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Comparison of Blood Lead Levels Between Children in an Urban Setting and Children in a Rural Setting

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COMPARISON OF BLOOD LEAD LEVELS BETWEEN CHILDREN IN AN URBAN SETTING AND CHILDREN IN A RURAL SETTING

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Dedication

I dedicate this thesis to my father, Juan M. Alvarez, to my mother Veronica Alvarez, and to my brother Ivan Alvarez. These past months, each and every one of them have been stressing about their respective jobs or school work and every single day, without fail, we would support each other and let each other know how blessed we were for being where we are. Finally I would also want to dedicate this thesis to RASCA, for morally supporting me.

COMPARISON OF BLOOD LEAD LEVELS BETWEEN CHILDREN IN AN URBAN SETTING AND CHILDREN IN A RURAL SETTING

By

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Abstract

Environmental heavy metal exposure is a public health problem that is of great concern because it is highly toxic for children. The urban setting in downtown El Paso is historically known to be contaminated through various sources of contamination of heavy metals. The goal of this study was to compare whether children in a historically contaminated urban downtown area had significantly increased levels of lead exposure as compared to children in a demographically similar rural area approximately 20 miles north of the urban center, while controlling for gender and age. Cadmium and mercury were also measured for comparison purposes. It was predicted that children living in the urban setting would have significantly higher BLLs than children living in the rural community.

This was an observational study which included a total of 222 children, 111 children from a rural setting and 111 children from the downtown urban setting. Fewer children were tested in the rural setting, thus all rural children tested were included, and 111 from the urban setting were selected for inclusion based on an age and gender match to the rural children. Blood lead, cadmium, and mercury levels were analyzed with inductively coupled plasma mass spectrometry (ICP-MS). General linear model regression analyses were conducted to determine whether blood lead, cadmium and/or mercury levels were predicted by location, controlling for gender and age.

Children living in the urban setting had higher BLLs (2.86, ±1.29), than children living 20 miles north of El Paso (1.11±1.03). A regression analysis revealed a significant association between geographic location and BLLs, ($F(3, 218) = 125.13$, $p < 0.000$). Blood cadmium and mercury levels did not differ by geographic location.

The prevalence of lead poisoning has decreased significantly however low-level lead exposure persists. It is known that BLLs in the ranges observed in the urban sample examined

in this study are associated with early neurocognitive deficits and possible long-term effects. While the smelter plant located one mile from the urban setting has been shut down for ten years, continuing contamination exists in the region. Increased efforts should be made to monitor children's blood lead in this urban community and identify potential contamination sources. Finally, community-based approaches to education are needed for parents, school personnel and children, regarding the potential effects of early chronic low-level lead exposure.

Table of Contents

Page

List of Tables

Introduction

Environmental heavy metal exposure, particularly from lead, cadmium, and mercury, is a public health problem that is of great concern because it is highly toxic for children (Tchounwou, 2014). Child lead exposure has received the most attention. In 1991, the CDC set the child blood lead level (BLL) "threshold of action" at 10µg/dL. After decades of research showing ill effects at levels below 10, in January 2012 a "threshold of concern" was set at 5µg/dL (CDC, 2013). In 2010, 34 states in the United States including the District of Columbia (DC) identified an estimated 24,000 children <6 years old with blood lead levels (BLLs) at $\geq 10\ \mu g/dL$ and 243,000 children <6 years old with BLLs at $\geq 5\ \mu g/dL$ (Raymond, 2014). Health risks associated with low BLLs in children are well known, but less is known about mercury and cadmium (Hrubá, 2011).

1.1 Characteristics of Specific Heavy Metals

1.1.1 Lead

Lead is a versatile and ubiquitous heavy metal that occurs naturally in the earth's crust and is one of the earliest metals used by humans (Aelion, 2013; Flora, 2012, Tong & von Schirnding, 2000). Although high toxic levels are rarely found it persists for long periods of time in soil or other places of deposit because it is non-biodegradable. Major sources of lead contamination are from motor vehicles exhausts, lead water piping, industrial emissions such as lead smelting, battery recycling and coal combustion, and lead-based paint in houses built before 1978 (Aelion, 2008; Flora, 2012). Other lead sources include paints and materials used in toys, food, and materials used in crafts involving stained glass and pottery (Abelsohn & Sanborn, 2010; ATSDR, 2012). Airborne lead, which occurs from industrial emissions, may contaminate water, soil and ultimately crops. Rain can also be responsible for transporting this metal (de Lurdes Dinis & Fiúza, 2011).

1.1.2 Pathways of Lead Exposure in Children

The main pathways of lead exposure for children are ingestion and/or inhalation. Children might ingