, 1984) as the theoretical basis for the study. The HBM was developed in the early 1950s by U.S. social psychologists in response to poor uptake of free tuberculosis screening(Janz & Becker, 1984). The model has become a popular theory to explain preventive health behaviors in various disease conditions (Glanz et al., 2008; LaMorte, 2019; Sundstrom et al., 2015). The HBM posits that people are more likely to adopt a disease prevention behavior if they think they are susceptible to the disease (perceived susceptibility), if they think the disease can cause serious damage to their health (perceived severity), if they believe that they can achieve a better outcome by adopting the action (perceived benefits), and if they do not anticipate any negative consequences related to the health behavior (perceived barriers; Glanz et al., 2008; Janz & Becker, 1984).

In addition to these four original constructs (perceived susceptibility, perceived severity, perceived benefits, and perceived barriers), four other constructs including self-efficacy and cues to action were later added to the model (Janz & Becker, 1984; Sundstrom et al., 2015). Self-efficacy is the belief that a person can complete health behavior despite the existence of barriers (Glanz et al., 2008; Janz & Becker, 1984). Self-efficacy was added to the model recently (LaMorte, 2019) and was rarely evaluated in the mid-1980s (Carpenter, 2010; Jones et al., 2015). Cues to action can be viewed as the stimuli needed to trigger the decision to adopt healthy behavior. These stimuli are specific to the health condition, and they can be internal or external to the person such as disease symptoms and awareness advertisement (LaMorte, 2019; National Cancer Institute, 2005).

## Validity of the Health Belief Model

The validity of the HBM has been evaluated in many reviews and meta-analyses (Carpenter, 2010; Jones et al., 2015). Janz and Becker (1984) summarized the results of 46 HBM studies that examined various health behaviors including preventive-health behaviors, sick-role behaviors, and clinic utilization behaviors. Janz and Becker found that perceived barriers, perceived benefits, and perceived susceptibility are better predictors of the behavior than perceived severity.

A meta-analysis by Harrison et al. (1992) showed that HBM worked best for retrospective studies than for prospective studies. This finding suggests that the HBM may not be very good at predicting future behavior. This meta-analysis also suggested that perceived benefit and perceived barrier have a bigger effect on behavior than perceived severity.

In another meta-analysis, Zimmerman and Vernberg (1994) examined the ability of the HBM to predict behavior without regard to the effects of each construct on behavior. Zimmerman and Vernberg found that the HBM was a weak predictor of behavior compared to the social cognitive theory and the theory of reasoned action. More recently, Carpenter (2010) conducted a meta-analysis of HBM to elucidate uncertainty concerning which HBM construct is most strongly related to health behavior. Carpenter found that perceived benefits and perceived barriers were consistently the strongest predictors. Despite these inconsistencies, the HBM continues to be used widely to explore various health conditions such as breast cancer screening (Conley et al., 2019; Tapera et al., 2019), vaccination uptake (Fall et al., 2018; Sundstrom et al., 2015), or diabetes management (Alatawi et al., 2016; Tang et al., 2015).

## Use of Health Belief Model in Lead Exposure Studies

Studies that addressed HBM constructs in the contest of childhood lead poisoning are rare. Anderson et al. (1999) compared the perception of mothers of children diagnosed with EBLL with the perception of mothers with children without EBLL and found no statistically significant differences between these groups of mothers. Anderson et al. attributed the absence of significant differences between these groups to the fact that EBLL may not have symptoms, and so mothers of children exposed to EBLL do not perceive the threat of lead exposure, which could have driven them toward preventative health actions.

Polivka and Gottsman (2005) conducted focus group discussions to assess parental perceptions of barriers to blood lead testing in the state of Ohio. Polivka and

Gottsman found that most parents were not familiar with the causes and effects of lead poisoning. In addition, most parents wished to do lead testing during their WIC visits to limit the travel time. This finding suggests that in addition to the lack of perceived threat, transportation to the lead testing sites may also be a barrier to uptake of lead screening.

The fact that lead exposure is asymptomatic has been supported by many recent studies. Mayans (2019) reported that lead poisoning is often asymptomatic even at blood levels as high as 45 µg/dL; a value that is 9 times higher than the current CDC reference level of 5 µg/dL. Haboush-Deloye et al. (2017) remarked that without signs and symptoms, parents may not rush lead screening testing.

## Rationale for Using the HBM in the Current Study

The rationale for using the HBM for this study derived from two considerations. First, the data set for this study came from a CDC-funded CLPPP (CDC, 2020c), and the HBM has been widely used to explain people’s motivation and participation in disease-prevention screening programs (Conley et al., 2019; Glanz et al., 2008; Tapera et al., 2019). The HBM was associated with an X-ray screening campaign for the early detection of tuberculosis in the 1950s (Glanz et al., 2008).

Second, risk factors of childhood lead exposure can be mapped to constructs of the HBM. For example, it can be hypothesized that living in older lead-based paint houses would be a perceived susceptibility factor to motivate parents to screen their children for lead exposure (see Glanz et al., 2008). In addition, it can be assumed that evidence of loss of academic performance associated with childhood EBLL (see

Sorensen et al., 2019) would motivate parents to participate in the CDC-funded CLPPP as a perceived susceptibility factor (see Glanz et al., 2008).

## Properties and Utility of Lead

Lead can be described as a bluish-white metal, which when freshly cut shows a bright luster but tarnishes when exposed to air (Abadin et al., 2007). Lead has many physical properties that make it attractive for industrial use. Lead is very soft, highly malleable, and ductile. In addition, lead is a poor conductor of electricity and is very resistant to corrosion (Abadin et al., 2007; Wani, et al., 2015). These proprieties probably explain why lead was extensively used in plumbing during the Roman era. It worth noting that the word *plumbing* is derived from the Latin name of lead (Delile et al., 2017; Robin, 2008).

Lead also has properties that may explain its attractiveness to the paint industry. Lead makes the paint more durable and improves its adherence to surfaces. Lead compounds also allow the making of various paint colors such as the use of lead carbonate to make white paint and the use of lead chromate to make yellow paint (O’Connor et al., 2018). Today, the lead acid battery industry is the principal user of lead accounting for more than 85% of U.S. lead consumption in 2018 (Abadin et al., 2007). However, despite the enactment of many regulations to curb the presence of lead in the environment, lead-containing products are still ubiquitous in modern industrial and household items including paint, ceramics, pipes and plumbing materials, solders, gasoline, batteries, ammunition, and cosmetics (EPA, 2020).

# Problems of Lead Exposure

## Lead Toxicology

Lead has no physiologic value in the body, and its adverse impact on human health has been recognized since at least the second century BC (Delile et al., 2017). Much of lead's toxicity has been associated with distortion of the cell membrane, DNA, enzymes, and structural proteins (Wani et al., 2015). Lead also interferes with the synthesis of essential biomolecules such as Vitamin D and hemoglobin. Specifically, lead interferes with enzymes such as D-aminolevulinate dehydratase and ferrochelatase, which are essential for the synthesis of the heme ring (Wani et al, 2015), and this may explain the association between lead poisoning and anemia (Hauptman et al., 2017).

Many of lead's toxic properties are also due to its ability to mimic or compete with calcium. Lead is a divalent cation, and it can bind strongly to sulfhydryl groups of protein molecules (Wani et al., 2015). Also, because of its ability to successfully compete with calcium, lead can negatively affect neuronal signaling in the brain, and this is the most concerning aspect of childhood lead exposure (Mayans, 2019; Wani et al., 2015).

Lead is also associated with a condition called gingival lead line or Burton line. Gingival lead line is a blue-purplish line on the gums seen in lead-poisoned individuals, which is caused by a reaction between circulating lead with sulfur ions released by oral bacterial activity. As a result of this reaction, lead sulfide compounds deposit at the junction of the teeth and gums (Babu et al., 2012; Pearce, 2007).

## Effects of Lead Exposure on Children's Health and Academic Performance

Several studies have provided evidence that lead has wide-ranging health and developmental effects on young children. He et al. (2019) reported that lead levels as low as below 3 µg/dL in children's bloodstream can affect their brain's ability to control impulses and process information. Yeter et al. (2020) added that beginning at a blood lead content of 2 µg/dL, there is a loss of 1.88 IQ points for each doubling of blood lead level.

The effect of lead on children's school performance has also been documented. A longitudinal study of New Zealand children revealed that elevated lead levels were associated with poorer reading cores, failure to graduate from high school, and poorer examination scores (Needleman, 2004; Reuben et al., 2017). Recently Sorensen et al. (2019) studied the effect of lead hazard control programs on children's blood lead levels and students' test scores. Sorensen et al. found that children's math and reading scores increased for every 1 percentage point reduction in children's blood lead level, and years later average math test scores improved by 0.03 to 0.04 standard deviations while average reading scores improved 0.06 to 0.08 standard deviations.

The impact of lead exposure is not limited to the immediate health outcome on children because the impact of lead exposure can be irreversible, long-lasting, and affecting children's future workplace performance and future earning (Reuben et al., 2017; Mayan, 2019). The societal cost of lead-poisoned children can also be huge because of the cost of special education. In that perspective, the American Academic of Pediatrics reported that despite the historical reductions in blood lead concentrations, it has been estimated that the annual cost of childhood lead exposure in the United States is $50 billion (Council on Environmental Health, 2017).

## Route of Lead Exposure

Human exposure to lead can occur through many routes but inhalation, ingestion, and trans-placental are reported as the most common routes. Wani et al., (2015) reported that in adults, up to 40% of inhaled lead dust is deposited in the lungs and about 95% goes into the bloodstream and for ingested inorganic lead, about 15% is absorbed in the bloodstream. These absorption rates are generally higher in children, pregnant women, and people with deficiencies of calcium, zinc, or iron (Carrel et al., 2017; Wani et al., 2015). Besides, the rate of absorption of lead in other body organs such as bones and teeth appear to be affected by age as well. In adults, the combined rate of lead absorption in bones and teeth can reach 94%, while in children this rate was estimated to about 70% (Wani et al., 2015).

The relatively lower lead absorption in children's bones and teeth suggests that soft tissues such as the brain, liver, spleen, lungs, or kidneys would absorb more lead and that may explain lead in children has far greater health and developmental consequences than in adult (He et al., 2019; Yeter et al., 2020). Besides, according to Wani et al. (2015) children have rapidly developed and remodeling bones and this allows the lead to be continuously reintroduced into the bloodstream.

Lead is also known to readily cross the placenta of the developing fetus and impairs the function of multiple developing organ systems. Multiple studies have shown that lead in the maternal bone can move into the bloodstream, representing therefore an endogenous source of fetal lead exposure (Carrel et al 2017; Silver, et al., 2016).

According to Carrel et al. (2017), the endogenous lead exposure phenomenon typically occurs when physiologic stress of pregnancy stimulates mobilization of lead from bone into maternal blood as a consequence of high calcium demands. Carrel et al. (2017) added that any or combination of the following factors include high maternal blood pressure, low calcium levels and milk intake, low hemoglobin levels, and anemia, and alcohol intake in the third trimester of pregnancy may increase the transfer of lead to the fetus.

## Sources of Lead Exposure

The source of childhood blood lead is diverse. Hauptman et al. (2017) reported that lead-laden dust and paint chips from deteriorating lead paint on interior building surfaces constitute the major source of lead found in children diagnosed with EBLL. Mayan (2019) added that up to 70% of EBLL in children come from a combination of lead-based paint, lead-laden house dust, and lead-contaminated soil and that the remaining 30% come primarily from contaminated drinking water and imported goods such as candies, spices, pottery, and herbal remedies.

Evidence of drinking water as a source of childhood lead exposure is well documented in the US following the 2014 Flint, MI. water crisis events (Zahran, McElmurry, & Sadler, 2017). Evidence of imported goods as sources of lead exposure is also supported by many reports. In 2015 a local health department in the state of Wisconsin identified an adult with 85.8$\mu$g/dL blood lead level. Upon investigation, the source of this exposure was linked to Ayurvedic medications imported from India (Meiman et al., 2015). More recently, a 12-year-old recent immigrant from Thailand and two of his younger siblings were diagnosed with EBLL in the state of Georgia, in 2018 and the sources of these exposures were linked to imported tobacco products (El Zahran et al., 2018).

Another source of childhood lead exposure is “take-home” lead from adults working in industries such as painting, building renovation, demolition, shooting range, metal scrap cutting, plumbing, and recycling (Hauptman et al., 2017). In June 2010, a one-year-old boy and a two-year-old girl were diagnosed with EBLL with 18$\mu$g/dL and 14$\mu$g/dL, respectively in the state of Ohio. Subsequent investigations linked the sources of these exposures to the father of the children who has been working in a scrap factory without protective equipment at work (Newman et al., 2015).

## Risk Factors of Lead Exposure

### Housing Conditions

It is now widely accepted that children most at risk of lead exposure are those living in houses built before 1978. The EPA estimates that more than 80% of all homes built in the U.S. before 1978 contain lead-based paint (HUD, 2011; Yeter et al., 2020), and there is a significant amount of those houses in the US. For example, a 2011 American Healthy Homes Survey revealed that about 34.9% of all US homes have lead-based paint; about 21.9% of all homes have one or more lead-based paint hazards and that an estimated 3.6 million homes with lead-based paint have children below the age of 6 years (Hauptman et al., 2017; HUD, 2011).

The average age of housing in a community can therefore provide an indication of the extent of childhood lead exposure risk factors in a community. According to HUD (2011), the highest prevalence of lead-based paint housing is found in the Northeast and Midwest. However, Roberts et al. (2017) analyzed EBLL data from 1999 to 2010 and found that the greatest number of children with higher than 10µg/dL of blood lead content resides in the South.

In Indiana, a 2018 report of the State Department of Health indicated that about 60% of all housing was built before 1980, the year considered as the cutoff for lead-based paint housing stock. This report also indicated that the stock of older housing in Marion County, IN. was even higher, reaching 65% with potential suggesting a higher risk for children in that county (ISDH 2018, 2015, 216).

## Drinking Water Source

Another risk factor for childhood lead exposure is lead-containing water, either through service line or poor anti-corrosion control system as evidenced by the 2014 Flint, MI. water crisis (Zahran et al., 2017). However, it is important to indicate that homes without lead service lines may still have brass or chrome-plated brass faucets, galvanized iron pipes, or other plumbing soldered with lead. Infants who drink formula prepared with lead-contaminated tap water may be at a higher risk of exposure because of the large volume of water they consume relative to their body size (CDC, 2020; Hauptman et al., 2017).

## Socioeconomic Conditions

Risk factors of childhood lead exposure have also been associated with socioeconomic, racial, and ethnic factors. Children living at or below the federal poverty level are at higher of lead exposure because they are more likely to reside in older, poorly maintained housing with lead paint and lead-containing plumbing (CDC, 2019a; Hauptman et al., 2017).

In terms of racial, ethnic, and socioeconomic status, it is widely accepted that Blacks and Hispanics are most at risk of childhood lead exposure. Immigrant or refugee status is a risk factor since children born abroad or whose parents were born abroad may be more likely to use imported goods that contain elevated levels of lead (Hauptman et al., 2017). Lower socioeconomic status may also imply imbalanced nutrition such as iron deficiency. Iron deficiency has been associated with a five-fold increase in the risk of lead toxicity from the baseline value (CDC, 2019a; Hauptman et al., 2017).

Age is a risk factor because lead absorption, mobility, and behavior are significantly modified by age. Infant and young children are known to have higher hand-to-mouth activity, and this puts them at much higher risk of lead exposure than adults (Mayan, 2019; Wani, et al., 2015). Besides, younger children absorb lead more readily than older children and adults as evidenced by an analysis of 2009-2010 NHANES survey data which showed that the median blood lead levels for one-to-two-year age-old children is much higher (1.2 µg/dL) than that of six to ten years old children (0.8 µg/dL) (AAP-CEH, 2016).

## Prevalence of Elevated Blood Lead Level in Children

Childhood blood level has been declining over the past four decades in the US. Before between 1976 and 1980 the reference value of EBLL was 105 µg/dL and the prevalence of EBLL was over 80%. Between 1988 and 1991 the prevalence level dropped to less than 10% (AAP-CEH, 2016). Considering the reference level of ≥5 µg/dL, the prevalence level of EBLL dropped significantly from about 2.6% in 2010 to about 2.5% in 2017 (Hauptman, et al., 2017).

It is important to indicate that the prevalence of childhood lead exposure is linked to the current reference value 5 µg/dL which was derived from the 97.5th percentile of the blood level distribution among children between the ages of one and five years old in the 2007 to 2010 National Health and Nutrition Examination Survey (NHANES) data (Caldwell, et al., 2017; Mayan, 2019).

In 2012, the CDC adopted this reference value and planned to update it every four years but has not done so yet. Consequently, the prevalence of EBLL may be higher if the new NHANES data produces a lower reference value (Mayan, 2019). Caldwell, et al., (2017) used the 2011 to 2014 NHANES survey data, found the 97.5th percentile corresponded to 3.48 µg/dL (95% CI, 2.65–4.29 µg/dL) which is about 30% lower than the current reference value of 5 µg/dL.

There is also evidence that the use of NHANES survey data may underestimate the lead exposure prevalence in some urban schools. McLaine et al. (2013) reported that 20% and 67% of kindergarteners in a public school in the state of Iowa had least one BLL ≥10 µg/dL and one BLL ≥5 µg/dL, respectively

# Lead Exposure Prevention Strategies

## Primary Prevention

Primary prevention is the most effective way to protect children against the harmful effect of lead exposure. Because no safe blood lead level exists, successful primary prevention should remove every lead hazard from areas where children spend a significant amount of their time. These areas may home, school facilities, daycares centers, and playgrounds (Christensen et al., 2019; Ettinger et al., 2019).

Environmental health regulations have been the cornerstone of lead exposure prevention in the US (Health Impact Project. 2016; Kennedy et al., 2017, 2014). The first major legislation to remove lead in the environment is the 1971 Lead-Based Paint Poisoning Prevention Act which banned lead-based paint in the US. Then in 1973, the US started phasing out lead in gasoline, and in 1978 the US banned lead in residential paint (Council on Environmental Health, 2017; Health Impact Project, 2017).

In 1992, the Residential Lead-Based Paint Hazard Reduction Act or Title X was enacted, and in 1995 the US Housing and Urban Development [HUD] established guidelines for evaluating and controlling residential lead-based paint hazards. In 1999 created the Lead Safe Housing Rule, which was updated in 2012 with new requirements for lead-based paint notification, evaluation, and remediation (Council on Environmental Health, 2017; Health Impact Project, 2017).

In 2016, following events in Flint, MI, a renewed focus on identifying and removing lead from the environment led to the passage of the Water Infrastructure Improvements for the Nation (WIIN) Act (Ettinger et al., 2019). In 2017, the EPA finalized an amendment to the Lead Renovation, Repair, and Painting Program (RRP) Rule. The RRP requires that people engaged in Renovation, Repair, and Painting activities on facilities built before 1978 to be trained and certified in lead-safe work practices because these repair and renovation activities can create hazardous lead dust when surfaces with lead paint are disturbed. This rule is therefore created to protect from lead exposure (Council on Environmental Health, 2017; EPA, 2017; Health Impact Project, 2017).

Besides, the Occupational Safety and Health Administration (OSHA), has established standards to prevent workplace lead exposure for general industry, shipyards, and construction employers. These standards set also set an action level of 30 micrograms per cubic meter ($\mu g/m^3$) at which an employer must begin specific compliance activities such as blood lead testing for exposed workers (US Department of Labor, n.d.).

OSHA often uses the national Adults Blood Lead Epidemiology and Surveillance (ABLES) data to identify industries whose employees exhibit high BLLs (Alacron, 2016). In February 2016, an OSHA enforcement investigation found that shipyard workers in Superior, Wisconsin, were exposed at ≥20 times the permissible exposure limit (Egan, Tsai, & Chuke, 2019).

Regulations to prevent childhood lead exposure were expanded to other potential sources as well. The 2008 Safe Drinking Water Act allows the EPA to establish a treatment technique that prevents lead and copper from getting in the drinking water. In addition, the Lead-Free Toy Act allowed the Consumer Protection Safety Committee to set a limit on the lead content of toys (Council on Environmental Health, 2017; Health Impact Project, 2017).

Other federal agencies have also been actively involved in the prevention of childhood lead exposure. For instance, since 1998 the Centers for Medicare & Medicaid Services (CMS) required universal blood lead screening for children receiving program benefits (Ettinger et al., 2019). In 1995, the Council of State and Territorial Epidemiologists (CSTE) designated EBLLs as the first noninfectious condition to be voluntarily “notifiable” at the national level. Consequently, the CDC is now requiring elevated blood lead levels in the National Notifiable Diseases Surveillance System (Egan, Tsai, & Chuke, 2019).

It is widely that accepted these regulations and environmental health policies have made a significant improvement in the prevention of childhood lead exposure. Tsoi et al. (2016) analyzed blood levels among US children and found that the average blood lead level in children has declined by about 94%, from 15 µg/dL in 1976, to 0.86 µg/dL in 2014. Also, Kennedy et al. (2014) compared childhood lead prevention data from states of Massachusetts (MA) and Ohio (HO) which have enacted childhood lead prevention laws, and Mississippi (MS) which did not have lead exposure prevention. They found significant differences between lead law states (MA & OH) and the control state (MS) in terms of number of confirmed cases of lead poisoning at a given address. They also reported that the states with lead laws were 79% less likely than the ones without legislation to have residential addresses with subsequent lead poisoning cases among children younger than 72 months.

Despite the success of these regulations and policies in preventing or mitigating the effect of childhood lead exposure (Kennedy et al., 2016, Kennedy et al., 2014), an estimated 2.5% of US children between one and five years old are still being exposed to the effect of EBLL. Besides, this estimate does not include other groups at risk such as younger or older children pregnant and lactating women, or workers exposed on the job (Ettinger et al., 2019).

The persistence of lead in the environment in the US may be the consequence of US reluctance to join the internal community to control lead in the environment. According to the Health Impact Project (2017), many European countries including France, Belgium, and Austria banned white-lead interior paint as early as 1909. Besides, the Health Impact Project (2017) also reported that the US declined to adopt the International Labor Organization proposal that prohibits the use of lead-based paint in all member countries in 1921.

## Secondary Prevention

A central tenet of secondary prevention is to identify asymptomatic children with lead in their blood. This should allow the identification and removal of the lead hazard, and the treatment of contaminated children (Christensen, et al., 2019; Mayan, 2019).

Much of the guidance and recommendations of childhood lead prevention in the US come from the CDC (Ettinger et al., 2019a; Mayan, 2019). However, the CDC has been frequently updated its guidance and recommendations to consider new evidence about childhood lead exposure risk factors and health effect. Thus, in 1975 the CDC recommended screening only children who lived in or visited homes built before 1960 (Ettinger et al., 2019, Yeter et al., 2020).

In 1985, the CDC updated these recommendations to include that all children should be screened, but priority is should be given to those with one or combination of the following risk factors: a) living in the older, dilapidated housing, b) living near heavily trafficked highways, c) being siblings, housemates, visitors, or playmates of children with known lead toxicity or d) family members had occupational lead exposures. By 1991, the CDC recommended screening for all children between the ages of one and five (Ettinger et al., 2019, Yeter et al., 2020).

Presently, the CDC recommends that state and local health departments to development screening plans that are adapted to their local conditions, and this have led to a patchwork of screening pattern across the US, with some state and local health departments adopt universal screening while other applied targeted screening (Dickman, 2017; Michel et al., 2020).

### Universal Screening

Universal screening is regarded as the most effective approach to secondary prevention of childhood lead exposure (Dickman, 2017; Yeter et al., 2020). Thus, since 1998, the Centers for Medicare & Medicaid Services (CMS) require universal screening for all children receiving program benefits (Ettinger et al., 2019, Yeter et al., 2020). As of 2018, at least 14 states and the District of Columbia presently require universal screening of children for lead exposure (Dickman, 2017; Michel et al., 2020). In addition, some local health departments such as the city of Philadelphia, PA., and Marion County, IN., and East Chicago, IN. also require universal screening (Michel et al., 2020; ISDH, 2016).

Besides, some organizations such as the Pediatric Environmental Health Specialty Unit (PEHSU) and the American Academy of Pediatrics (AAP) also require universal screening of children for lead exposure (Michel et al., 2020). The AAP however, recommends universal screening for children with certain conditions, such as those living in communities with more than 27% of housing built before 1950 or where the prevalence of EBLL (≥ 10 µg/dL) for children between the ages 12 and 36 months is ≥ 12% (Council on Environmental Health, 2017).

### Targeted Screening

Presently, at least 18 health departments in the US are using a targeted approach to childhood lead exposure screening (Dickman, 2017; Michel et al., 2020). A major limitation of the targeted approach to childhood lead screening is the challenge of defining the target criteria that can successfully identify all of the children at risk. This consideration may make targeted screening less effective compare with the universal screening approach (Dickman, 2017; Michel et al., 2020).

If targeted screening should be used, the American Academy of Pediatrics (AAP) recommends screening children of 12 to 24 months old and living in areas where more than 25% of housing is built before 1960 (Yeter et al., 2020). Screening based on location could however result in under testing of children in a community. As an example, a local health department may recommend screening children based on the zip code of residence of children while another health department may recommend testing based on the location of children’s primary care physician’s practice (Dickman, 2017).

## Clinical Diagnosis and Treatment of Lead Exposure

Medical providers play a crucial role in the prevention and early detection of childhood lead exposure. Mayan (2019) that symptomatic lead poisoning should be an emergency with immediate hospitalization. The problem is that lead poisoning may not have specific symptoms and therefore a variety of symptoms and signs can be the result of lead poisoning (Haboush-Deloye et al., 2017, Mayan, 2019).

Hampton et al. (2017) suggested that “*children who present to the emergency department with the following including persistent gastrointestinal symptoms (e.g. constipation, abdominal pain, vomiting), unexplained weight loss, unexplained neurological symptoms (e.g. headaches, fatigue), or behavioral changes (e.g., withdrawn, confusion, irritability, hyperactivity) or whose skin has a distinct pallor from severe anemia, should be suspected of suffering from acute lead poisoning*” (Clinical Diagnosis section). In terms of treatment, the CDC recommends chelation therapy only when the blood lead level is ≥ 45µg/dL. For lower blood lead levels, the CDC recommends prompt case management and environmental investigations to identify and remove the source of exposure, despite evidence that the lead levels below 5µg/dL have been associated with irreversible impaired neurocognitive and behavioral development (Mayan, 2019; Reuben et al., 2017).

Presently, states use different definitions of EBLL, recommendations for screening, reporting, follow-up, and case management (Mayan, 2019; Michael et al., 2020). Even the existing CDC recommendations are not being followed by all states and by every health provider. For example, Michael et al. (2020) observed that only 37 states use the CDC definition of EBLL. Besides, Haboush-Deloye et al. (2017) reported that in Clark County, Nevada, only 52% of medical doctors involved in pediatric lead screening admitted to adhering to CDC BLL testing guidelines. According to Michael et al. (2020), the lack of a uniform sharable clinical decision system is a challenge to effective pediatric childhood lead screening and management.

## Childhood Lead Poisoning Prevention Program

Since the early 1990s, the CDC has been funding a Childhood Lead Poisoning Prevention Program (CLPPP) across the US. Today, more than 60 states and local health departments, are participating in this program (CDC, 2020b). CLPPP aims to eliminate childhood lead exposure as a public health problem, through strengthening blood lead screening, surveillance, follow-up, and case management (CDC, 2020b). The CDC provides guidance and recommendation for the activities of the CLPPP, but most operational activities of the program at each participating health department are regulated by the state laws and regulations (Raymond & Mary, 2017).

## CLPPP in Indiana

CLPPP activities across the state of Indiana are regulated by Article 29 of the Indiana Administrative Code (410-IAC-29) which mandates much of the screening, data reporting, case definitions, follow-up, and case management services (ISDH, 2016, 2018). In particular, 410-IAC-29 mandates that a child becomes a confirmed case of EBLL and qualify for case management when the result of a blood lead test, taken from a single venous blood test sample or two consecutive capillary blood samples, is ≥10µg/dl (ISDH, 2016, 2018).

However, in 2015 ISDH’s Lead and Healthy Homes Program (LHHP) started recommending that case management be provided to children with blood lead level ≥5µg/dL (ISDH, 2016). Thus, the majority of local health departments in the state of Indiana use blood lead value ≥10µg/dL as a reference value for EBLL. However, some jurisdictions such as the city of East Chicago and MCPHD do use ≥5µg/dL as a reference value for EBLL (ISDH, 2016, 2018).

Blood lead testing is most often conducted by family physicians and pediatricians, either in-office or through a referral to a testing laboratory (ISDH, 2016, 2018). However, local health departments clinic also routinely provides lead screening (ISDH, 2016, 2018). Organizations like the Indiana Women, Infants, and Children (WIC) program and Head Start also provide lead screening services (ISDH, 2016, 2018).

The number of children who received blood lead screening in Indiana has been increasing from 40,811 in 2014 to 68,868 in 2018, suggesting a 69% increase. Similarly, the prevalence of EBLL (≥10µg/dL) at the state level has increased, from about 0.25% in 2014 to about 0.4% in 2017. The prevalence has however dropped to 0.3% in 2018 (ISDH, 2018).

The rate of childhood lead screening is significantly low in Indiana when considering CDC and CMS requirements (ISDH, 2018). For example, Medicaid-insured children are required to receive a blood lead test at 12 and 24 months of age, or as soon as possible before age 6 (ISDH, 2018; ISDH, 2016). But in 2018, only 21% of Medicaid-insured Indiana’s children between the ages of one and two had been screened, suggesting that up to 79% of Medicaid-insured children eligible for screening did not get tested for childhood lead exposure (ISDH, 2018).

## Summary and Conclusions

In this chapter, I reviewed the literature about childhood lead exposure. In the first section, I synthetized research findings of the HBM (Janz & Becker, 1984) as the theoretical background for this study. While the HBM was created to explain the poor uptake of free tuberculosis screening in the 1950s, it has since become a popular theory to help explaining preventive health behaviors in various disease conditions (Glanz et al., 2008; LaMorte, 2019; Sundstrom et al., 2015). The rationale for using HBM for this study was also explained in this section. First, because this study uses secondary screening data, and second because HBM constructs such as perceived susceptibility and perceived severity (Janz & Becker, 1984; Glanz et al., 2008 ) can be mapped respectively a) to childhood lead exposure risk factors such as living in older houses (Hauptman et al., 2017; HUD, 2011), b) and the to the negative effect of lead exposure on children’s academic performance (He et al., 2019; Yeter et al., 2020).

In the second section, I described the physical and chemical properties that make lead attractive to many industries. Lead has low electrical conductivity, high malleability, and is highly resistant to corrosion (Wani et al., 2015). Despite heavy regulations, lead continues to be ubiquitous in US household and consumer products (EPA, 2020).

The human health problems associated with lead exposure were addressed in the fourth section of this chapter. Evidence of lead toxicity is well documented with much of the toxicity associated with distortion of the cell membrane, DNA, enzymes, and other structural proteins due to its ability to mimic or compete with calcium (Wani et al., 2015). The effect of lead on children is however most concerning because lead affects children's brain development (Sorensen et al., 2019; Reuben et al., 2017), their academic performance (He et al., 2019; Reuben et al., 2017 and their future earnings (Mayan, 2019, Council on Environmental Health, 2017).

The routes of exposure section show that ingestion and inhalation are the two most common ways lead get into the body (Carrel et al., 2017; Wani et al., 2015; Yeter et al., 2020). This section also showed that children are most at risk of lead exposure because they have rapidly developing and remodeling bones and this allows the lead to be continuously reintroduced into the bloodstream (Wani et al., 2015; Yeter et al., 2020).

The source of lead exposure section shows that children can be exposed to lead from a variety of sources (Mayan, 2019), but the most widely cited including, lead paint on the interior on older building surfaces (Hauptman et al., 2017; Mayan, 2019). However, other sources such as lead from drinking water (Zahran et al., 2017), imported goods Newman, et al., 2015) and take-home lead from parents working in lead associated industries (El-Zahran et al., 2018, Newman et al., 2015) are often cited as well.

The lead risk factors section also indicates the existence of many risk factors for childhood lead exposure including the age of the house (HUD, 2011; Yeter et al., 2020) socioeconomic status of children (CDC, 2019a; Hauptman et al., 2017), as well as being immigrant or refugee (Hauptman et al., 2017).

In term of prevalence, the consensus is that the number of children exposed to in the US has been decreasing since but there is still about half a million children that are present with elevated blood level (AAP-CEH, 2016; Caldwell et al., 2017; Hauptman et al., 2017; Mayan, 2019). Besides estimation of the prevalence of EBLL in children depends on the reference level which has been changing at the national and state levels. This variation between states is cited as a limitation to an accurate national prevalence value of childhood lead exposure (AAP-CEH, 2016; Caldwell et al., 2017; Hauptman et al., 2017; Mayan, 2019).

The section on childhood lead exposure prevention shows two main strategies including one, primary prevention through environmental regulation and policies, and two, secondary prevention through blood lead screening and surveillance (Health Impact Project, 2017; Christensen et al., 2019). Since the early 1970s agencies such as EPA and HUD have enacted laws and policies that were widely accepted to have significantly reduced the prevalence level of childhood lead exposure in the US (Health Impact Project, 2017; Kennedy et al., 2027, 2014). Besides, the CDC has been providing guidance and recommendation about to best to screen children for lead exposure and what type of follow-up to provide to children diagnosed with EBLL (Christensen et al., 2019; Ettinger et al., 2019a; Mayan, 2019).

The CDC also funds a national childhood prevention program called CLPPP (CDC, 2020b). Thus, more than 60 states and local health departments, including the state of Indiana and Marion County public health department are partnering with the

CDC to prevent childhood lead exposure (CDC, 2020b), though operational activities of the CLPPP are mostly regulated by state laws (Raymond & Mary, 2017).

# Chapter 3: Research Method

This chapter includes a description of the research design, methodology, and strategy for handling internal and external validity threats as well as the ethical considerations of the study. The research design states the nature of the study and addresses how the research questions were connected to the design. The methodology provides information to enable replication of the study. The following topics are addressed in the methodology: study population, data source, sampling criteria, rationale for using sampling criteria, variables, and data analysis plan.

The dataset for this study came from the CLPPP, a CDC-funded nationally recognized program (CDC, 2020). CLPPP has been used in many national and state reports to describe the prevalence of childhood lead exposure (Ettinger, Leonard, & Mason, 2019, 2019; ISDH, 2018). The findings of the current study may be compared to previous reports about childhood lead exposure in the United States.

The ethical dimension of this study hinged on the fact that the study population included young children. Children are widely recognized as a vulnerable population because they are not competent to assign informed consent (Bagattini, 2019). For the current study, ethical considerations included parental consents and privacy. Strategies to ensure a higher level of ethical standards were discussed. These strategies included submitting the research documents to the institutional review board (IRB) of the MCPHD and Walden University.

## Research Design

This was a quantitative study with a retrospective cohort design. The data set for this study was extracted from records of the CDC-funded CLPP conducted in Marion County, Indiana, in 2018 and 2019. I applied a secondary analysis approach to case management and follow-up records of children diagnosed with EBLL in Marion County, Indiana, between January 2018 and December 2019 (see ISDH, 2017, 2018). The objective of the study was to answer the following research questions:

1. Is there a difference between blood lead level at baseline and blood lead level at post-case-management time?
2. Is there a difference between blood lead level at baseline and blood lead level at post-case-management time that may be modifiable by parental race, education, income, and zip code levels?
3. Can the difference between baseline and post-case-management be modified by the severity of the baseline blood lead level?

## Methodology

### Study Population

According to Frankfort-Nachmias and Nachmias (2008), content, context, and time frame of the study population should be stated to describe the study population. The target population for the current study included children in Marion County, Indiana, who were diagnosed with EBLL during the CDC-funded CLPPP and who were enrolled in case management and follow-up program. A major characteristic of this population was that they were considered the children at risk of lead exposure (Indiana Administrative

Code, 2007). The size of this population varied depending on the choice of the reference value. For example, in 2016 when the reference value was ≥ 5 µg/dL, the total number of children with EBLL in Marion County Indiana was 307, but in 2018 the reference value was ≥ 10 µg/dL and the number of children with EBLL dropped to 83 (ISDH, 2016, 2018). Presently the statute that regulates childhood lead poisoning prevention programs in Indiana mandates that case management and follow-up services start at BLL ≥ 5 µg/dL (ISDH, 2016, 2018). Therefore, I used a BLL of ≥ 5 µg/dL as a reference value for EBLL.

## Data Source

The data for this study consisted of children's blood lead test results collected in Marion County, Indiana, from January 1, 2018, to December 31, 2019. By regulation, all testing laboratories were to report their blood test results to the ISDH within 1 week (Indiana Administrative Code, 2007). ISDH maintains these test results in a database that is only accessible by authorized users to maintain the quality, integrity, security, and safety of the records. For the current study, the data were accessible through the MCPHD IRB process.

## Sampling Criteria

I used a convenience sampling method with the following criteria: (a) children with confirmed EBLL, (b) children age 6 or younger, and (c) children whose case management and follow-up had been completed.

## Rationale for the Sampling Method

Convenience sampling is appropriate in situations where data are collected from individuals in easily accessible locations such as schools and clinics. These locations are routinely visited to collect data on individuals as part of program implementation (Hedt & Pagano 2011). Most of the original data set for the current study had been collected on children in public schools, at Head Start program locations, during WIC visits, at day care centers, or during primary care physician office visits as part of the CLPPP implementation in Marion County, Indiana. Therefore, the use of a convenience sampling method for this study was fully justified.

## Justification of Sampling Criteria

The reason for using the first sampling criterion was that children may be tested multiple times, either using venous or capillary blood. However, many jurisdictions, including Marion County, Indiana, require a test result to be confirmed before making the diagnostic designation of elevated blood lead and subsequent case management (Indiana Administrative Code, 2007; Michel et al., 2020). However, the time to confirm an EBLL depends on the level of the initial blood tests (Mayans, 2019). Table 1 shows the CDC recommendations for test confirmation schedule, which were also adopted during the collection of the data set for this study.

**Table 1**

*CDC Recommendation for Venous Blood Lead Level Confirmation Schedule*

| Blood lead level (µg/dL) | Time to confirmation testing |
|---|---|
| ≥ 5 | 1 to 3 months |
| 10–44 | 1 week to 1 month |
| 45–59 | 48 hours |
| 60–69 | 24 hours |
| ≥ 70 | Urgently, as an emergency test |

The rationale for using the second selection criterion was that children less than 6 years old are widely reported to be the most vulnerable to lead exposure. The impact of lead exposure on this segment of the population has been associated with a long-term effect on children’s health, development, and academic performance (Hauptman et al., 2017; Mayans, 2019; Sorensen et al., 2019). The analysis of a data set limited to younger children’s blood lead content may yield useful evidence that could be integrated into future lead exposure prevention.

The rationale for using the third sampling criterion was that there are two outcomes for children enrolled in case management: case-completed and administratively closed case children. Case-completed refers to a child who has at least two consecutive blood lead test results lower than the reference value within 6 months. An *administratively closed case* is one in which a child enrolled in a case of management program has moved to another county or state (Indiana Administrative Code, 2007). The use of the third sampling criterion restricted the data set for this study to contain only case-completed children. Most public health jurisdictions follow the CDC recommendation or establish their specific follow-up schedule for case management of EBLL (Michel et al., 2020). Table 2 shows the follow-up schedule for EBLL in Marion County, Indiana.

**Table 2**

*Schedule for Follow-Up Blood Lead Testing in Marion County IN*

| Venous blood lead level (µg/dL) | Early follow-up for two to four tests after identification | Later follow-up, after blood lead levels declining |
|---|---|---|
| 5 to 9 | 3 months | 6 to 9 months |
| 10 to 19 | 1 to 3 months | 3 to 6 months |
| 20 to 24 | 1 to 3 months | 1 to 3 months |
| 25 to 44 | 2 weeks to 1 month | 1 month |
| ≥ 45 | As soon as possible | As soon as possible |

*Note*. Adapted from MCPHD (n.d.).

## Variables

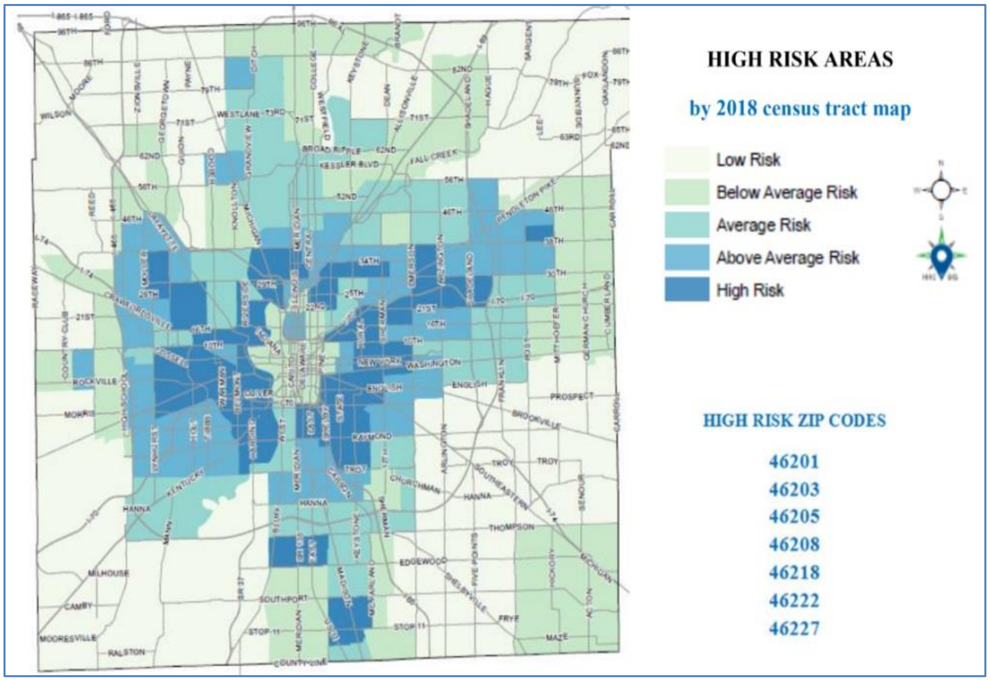
The dependent variable in this study was children’s BLL in micrograms per deciliter (µg/dL). Blood lead measurements can be obtained from capillary or venous blood specimens (CDC, 2019a). In Marion County, Indiana, one measurement from a venous blood specimen is sufficient to confirm an EBLL status. However, an EBLL from capillary blood needs to be confirmed by a subsequent EBLL from a venous blood lead test or two consecutive capillary blood lead tests carried out within a maximum of 2-week period (Indiana Administrative Code, 2007). The independent variables include the following:

- the severity of BLL at baseline,
- post-case-management time,
- parental education,
- parental race,
- parental income, and
- children’s zip code.

Severity at baseline, post-case-management time, and zip code were coded as ordinal variables. Severity at baseline had four levels corresponding to the blood groups described in Table 1. Post-case-management time had five levels matching the follow-up schedule described in Table 2.

**Figure 1**

*Lead Risk Level of Marion County, IN Zip Codes*



*Note*. Adapted from MCPHD (n.d.).

MCPHD (n.d.) established lead exposure risk levels for each zip code in the county (see Figure 1). This map was used to group children's BLL measurements in three categories:

- high lead risk zone,
- medium lead risk zone, and
- low lead risk zone.

Parental race and ethnicity, education, and income were nominal variables. Race and ethnicity had four levels:

- Black,

- White,
- Hispanic (people of Spanish origin), and
- other (subject not represented by Black, White, or Hispanic).

Parental education was coded in four education levels:

- below high school level,
- high school graduates,
- college graduate, and
- other (parents whose education does not fit in Education Level 1, 2, or 3)

Parental income had two levels:

- Medicaid and
- non-Medicaid.

## Data Analysis Plan

Data analysis will be performed with SPSS version V27 (IBM, n.d.). Before analysis, the dataset will be cleaned to ensure that incomplete records, unknown values, and duplicate records are removed. Also, missing data will be handled following SPSS default settings (IBM, n.d.).

There will be two stages of statistical analysis. First, a descriptive analysis will be performed to generate the measures of central tendency and measures of dispersion of the dataset (Daniel & Cross, 2013; IBM, n.d). This will include the calculation of the mean, median, mode, and standard deviation (SD) of children's blood lead measurements. These statistics will be stratified study subject socioeconomic factors such as race, gender, and parental education level. The second level of analysis will involve inferential statistics including simple *T-TEST*, *ANOVA*, and *Multiple Linear Regression* (MLR) (Daniel & Cross, 2013; IBM, n.d). These inferential statistics techniques will help to answer research questions 1, 2, and 3 respectively. However, before executing these statistical techniques, a diagnostic analysis will be performed to verify that the assumptions of each inferential statistical technique are met. If assumptions were not met, then appropriate alternative methods will be used. For example, the Kruskal-Wallis be a non-parametric alternative to the ANOVA if assumptions were not met. Also, the *Mann-Whitney U test* will be used in case children's blood lead measurements are not normally distributed (Daniel & Cross, 2013; Lund Research, 2013).

## Threats to Validity

Two types of validity, including internal and external validity, are frequently addressed in most research studies (Szklo & Nieto, 2019). Internal validity refers to the degree to which the study will achieve what it is intended to achieve. External validity refers to the generalizability of the result to the general population from which the study subjects were taken (Smith et al., 2011; Szklo & Nieto, 2019).

Internal validity can be threatened by many factors, including errors in measurement and selection of the study participants (Patino, & Ferreira, 2018). In terms of measurement errors, it is important to mention that the blood lead values in this study were measured following both CDC, state, and local health department protocols. Also, only CLIA-certified laboratory test results are included in the dataset (410-IAC-29). Besides, the CLPP data has been widely used in various research reports as evidence of its validity to accurately represent childhood blood lead levels (Egan et al., 2019; Hauptman, et al., 2017).

External validity can be is affected by the characteristic of the population on whom the findings of the research are expected to apply as well as by the nature of the study design (Khorsan & Crawford, 2014). In terms of design, it is important to mention that secondary data analysis is inherently prone to weaker generalizability because the intent of the original data collection may not much the analytical approach of the second author (Chalamandaris et al., 2016). One strategy to limit the threat of internal and external validity is to narrow the eligibility or inclusion criteria during sampling (Khorsan & Crawford, 2014).

## Ethical Factors

Institutional Review Board (IRB) approval was obtained from Walden University prior to the accessing and analysis of the data. The Walden University IRB approval number for this study is 04-12-21-0761141. This study is about children, a generally considered vulnerable population because they do not have the intellectual and emotional capacities to give valid informed consent (Bagattini, 2019). Moreover, the original dataset that contains children blood lead measurements also contains the following information: children’s full name, date of birth (DOB), gender, full address, county of residence, race and ethnicity, parent or guardian’s name and phone number, and information required to receive federal funding (ISDH, 2017; 2018). These are individually identifiable information that misuse could lead to HIPPA violations (HIPPA

Journal, 2018). These considerations imply extra vigilance and caution to protect children and parents' privacy and avoid causing children some harm (Bagattini, 2019).

This study will take the following steps to minimize the risk of ethical issues. One step is to obtain Institutional Review Board (IRB) approval from both Walden University as well as from the Marion County Public Health Department. The second step is to apply the principle of both *Safe Harbor* and *Expert Determination* (HIPPA Journal, 2017). Applying the *Safe Harbor* will consist of de-identifying children in the study dataset by removing selected information such as full name, DOB, full address, parent, and guardians' contact information. Applying the *Expert Determination* strategy will consist of obtaining an opinion from a statistical expert at Walden University.

Age, gender, and zip code will however be used with caution because they are relevant to answer the research questions. But zip codes with less than 5 elevated blood level records will be excluded to avoid violation of the principle of Protected Health Information [PHI] (HIPPA Journal, 2018).

## Summary

This study is designed as a quantitative retrospective cohort research with a convenient sampling technique. It is essentially a secondary analysis of data from the CLPP conducted in Marion County, IN. from January 1, 2018, to December 31st, 2019. CLPP is a nationally recognized program and its data have been wildly used to describe the prevalence of lead exposure across the US (Egan et al., 2019; Hauptman, et al., 2017). I believe that the popularity of this CLPP program contributes to the validity of the data set in this study.

In the methodology section, I detailed many important research elements including the study population, the sampling strategy, the variables, and the data analysis plan. In terms of the study population, this research works is about children who had confirmed EBLL in Marion County, IN., during the 2018 and 2019 CLPP and when using a reference blood lead level of ≥5µg/dL (ISDH, 2017; 2018).

The dependent variable is children's blood lead content in micrograms per deciliter (µg/dL). The independent variables include 1) severity of blood lead level at baseline, 2) post-case management time, 3) parental education 4) race and ethnicity, 5) parental income, and 6) zip code. The following inferential statistics will be used for answering the research questions: simple T-TEST, ANOVA, and Multiple Linear Regression (MLR). For each of these parametric methods, I plan an alternative non-parametric approach if the data fail to conform to the assumption of the parametric method (Daniel & Cross, 2013; Lund Research, 2013).

In this study, ethical questions are related to parental consent and confidentiality of children's identity (Bagattini, 2019). To respect these ethical considerations this study will seek Institutional Review Board (IRB) approval from both Walden University as well as from the Marion County Public Health Department. Also, data that can potentially be used to identify a study subject will be removed. For example, zip codes with less than 5 records will be excluded (HIPPA Journal, 2017; 2018). I believed that this detailed description of the methodology will allow this study to be replicated if needed.

# Chapter 4: Results

Childhood lead poisoning continues to be a public health problem in many communities in the United States (Mayans, 2019). In Marion County, Indiana, children diagnosed with EBLL (≥ 5 µg/dL) are provided case management and follow-up services including (a) home inspections by a state-certified lead inspector; (b) education for parents and guardians about lead hazards and the importance of good nutrition for the prevention and treatment of lead exposure; and (c) referring children to social programs that provide additional help for improving child health, nutrition, and education (Delgado et al., 2018; Michel et al., 2020). However, researchers had not evaluated the effectiveness of these services in bringing children's BLL below the reference level of 5 µg/dL in Marion County, Indiana. The purpose of the current study was to fill that gap. I sought to answer three questions: (a) Is there a difference between blood lead level at baseline and blood lead level at post-case-management time? (b) Is there a difference between blood lead level at baseline and blood lead level at post-case-management time that may be modifiable by race, zip code of residence, or poverty level? and (c) Can the difference between baseline and post-case-management be modified by the severity of blood lead content at baseline?

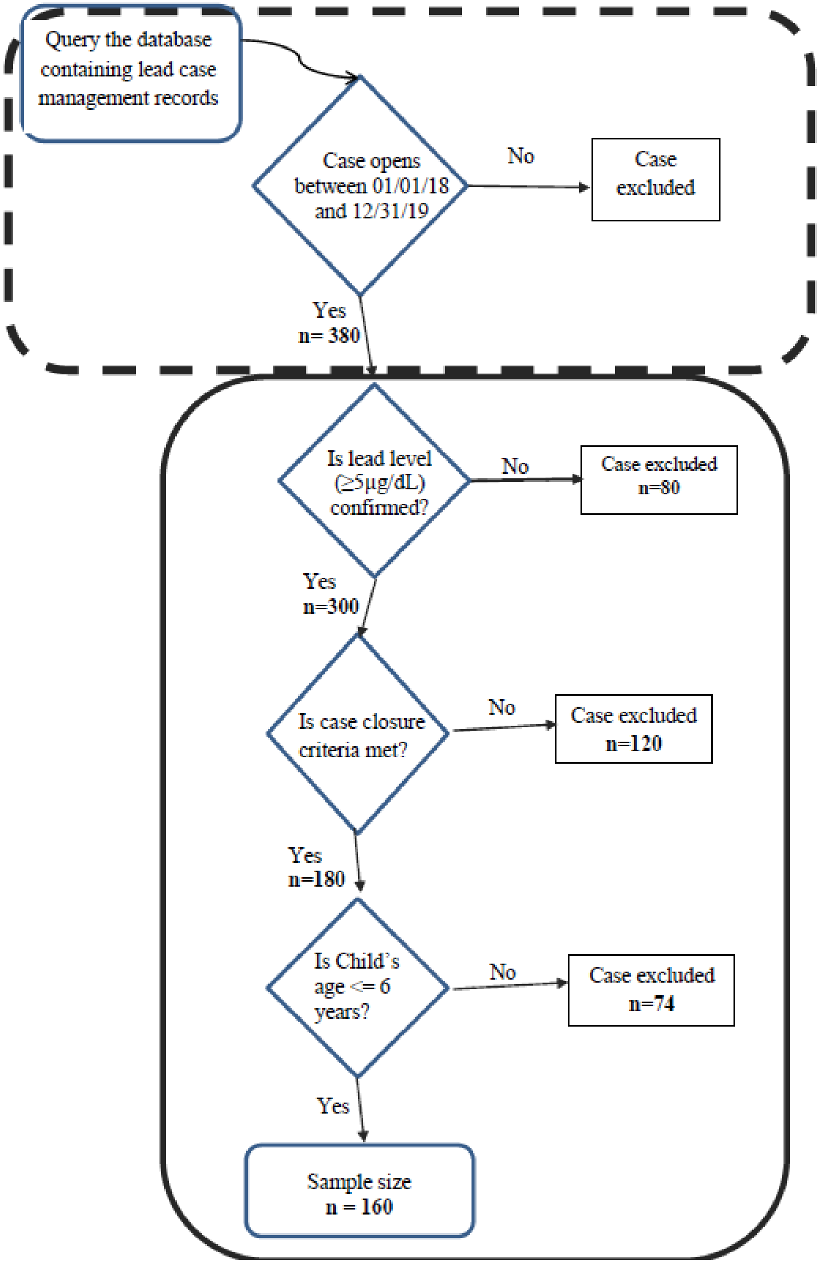
To answer these questions, I analyzed childhood lead case management records from Marion County, Indiana, for the period between January 1, 2018, and December 31, 2019. In this chapter, I explain the data extraction process and the sample subjects' inclusion–exclusion criteria. I also describe the independent and dependent variables. In addition, I present the results of the test the normality assumption of the variables and provide descriptive statistics of the variables. I used appropriate inferential statistical methods to answer each research question. Finally, I use tables and graphs to summarize the results of these statistical methods.

# Data Collection

## Data Extraction

**Figure 2**

*Flowchart of the Inclusion–Exclusion Process*



The data used in this research were accessed in two steps as shown in Figure 1. First (broken line) the database that hosts blood lead exposure case management records was queried to obtain cases that were opened and closed between January 1, 2018, and December 31, 19. Second (solid line), each case was subsequently queried, and the inclusion–exclusion criteria were applied.

### Inclusion–Exclusion Criteria

A case was excluded from the study if any of the following were not satisfied: (a) the age of the subject was less than or equal to 6 years, (b) the case was confirmed by a venous blood test or by two successive capillary blood tests, and (c) the case was closed with the comment “met closure criteria.” A total of 380 cases were opened between January 1, 2018, and December 31, 2019. At the end of this two-step process, the final sample size for this study was 160 cases.

## Variables

The dependent variable in this study was the children’s blood lead content (blc) in microgram per deciliter (µg/dL). Blc was measured as a continuous variable with one decimal level. The independent variables included (a) post-case-management time (checkup), (b) severity of lead exposure at baseline (severity), (c) the lead risk status in zip code of residence (risk), and the poverty status (Medicaid) of the child at the time of registration for case management. The variable checkup was recorded on an ordinal scale. It represented the number of times a subject had a blood test during their case management follow-up. Therefore, the level of variable checkup varied by subject. Most subjects (94.4%) had three checkups while a small number (5.6%) had four checkups during the case management.

The severity variable was also recorded as an ordinal variable with two levels including Severity Level 1 (blood lead content ≤ 9 µg/dL) and Severity Level 2 (blood lead content between 10 and 44 µg/dL). Variable risk was on an ordinal scale with three levels: (a) high lead risk zip code (*High risk*), medium lead risk zone (*Medium risk*), and low lead risk zones (*Low risk*). Variable poverty was measured on a nominal scale with two levels: (a) Yes = Medicaid and (b) No = non-Medicaid. Race, age, and gender of the subjects were recorded as covariates. In this study, race had four groups: Asian, Black, Latino, and White. Age had three groups: <1 year, 1–3 years, and 4–6 years. Gender had two groups: male and female.

**Table 3**

*Descriptive Statistics of Blood Lead Level at Baseline*

| | | Arithmetic statistics | | | Geometric statistics | | |
|---|---|---|---|---|---|---|---|
| Covariates | *N* (%) | Mean | *SD* | Median | Mean | *SD* | Median |
| Age (year) | | | | | | | |
| < 1 | 8 (5%) | 8.6 | 3.8 | 8.0 | 8.0 | 1.4 | 8.0 |
| 1–3 | 128 (80%) | 8.3 | 3.4 | 7.0 | 7.7 | 1.4 | 7.0 |
| 4–6 | 24 (15%) | 8.1 | 3.1 | 7.5 | 7.6 | 1.6 | 7.4 |
| Gender | | | | | | | |
| Female | 72 (45%) | 8.3 | 3.5 | 7.0 | 7.7 | 1.4 | 7.0 |
| Male | 88 (55%) | 8.3 | 3.2 | 8.0 | 7.7 | 1.4 | 8.0 |
| Race | | | | | | | |
| Asian | 30 (19%) | 7.2 | 2.6 | 6.0 | 6.8 | 1.3 | 6.0 |
| Black | 44 (27%) | 7.8 | 2.6 | 7.0 | 7.3 | 1.3 | 7.0 |
| Latino | 49 (31%) | 9.2 | 3.5 | 8.0 | 8.5 | 1.4 | 8.0 |
| White | 37 (23%) | 8.7 | 4.2 | 7.0 | 7.9 | 1.5 | 7.0 |
| Zip code | | | | | | | |
| High risk | 101 (63%) | 8.6 | 3.4 | 8.0 | 8.0 | 1.4 | 8.0 |
| Medium risk | 21 (13%) | 8.2 | 3.9 | 7.0 | 7.6 | 1.4 | 7.0 |
| Low risk | 38 (24%) | 7.5 | 2.9 | 6.5 | 7.1 | 1.4 | 6.4 |
| Medicaid | | | | | | | |
| Yes | 98 (61%) | 8.6 | 3.3 | 8.0 | 8.0 | 1.4 | 8.0 |
| No | 62 (39%) | 7.7 | 3.3 | 6.6 | 7.2 | 1.4 | 6.4 |
| Severity | | | | | | | |
| ≤ 9 µg/dL | 121 (76%) | 6.7 | 1.6 | 6.0 | 6.6 | 1.2 | 6.0 |
| 10 to 44 µg/dL | 39 (24%) | 13.1 | 2.8 | 12.0 | 12.8 | 1.2 | 12.0 |

## Frequency Distribution

Table 3 shows descriptive statistics of the dependent variable blc stratified by covariates. Considering age, children between the ages of 1 year and 3 years constituted 80% of the cases. Children between the ages of 4 years and 6 years represented 15% of the sample while children less than 1 year old represented 4% of the sample.

Considering gender, most cases (55%) were male compared to 45% female. In terms of race, Latinos accounted for most of the cases (31%), followed by Blacks (27%), Whites (23%), and Asians (19%). Considering zip code of residence, most cases (63%) came from zip codes with high lead risk. Low lead risk zip codes and medium lead risk zip codes accounted for 24% and 13% of the cases, respectively.

Table 3 also indicates that 76% of cases were Severity Level 1 (baseline blood lead content ≤ 9µg/dL) while the remaining 24% of cases were Severity Level 2 (baseline blood lead content between 10 and 44 µg/dL). In addition, stratification by poverty level indicated that up to 61% of children qualified for Medicaid at the time of registration of case management.

## Blood Lead Content

Table 3 shows that children below the age of 1 year had the highest geometric mean BLL (8.0 µg/dL) compared with the other age groups. Males and females showed no difference in terms of mean BLL. Each group had a geometric mean BLL of 7.0 µg/dL. The difference in blood lead content between racial groups was more pronounced. The Latino group had the highest geometric mean BLL (8.5 µg/dL) followed by Whites (7.9 µg/dL), Blacks (7.3 µg/dL), and Asians (6.8 µg/dL), respectively. Zip code variable also showed clear differences in terms of mean BLL. Children living in zip codes with high lead risk had geometric mean blood lead content of 8.0 µg/dL compared with 7.6 µg/dLfor medium lead risk zip codes and low lead risk zip codes (7.1 µg/dL). In respect to the poverty variable, Table 4 shows that Medicaid-eligible children had a higher geometric mean of blood lead content (8.0 µg/dL) compared with children who were not Medicaid eligible (7.2 µg/dL).

**Table 4**

*Descriptive Statistics of Blood Lead Level at Baseline and Post-Case-Management Checkup*

| | | Arithmetic statistics | | | Geometric statistics | | |
|---|---|---|---|---|---|---|---|
| Baseline and post-case-management time | *N* | Mean (µg/dL) | *SD* | Median (µg/dL) | Mean (µg/dL) | *SD* | Median µg/dL |
| Baseline | 160 | 8.3 | 3.4 | 7.5 | 7.7 | 1.4 | 7.0 |
| First checkup | 160 | 7.2 | 2.8 | 4.0 | 4.4 | 1.7 | 4.0 |
| Second checkup | 76 | 6.5 | 2.0 | 4.0 | 4.4 | 1.4 | 4.0 |
| Third checkup | 32 | 5.5 | 1.3 | 4.0 | 3.8 | 1.4 | 4.0 |
| Fourth checkup | 10 | 3.3 | 1.1 | 3.0 | 3.0 | 1.6 | 4.0 |

Table 4 shows descriptive statistics of the dependent variable blc at baseline and at post-case-management time (*checkups*). As expected, the mean BLL at baseline (before case management started) was the highest (geometric mean =7.7µg/dL) while the mean blood lead content at the fourth checkup (geometric mean = 3.0 µg/dL) was the lowest.

**Table 5**

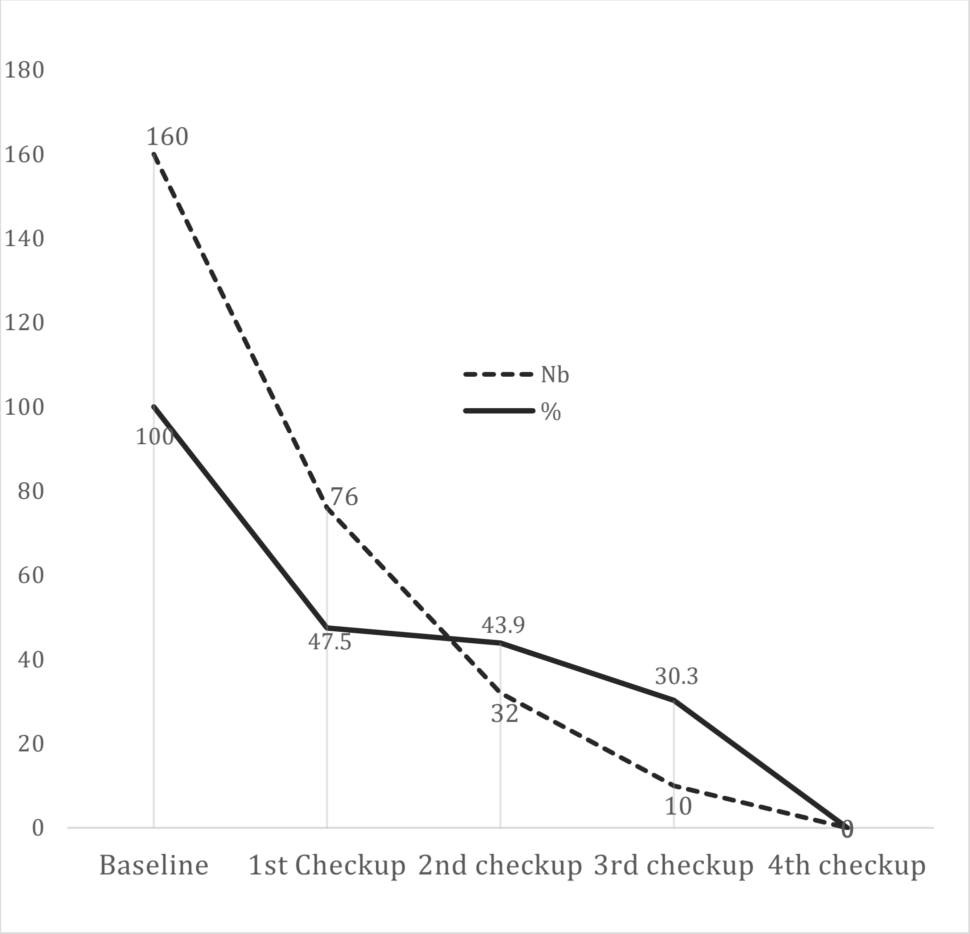
*Prevalence of EBLL at Baseline and at Post-Case-Management Checkup*

| Post case management time | EBLL$^+$ | | EBLL$^-$ | |
|---|---|---|---|---|
| | N | % | N | % |
| Baseline | 160 | 100 | 0 | 0 |
| 1st checkup | 76 | 47.5 | 84 | 52.5 |
| 2nd checkup | 32 | 43.7 | 44 | 56.3 |
| 3rd checkup | 10 | 30.3 | 22 | 69.7 |
| 4th checkup | 0 | 0.0 | 10 | 100 |

Table 5 shows that 52.5% of children diagnosed with [EBLL] recovered by their 1st checkup time after going through case management intervention (EBLL =52.5%). By the 3rd checkup, 94 % [(160-10)/160) *100)] of the children got their blood lead level below the reference level of 5.0 µg/dL. Only a relatively small percentage (about 6%) of children had to get to their 4th checkup before their blood lead level drop below the reference value of 5.0 µg/dL. These trends are graphically represented in Figure 3 where Nb represents the number of children at each checkup and % represents the percentage.

**Figure 3**

*Trend of the Prevalence of EBLL at Baseline and Post-Case-Management Checkup*



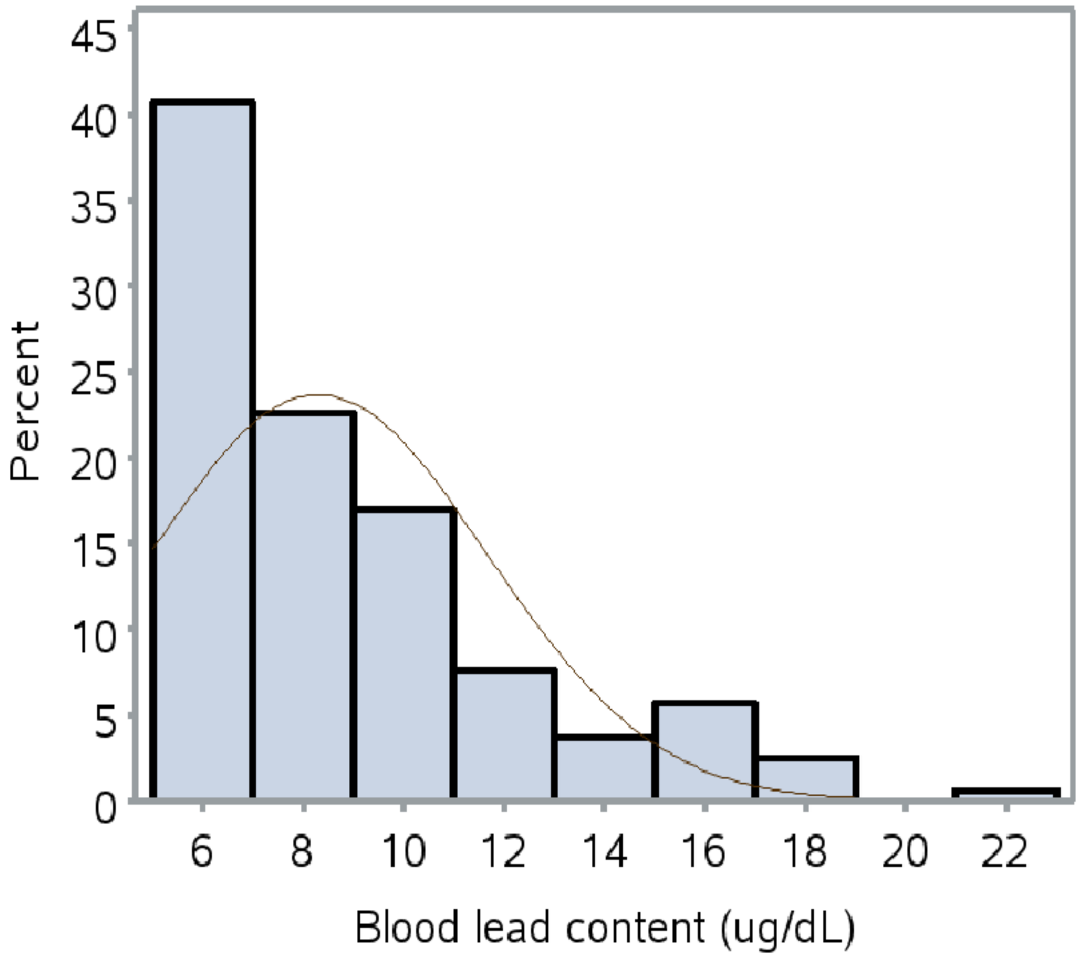
## Inferential Statistics

### Normality Assumption

Checking for normality assumption is a critical step in the choice of appropriate statistical methods for research data. For example, if a variable is normally distributed then many parametric methods such as ANOVA, t-test, or regression analysis can be applied to the variable. However, if the normality assumption is violated, non-parametric methods might be a more appropriate analytical approach (Daniel & Cross, 2013; Frankfort-Nachmias & Nachmias, 2008).

**Figure 4**

*Histogram and Normal Distribution Curve of Blood Lead Content*



Checking for normality of variable can be achieved through a combination of graphical and numerical methods including histogram, normal curve, and Kolmogorov-Smirnov (D) or Cramer-von Mises (W-Sq) test statistics. It is generally accepted that a normally distributed variable should have a bell shape curve with skewness and near-zero (Daniel & Cross, 2013; Frankfort-Nachmias & Nachmias, 2008).

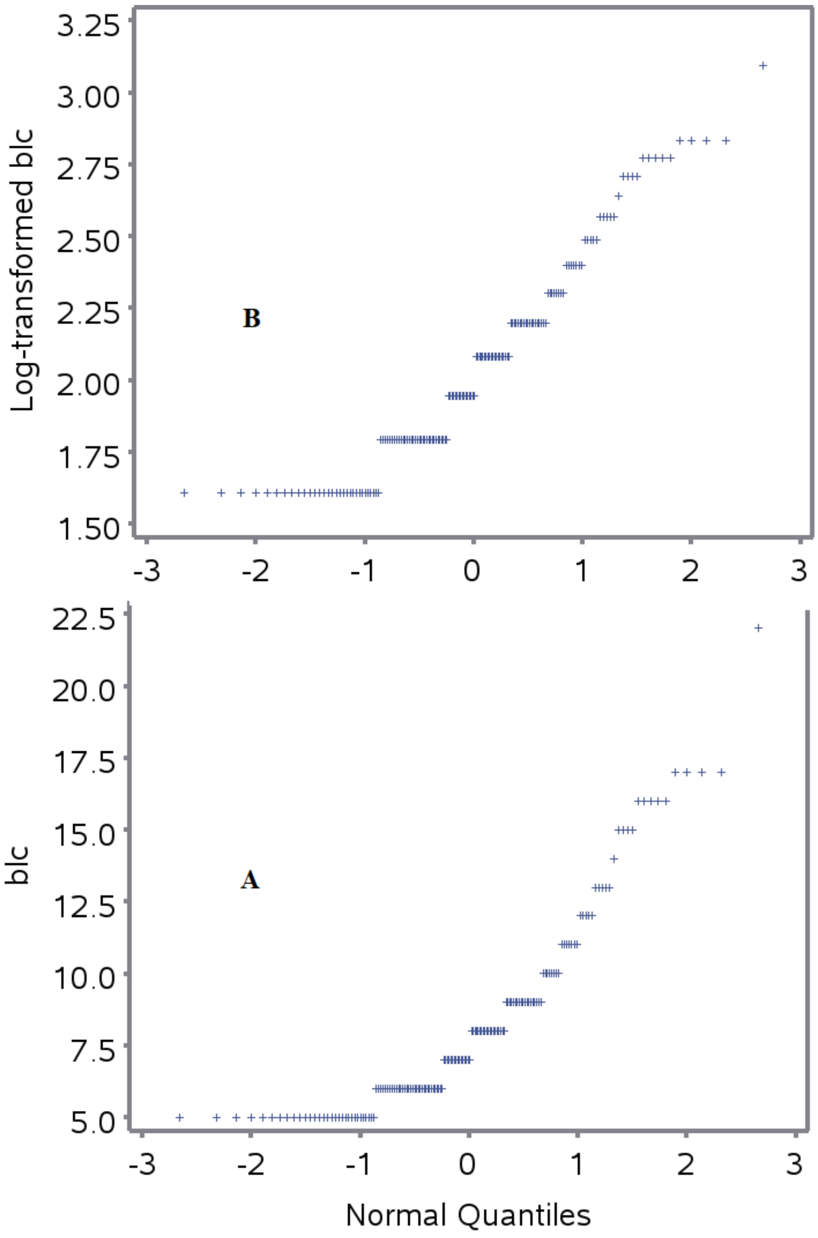
Figure 4 shows that the dependent variable for this study (*blc*) is not normally distributed. The normal curve over the histogram is highly skewed to the right (Skewedness =1.37) with a relatively large kurtosis (1.67). In addition, the goodness-of-fit tests (D and *W-Sq)* for normality distribution show p-values that are less than 0.05, which indicates a lack of normality (Daniel & Cross, 2013; Frankfort-Nachmias & Nachmias, 2008).

## Alternative Analytical Approach

Log transformation is a common approach to bringing research data to approximate normal distribution, particularly when the data is skewed to the right (Feng et al., 2014). However, even log transformation cannot bring the current research dataset to an approximately normal distribution as shown in Figure 5. The Normal Quintile Plot for both the original *blc* values (Figure 5a) and the log-transformed *blc* values (Figure 5b) remained skewed. Consequently, I will be using nonparametric methods to answer the research questions as suggested in Chapter 3.

**Figure 5**

*Normal Quantiles Plots for Variable blc (A) and Log-Transformed blc (B)*



## Research Question 1

The first research question in this study is: Is there a difference between blood level at baseline and blood lead level at post-case management time? The null hypothesis (*Ho)* and alternative hypothesis *(Ha)* at alpha = 0.05 probability level for this question follow.

- $H_o1$: there is not a statistically significant difference between blood lead level at baseline and blood lead level at post-case management time
- $H_a1$: there is a statistically significant difference between blood lead level at baseline and blood lead level at post-case management time

To test these hypotheses, I used the Wilcoxon and Kruskal-Wallis statistical methods (Daniel & Cross, 2013; Frankfort-Nachmias & Nachmias, 2008) to analyze the data, using *blc* as the dependent variable and *checkups* as the explanatory variable. The result of this analysis is shown in Table 6. and Figure 6.

**Table 6**

*Analysis of Variance of Blood Lead Content at Baseline and Post-Case-Management Checkup*

| LabTest | Sum of Scores | Expected under Ho | SD under Ho | Mean Score* |
|---|---|---|---|---|
| Baseline | 49784.50 | 34880.0 | 1255.63 | 311.15a |
| 1st checkup | 27725.00 | 34880.0 | 1255.63 | 173.28b |
| 2nd checkup | 12237.50 | 15914.0 | 973.09 | 167.67b |
| 3rd checkup | 4291.50 | 7194.0 | 689.45 | 130.04bc |
| 4th checkup | 791.50 | 1962.0 | 370.65 | 87.94c |

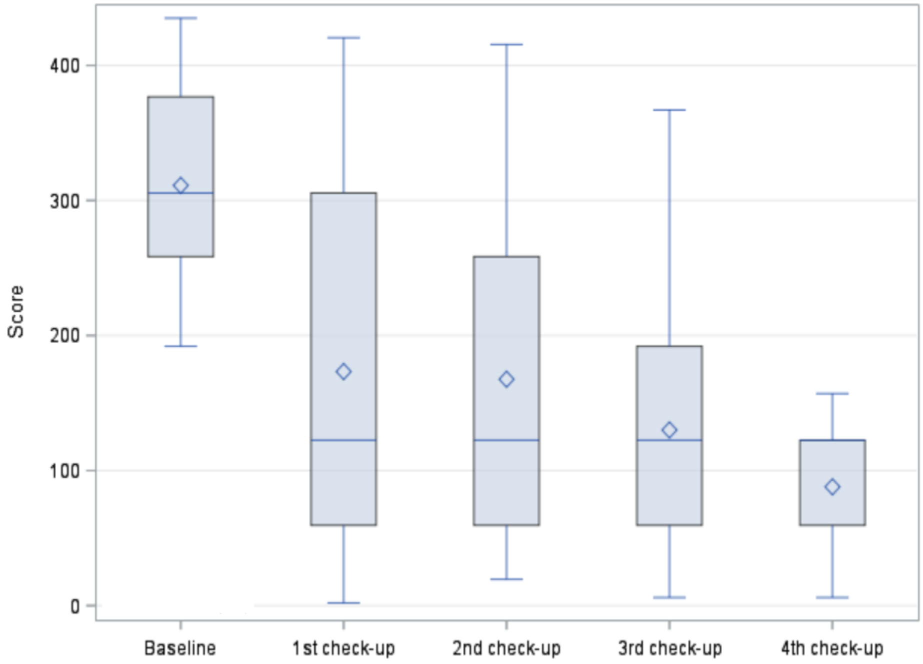
Kruskal-Wallis Test: $X^2 = 147.67$ *df=4* $p<0.0001$

*Scores followed by the same letter are not statistically different

Table 6 shows a statistically significant difference between scores of blood lead content at baseline and score of blood lead content at each check-up after case management was initiated as evidenced by significant Kruskal-Wallis test statistics ($X^2=147.62$, $df = 4$, $p <0.0001$). Thus, the null hypothesis (Ho) must be rejected, and the alternative hypothesis (Ha) must be accepted. In order words, there is enough statistical evidence to declare that case management activities have a significant effect on children blood lead level after they were diagnosed with EBLL.

**Figure 6**

*Box Plot of Mean Scores of blc at Baseline and Post-Case-Management Checkup*



The mean separation column in Table 4 and the graphical representation of the mean scores in Figure 6 suggest that there is a significant reduction in blood lead content between the baseline and the first post case management time (1st checkup time). However, the difference in blood lead content between 1st, 2nd, and 3rd checkups is not statistically significant. Also, blood lead content at the 4th checkup was not statistically significant from blood lead level at the 3rd checkup.

## Research Question 2

The second question for this research study is: *Is the change in blc between checkups associated with race, zip code lead risk status, or poverty?* The null hypothesis (*Ho)* and alternative hypothesis *(Ha)* for this question considering alpha = 0.05 probability level follow

- $H_o$2: the change of *blc* between *checkups* levels is not associated with subject race, zip code lead risk status, or poverty
- $H_a$2: the change between *blc* between *checkups* levels is associated with subject race, zip code lead risk status, or poverty

To answer this question, I analyzed the data using *blc* as a dependent variable and *checkups* as an explanatory variable while controlling independently for race, zip code, and poverty. As in research question one, I used the Wilcoxon rank transformed scores instead of the original blood content values because the original values were not normality distributed (Daniel & Cross, 2013; Feng et al. 2014; Frankfort-Nachmias & Nachmias, 2008).

### Race and Case Management

**Table 7**

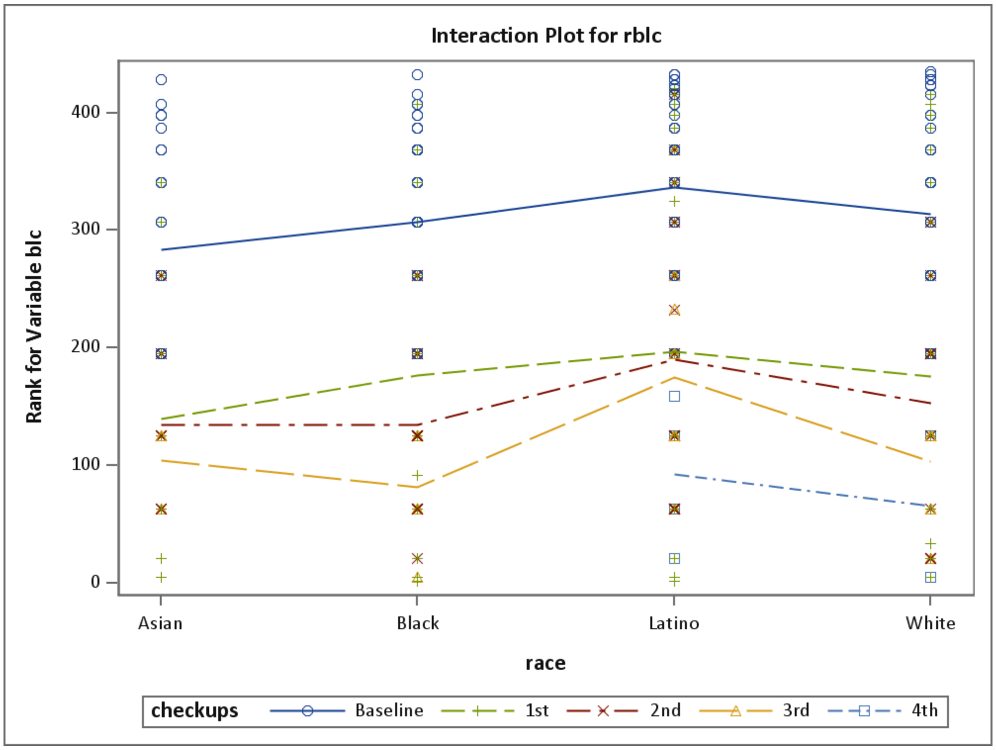
*Analysis of Variance for Race and Post-Case-Management Checkup Interaction*

| Source | DF | Type III SS | Mean Squares | F value | Pr > F |
|---|---|---|---|---|---|
| race | 3 | 73.468 | 24.489 | 3.21 | 0.0231 |
| checkups | 4 | 1266.734 | 316.683 | 41.48 | .0001 |
| race*checkup | 10 | 18.364 | 1.836 | 0.24 | 0.990 |

Table 7, Figure 7, and Table 8 are about the part of research question two which is related to the effect of race on the outcome of case management. Table 7 shows that there is a statistically significant difference between r*ace* levels, but there is no statistically significant interaction between r*ace* groups and *checkup* levels (Figure 7).

**Figure 7**

*Interaction Plot Between Race and Post-Case-Management Checkup*



It appears that each race group has experienced a significant drop in blood lead content between the baseline level and the first blood check-up after case management was initiated. However, the Latino group appears to lag behind other racial groups when comparing blood lead reduction between 1st, 2nd, and 3rd checkups (Figure 7, Latino). In addition, Figure 7 shows that the Latino and White groups are the only ones that reached the 4th check-up stage before the blood content fell below the reference level of 5 µg/dL. Interestingly, Figure 7 shows that children of Asian and Black racial groups recovered from EBLL by their 3rd checkup.

**Table 8**

*Means (*µg/dL) *Blood Lead Content per Race*

| Race | N | Mean* | SD |
|---|---|---|---|
| Latino | 143 | 6.6a | 5.5 |
| White | 102 | 6.1ba | 3.8 |
| Black | 117 | 5.8ba | 2.8 |
| Asian | 73 | 5.3b | 2.5 |

*Mean followed by the same letter are not statistically different

Table 8, show that the highest (6.6 µg/dL) and lowest (5.3 µg/dL) means for blood lead content occurred in Latino and Asian groups, respectively. The blood lead content of Whites (6.1 µg/dL) and Blacks (5.8 µg/dL) are not statistically different.

## Zip Code and Case Management

**Table 9**

*Analysis of Variance for Zip Code and Post-Case-Management Interaction*

| source | DF | Type III SS | Mean Squares | F value | Pr > F |
|---|---|---|---|---|---|
| zip code | 2 | 90292.245 | 45146.123 | 4.60 | 0.0106 |
| checkups | 4 | 1764246.400 | 441061.600 | 44.92 | .0001 |
| zip code *checkups | 6 | 32358.407 | 5393.068 | 0.55 | 0.770 |

**Table 10**

*Means(µg/dL) of Blood Lead Content per Zip Code Risk*

| Zip code | N | Mean* | SD |
|---|---|---|---|
| High lead risk | 290 | 6.2a | 3.3 |
| Medium lead risk | 54 | 5.7ba | 3.5 |
| Low lead risk | 91 | 5.4b | 3.0 |

*Mean followed by the same letter are not statistically different

**Figure 8**

*Interaction Plot Between Lead Risk and Post-Case-Management*

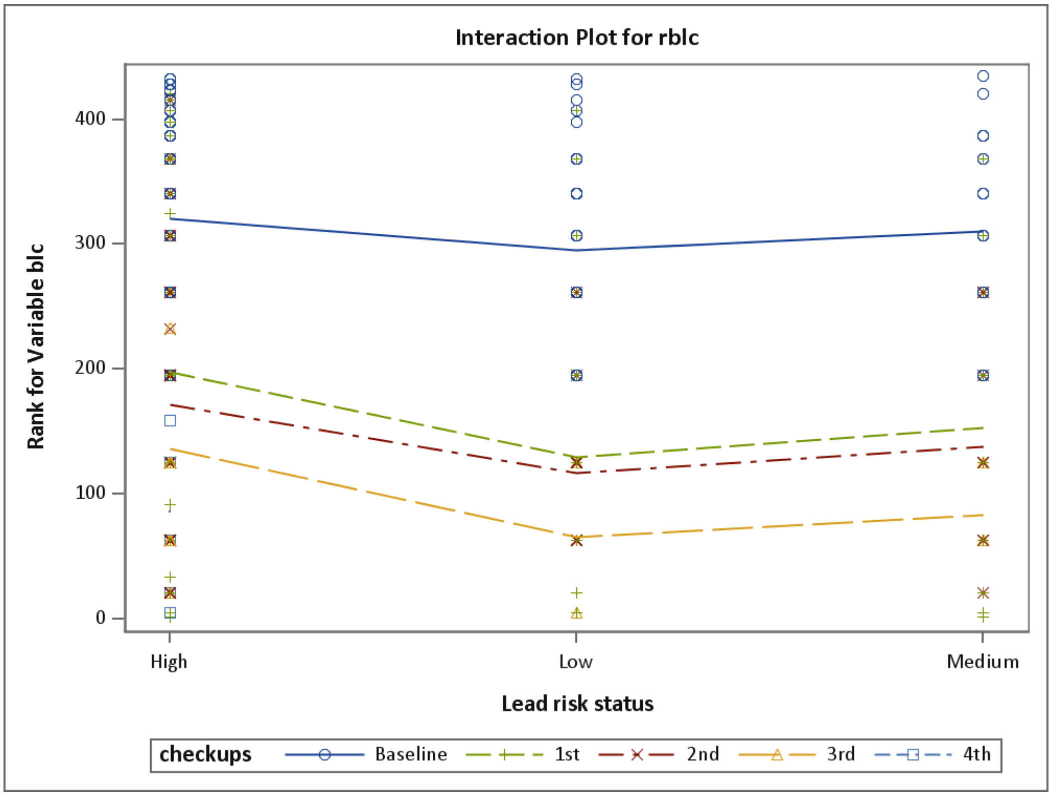


Table 9, Figure 8, and Table 10 are about the part of Research Question Two related to the effect of zip code lead risk status on the outcome of case management. Table 9 shows that zip code lead risk status has a statistically significant effect on blood lead content (f=*4.60, df= 2, p > 0.01*). However, there is no statistically significant interaction between lead risk status and checkup level as shown in Figure 8. As expected, zip codes with high lead risk levels scored the highest mean (6.2 µg/dL) blood lead level and low lead risk zip codes have the lowest mean (5.4 µg/dL) blood contents (Table 9).

## Poverty and Case Management

**Table 11**

*Analysis of Variance for Poverty and Post-Case-Management Interaction*

| Source | DF | Type III SS | Mean Square | F Value | Pr > F |
|---|---|---|---|---|---|
| poverty | 1 | 15390.684 | 15390.684 | 1.49 | 0.2231 |
| checkups*poverty | 8 | 2338926.275 | 292365.784 | 28.27 | <.0001 |

**Figure 9**

*Interaction Plot Between Poverty and Post-Case-Management*

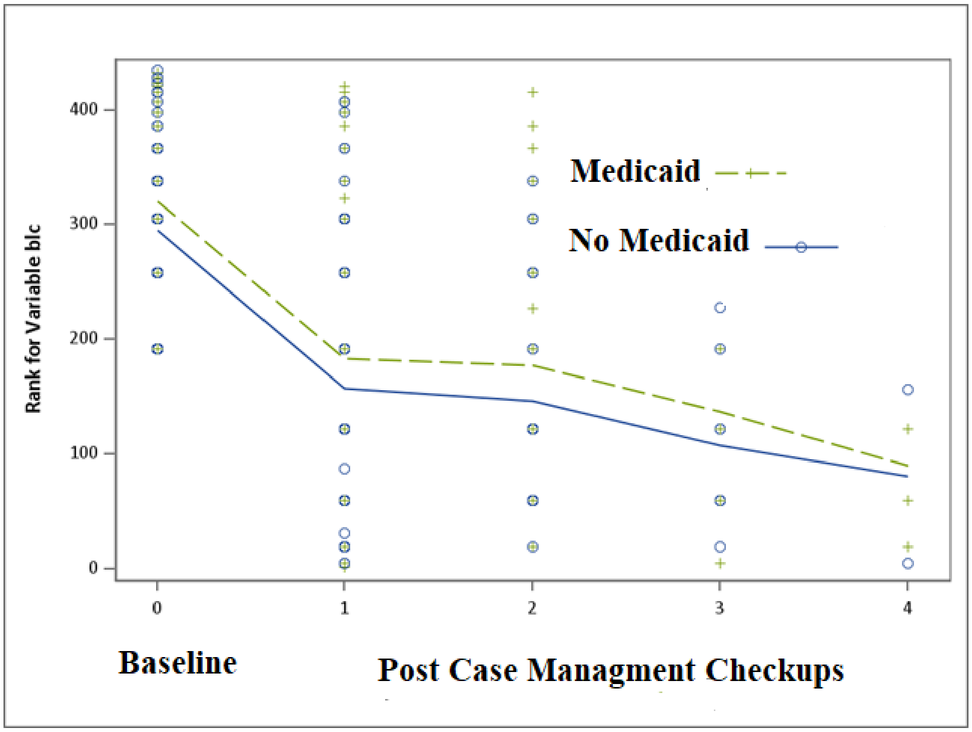


Table 11 shows that there is no statistically significant difference between Medicaid (poverty) levels. However, the interaction between Medicaid level and post case management levels is statistically significant as shown in Table 11 *(f = 28.27, df= 8, p<.0001)*. Figure 9 suggests that both Medicaid eligible and the non-Medicaid eligible group experienced a similar drop in their blood lead content between baseline and 1st checkup. But the slope of the Medicaid eligible line between the 2nd and 4th checkup appears to be more conspicuous compared with that of the non-Medicaid eligible line in the same period.

Results of Research Question Two show that race (Table 7, Figure 7) and zip code (Table 9, Figure 8) both affect the outcome of case management on blood lead content, but they do not have an interaction effect on the case management outcome. In contrast, poverty (Table 9, Figure 8) showed no significant differential effect on the mean blood lead content but showed an interaction effect on blood lead content.

## Research Question Three

The third question for this research study is: Can the difference between blood lead content at baseline and blood lead content at post-case management time be modified by the severity of the blood lead level at baseline? The null hypothesis (*Ho)* and alternative hypothesis *(Ha)* for this question considering alpha = 0.05 probability level follow

- $H_o3$: the difference between baseline blood content at baseline and blood level content at post-case management time is not associated with the severity of the lead level at baseline?
- $H_a3$: the difference between baseline blood content at baseline and blood level content at post-case management time is associated with the severity of the lead level at baseline?

To answer this question, I analyzed the data using *blc* as a dependent variable and *checkup* as an explanatory variable while controlling for the severity of blood lead at baseline. Here too, the analysis was carried out on the Wilcoxon rank transformed scores because the original values were not normality distributed (Daniel & Cross, 2013; Feng et al. 2014; Frankfort-Nachmias & Nachmias, 2008).

**Table 12**

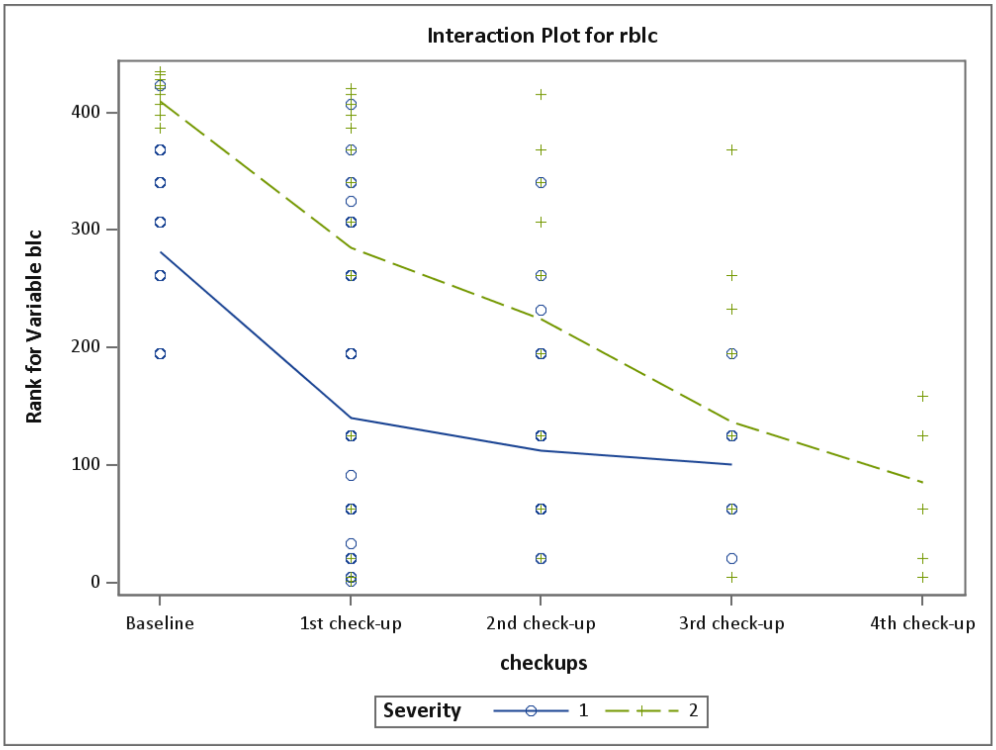
*Analysis of Variance for Severity at Baseline and Post-Case-Management*

| Source | DF | Type III SS | Mean Square | F Value | Pr > F |
|---|---|---|---|---|---|
| checkups | 4 | 2427374.247 | 606843.562 | 85.67 | <.0001 |
| severity | 1 | 639283.792 | 639283.792 | 90.25 | <.0001 |
| checkups*severity | 3 | 67031.951 | 22343.984 | 3.15 | 0.0248 |

The result of the analysis related to Research Question Three is shown in Table 12 and Figure 10. As expected, there is significant difference between severity at baseline ($f = 90.25, df = 1, p < 0.0001$). More interestingly, the interaction between *severity and checkups* variables are statistically significant ($f = 3.15, df = 3, p < 0.02$). This numeric interaction is graphically represented in Figure 10.

**Figure 10**

*Interaction Plot Between Severity at Baseline and Post-Case-Management*



Based on the statistical evidence shown in Table 12 and Figure 10, it is safe to reject the null hypothesis (Ho) which states that the difference between baseline and post-case management blood content is not modified by the severity of blood lead exposure baseline. In another word, the severity of lead exposure at baseline has an impact on the outcome of the case management.

Figure 10 shows that when the severity level is 1, the slope of the line between the 1st, 2nd, and 3rd checkup is modest. But when the severity level is 2 the slope of the line between the 1st, 2nd, and 3rd checkup is steep. In addition, Figure 9 shows that for severity level 1 case management follow lab test stops at the 3rd checkup while for severity level 2, case management follow labs continue to the 4th lab test. This indicates that the higher the level of lead at baseline, the longer the time it takes to bring blood lead level below the reference level of 5 µg/dL.

## Summary

This chapter presents the results of the statistical analysis to answer the three research questions. The result of research question 1 indicates that the difference in blood lead content between baseline and post-casement time ( Checkups) is statistically different, suggesting that case management can effectively help to bring children's blood level down to below the reference level of 5.0 µg/dL.

The result of the second research question indicates a statistical difference between race groups as well as between zip codes of residence in terms of children's blood lead content. However, neither race nor zip code has significant interaction with case management. The result of research question 3 shows that there is a significant interaction between blood lead severity at baseline and case management. This suggests the magnitude of change in blood lead content between baseline and 1st checkup is similar for children with both severity levels. However, this magnitude tends to shrink as the number of checkups increases.

# Chapter 5: Discussion, Conclusions, and Recommendations

Childhood lead exposure has been associated with decreased intelligence, behavioral difficulties, and learning problems in children (Mayans, 2019). In the United States, childhood lead exposure has been declining since early 1979 (American Academy of Pediatrics Council on Environmental Health, 2016; Hauptman et al., 2017). However, many communities in the United States continue to observe a high prevalence of childhood lead exposure. For example, in 2018 about 1.10% of children in Marion County, Indiana, had been diagnosed with EBLL (ISDH, 2018). In Marion County, Indiana, children diagnosed with EBLL were provided with case management services as a public health intervention. However, no study had addressed the effectiveness of these services for bringing children's BLL down to below the current reference level of 5 µg/dL.

In Chapter 4, I provided statistical evidence that case management is an effective intervention to control EBLL in children. In Chapter 4, I also showed a statistical association between post-case-management BLL and some socioeconomic factors such as race, zip code, and poverty. In Chapter 5, I interpret the results and provide contexts for a better understanding of the findings. I also compare the findings of this study to those reported by other researchers who conducted childhood lead exposure investigations. In addition, I discuss the limitations of the study, provide some recommendations, and describe the implications for positive social change. In the last section of this chapter, I present some concluding remarks by summarizing the main steps and the main finding of the study.

## Research Question 1

The first research question of this study addressed whether case management is an effective intervention to bring down children’s BLL below the reference level of 5 µg/dL. Analysis of the data as shown in Table 6 indicated that the mean rank score of BLL dropped from 311.15 at baseline to 87.94 at the fourth checkup of post-case-management time. Moreover, Table 4 shows a significant drop in the geometric mean of BLL from 7.7 µg/dL at baseline to 3.0 µg/dL at the fourth checkup of post-case-management time. These results provide evidence that case management was an effective intervention to control the prevalence of childhood EBLL in Marion County, IN.

These results also support findings by Bellings and Schnepel (2018) who analyzed the effect of case management services on elevated blood lead data of children in North Carolina. In their study, Bellings and Schnepel evaluated the impact of case management services using behavioral and educational outcomes, including antisocial behaviors and school educational performance. Bellings and Schnepel reported that antisocial behavior decreased by a 0.184 standard deviation relative to the control group. Bellings and Schnepel also reported a significant 0.117 increase in educational performance among children eligible for case management intervention. In the current study, I evaluated the impact of case management services using the numeric value of children’s blood lead content. Therefore, these two studies appear to complement each other, and together they provide strong evidence that case management is an effective intervention for children diagnosed with EBLL.

## Research Question 2

### Race, Ethnicity, and Case Management

The second research question of this study addressed whether the effect of case management intervention on BLL is modifiable by socioeconomic factors such as race, zip code, and poverty. In terms of race, Table 3 shows that 19% were Asians, 27% were Blacks, 31% were Latinos, and 23% were Whites. Analysis of the data as shown in Table 6 indicated a significant difference between these races with Latinos having the highest mean BLL (6.6 µg/dL), followed by Whites (6.1 µg/dL), Blacks (5.8 µg/dL), and Asians (5.3 µg/dL), respectively.

The results in this study, therefore, suggest that Latinos are at higher risk of childhood lead exposure compared with Asians, Blacks, and Whites in Marion County, Indiana. However, the review of the literature indicated that these findings are not consistent with previous findings (see CDC, 2013a; EPA, 2013), which suggests that being Black is a risk factor but being Hispanic is not a risk factor for lead poisoning. Findings reported by the EPA (2013a) and CDC (2013a) were observed from analysis of national survey data, which tend to mask local level population disparities.

On the other hand, the results of the current study are consistent with the notion that childhood lead exposure disproportionally affects the minority population as stated in Egan et al. (2021). Latinos and Asians represented, respectively, only 10.9% and 3.8% of the population in Marion County, Indiana (U.S. Census Bureau, 2019.). However, in the current study, Latinos and Asians disproportionately accounted for 19% and 31% of EBLL exposure, respectively.

Disparities in lead exposure can be explained by many factors including cultural factors (Trotter, 1990; WHO, 2010). The disproportionately higher EBLL exposure level observed in Latinos and Asians in the current study could be related to cultural and immigration status. Lead-glazed ceramics, lead-based traditional (folk) remedies, and contaminated spicy food have long been associated with childhood lead poisoning in immigrant populations (Welton et al., 2018). Ritchey et al. (2011) identified *Daw Tway*, a digestive folk remedy used by Burmese refugees, as a source of childhood lead exposure in Fort Way, Indiana.

## Poverty and Case Management

In the current study, 61% of the subjects were Medicaid-eligible children and 39% were non-Medicaid eligible. The high proportion of Medicaid-eligible children in this study was consistent with the notion that living at or below the federal poverty level is a risk factor for childhood lead exposure (CDC, 2019a). Also, Egan et al. (2021) observed higher geometric mean BLL in children with lower socioeconomic indicators, such as those with no health insurance, those receiving Medicaid, and those receiving WIC assistance.

The current study also showed a significant interaction effect between poverty and case management ($f = 28.27$, $df = 8$, $p < .0001$). Figure 8 shows that Medicaid eligible and non-Medicaid-eligible children experienced similar drops in their BLLs by the first checkup of post-case-management time (46.66% and 42.94%, respectively). However, Medicaid-eligible children experienced significantly higher drops in their BLLs than non-Medicaid-eligible children at the fourth checkup (34.31% and 24.67%, respectively). This finding can be explained by the fact that Medicaid-eligible children are required to have lead tests at regular intervals, and failure to conduct the lead test at an age-appropriate time may result in loss of revenue for the health provider and loss of insurance coverage for the family (Bruce et al., 2019).

Poverty affects childhood lead exposure in many ways such as limited access to quality health services (Lazar & Davenport, 2018) and quality homeownership (Lynch & Meier, 2020). Older and poorly maintained houses are well known to be potential sources of lead exposure (HUD, 2011; Yeter et al., 2020). Housing options for Latino and immigrants are limited to lower quality housing given their low incomes (PolicyLink, 2004).

## Zip Code and Case Management

In this study, subjects were grouped in three nominal zip code levels including *High Lead Risk* zip codes, *Medium Lead Risk* zip codes, and *Low Lead Risk* zip codes. Analysis of the data showed that 63% of the subject reside in *High Lead Risk* zip codes, 13% reside in *Medium Lead Risk* zip codes and 24% reside in *Low Lead Risk* zip codes. In addition, Table 8 shows a statistically significant difference between the mean BLL in children living *High Lead Risk* zip codes (6.2 µg/dL) and those living in *Low Lead Risk* zip codes (5.4 µg/dL). These results suggest that zip code of residence is a factor in childhood lead exposure in Marion County, Indiana. Similar findings have been reported elsewhere. For example, Egan et al. (2021) found that children born in Mexico consistently had higher geometric mean BLL compared with those born in the United States.

Analysis of childhood lead exposure along zip code lines is common (Gupta et al., 2018; Kaplowitz et al., 2010). Zip code level analysis may help to identify areas or communities for targeted interventions (Gupta et al., 2018). The use of zip code to explain blood lead exposure, however, depends on how the risk factor is coded. For example, data reported by Kaplowitz et al. (2010) indicated that census block is a better predictor of blood lead prevalence than zip code if the zip code variable is dichotomized.

## Research Question 3

The third research question of this study addressed whether the severity of lead exposure at baseline has a modifying effect on the case management outcome. In this study, the data were grouped into two severity levels: Level 1 (BLL ≤ 9 µg/dL) and Level 2 (BLL between 10 and 44 µg/dL). Analysis of the data showed that 76% of the subjects were Severity Level 1 and 24% were Severity Level 2. In addition, the severity of lead exposure at baseline had a significant effect on the outcome of the case management ($f = 3.15$, $df = 3$, $p < 0.02$). As seen in Figure 9, children in Severity Level 1 recovered from EBLL faster (by the third checkup) than those in Severity Level 2 (not until the fourth checkup).

These results suggest that the higher the blood level at baseline the longer the time to recovery. Similar findings have been reported in previous studies. For example, Roberts et al. (2001) measured the time it takes for blood lead content to decline in lead-poisoned children following case management intervention. Roberts et al. found that children with higher initial blood lead content take a longer time to reach below the desired reference level of 10 µg/dL compared to children with lower initial lead levels.

Similar findings were also reported by Keller et al. (2017) who applied the product-limit survival estimates to calculate the time from the first BLL ≥ 45 μg/dL until BLL declined to ≤ 10 μg/dL among lead-exposed children in New York City.

Blood lead has a lower half-life of just about 40 days in humans (Wani et al., 2015). Therefore, the longer time to recovery may not be solely due to high blood lead content. For example, the AAP (2016) remarked that if the source of the exposure is not removed from the children's environment, BLL may continue to rise or stagnate. In the present study, the source of lead in the children's environment had not been recorded, suggesting insufficient evidence to evaluate the effect of case management on the time it takes to bring children's BLL to below the reference level.

In another perspective, Schmidt (2017) remarked that the longer a child is exposed to lead, the longer the decline in BLL will take. In other words, even a relatively small BLL can take a longer time to decline if the child has been exposed to lead sources for a longer time. The reason is that lead may accumulate in bones and subsequently be released slowly in the bloodstream over the years (Wani et al., 2015). This can result in persistent elevations in BLL, even in the absence of further exposure (Schmidt, 2017). In addition, poor nutrition may also influence excretion rates. For example, iron and calcium deficiencies are known to increase the lead in the bloodstream (Kordas, 2017).

## Age and Gender

In this study, 55% of the subjects were male and 45% were female. However, the analysis of the data showed that males and females had equal geometric BLLs of 7.7 ug/dL each. In terms of age, 5% of the subjects were < 1 year old, 80% were between the ages of 1 and 3 years, and 15% were between the ages of 4 and 6 years. Analysis of the data showed that < 1-year-old children had the highest geometric mean BLL (8.0 ug/dL), followed by those between 1 and 3 years old (7.7 µg/dL), and those between 4 and 6 years old (7.6 µg/dL), respectively.

A 2010 EPA report indicated that, at the national level, boys had about 0.5 µg/dL more blood lead content than girls. However, Morrison et al. (2013) reported lead study results that showed higher average BLLs for girls compared with boys in Marion County IN. But the results of this study showed no difference between boys and girls in term of BLL.

In terms of age, it was previously reported that 2-year-old children tend to have higher BLLs than 1-year-olds, probably due to mobility and hand-to-mouth behaviors (EPA, 2013; Morrison, 2013). The results of his study, however, show that 1-year old children had the highest geometric mean blood lead level compared with older children, which does not support these previous findings.

## Limitations of the Study

This study is designed as a retrospective cohort research. Selection and information bias due to misclassification are obvious limitations (Howe et al., 2016). Also, this study used a convenient sampling method. A limitation associated with this type of sampling method is that results may not be generalizable (Jager, Putnick, & Bornstein, 2017). The data was observational and cross-sectional, as result, the causal relationship between variables cannot be implied. In addition, the prevalence of EBLL, the disease factor, in the general population is also low and that may constitute an additional limitation to generalize the outcome of the research (Szklo & Nieto, 2019).

This study used the HBM as a theoretical framework. HBM is mostly used to explain the motivation of participants in disease prevention or a health promotion program. However, in this study, no variable has been recorded to represent the perception of parents and guardians for participating in the case management intervention. The absence of variables to evaluate parent perception about lead exposure and lead screening constitutes a major limitation of this study.

Parental education is an important variable for the study of childhood lead exposure. For example, in a randomized control design, Shen et al. (2014) showed that parental education can reduce the children’s blood lead level by up to 35%. Zhang et al. (2013) analyzed childhood lead screening data in combination with school performance and parental socioeconomic factors. They found that the odds ratio of having less than a proficient score in math, science, and reading is high for children whose parents achieved less than high school education. Another dimension of parent’s education about childhood lead exposure can be about understanding common sources of lead, ways to protect children from being exposed to lead, and the role of nutrition in the prevention of childhood lead poisoning (Mayan, 2019, add another). In the present study, elements of parent education have not been recorded, and this constitutes an additional limitation of the present study.

## Recommendations

Results of this study have provided statistical evidence that case management is an effective intervention for children diagnosed with EBLL. Unfortunately, only children with blood lead levels above 5µg/dL benefited from the beneficence of this intervention. In addition, considering that no amount of blood lead is acceptable (Dickman, 2017, Mayan 2019), a logical recommendation is to lower the reference level to less than 5µg/dL so that more children will benefit from case management intervention.

A similar recommendation has been proposed in previous reports. For example, Caldwell, et al., (2017) analyzed the 2011 to 2014 National Health and Nutrition Examination Survey (NHANES) data. They found that the 97.5th percentile corresponded to 3.48 µg/dL which is about 30% lower than the current reference value of 5 µg/dL.

The present study is a retrospective analysis of secondary data. In a retrospective study, the researcher does not have control of data collection. A prospective design would allow the researcher to collect all necessary data for the study (Euser et al., 2009; Song & Chung, 2010). For example, in this study important variable such as parental education has not been collected and that limit the interpretation of the data. In addition, no variables to assess parental perception about lead exposure were collected. A prospective design would allow the researcher to collect additional usage data to enrich the interpretation of the findings (Euser et al., 2009; Song & Chung, 2010). Therefore, I would recommend further research on this topic using a retrospective design approach.

# Implications

## Positive Social Change at the Organizational Level

The findings of this study can be used by the local public health authorities to make evidence-based decisions on resource allocation for the prevention and mitigation of childhood lead poisoning. For example, these findings suggest that the majority of children with EBLL are Latinos (49%) and Asians (30%), therefore more resources, including for example hiring more culturally competent case managers, should be directed toward those communities to curve the prevalence and incidence of EBLL.

Another implication of this study is to devise targeted outreach programs to educate those communities about the risk factor of lead exposure. For example, about 20,000 ethnic Chin communities from Southeast Asian country Burma live on the south side of Indianapolis. To reach this community, lead prevention education material such as flyers and posters must be translated into Chin and Burmese languages (Salaz, & Raymer, 2020).

## Positive Social Change at the Individual level

This study can bring positive social change in two ways. First, it was widely reported that Black children are the most affected by childhood lead exposure. This study brings a social change in that it provides statistical evidence that Latinos and Asians, not Blacks, are the most affected by lead exposure in Marion, County, IN. This may change the public health authority’s approach to lead prevention activities in the community.

Second, communicating these results to the members of the Latino and Asian communities will increase awareness about the negative impact of lead on children. This can bring a social change in the form of change in behavior to protect children from lead exposure.

## Conclusion

In this study I analyzed lead exposure screening data collected between January 2018 and December 2019 to answer three research questions including: 1) Is there a difference between blood level at baseline and blood lead level at post-case management time? 2) Is the change in blood lead content between baseline and post case management time associated with race, zip code lead risk status, or poverty? and 3) Can the difference between blood lead content at baseline and blood lead content at post-case management time be modified by the severity of the blood lead level at baseline?

Analysis of the data revealed that case management is an effective intervention to bringing children's blood lead level below the reference level because there was a statistically significant difference between blood lead level at baseline and blood lead level at post casement time. Also, all the socioeconomic variables tested, including race, zip code, and poverty had a statistically significant effect on the outcome of case management. However, only the poverty variable showed a statistically significant interaction with case management levels.

As expected, the higher the severity of lead exposure at baseline the longer it takes to bring the blood lead below the reference level. also, children from zip codes with high lead risk status and those eligible for Medicaid were most exposed to EBLL. The analysis of the data revealed that minority races including Latinos and Asians were the most exposed to EBLL. However, there was no difference between boys and girls in terms of exposure, but the younger age group (< 1-year-old) had the highest median blood lead content compared with other age groups.

These results have important implications for the local public health authorities because the result shows the need to direct more resources to communities that were most affected by EBLL. The results of this study also add support to the call to the CDC to bring the reference level of childhood blood exposure to below the current level of 5µg/dL. However, this study has some limitations that need to be considered when using the findings. For example, the data were observational and cross-sectional, as result, a causal relationship between variables cannot be implied. Also, due to the convenient sample approach, selection, and information bias due to misclassification may limit the generalizability of the findings.

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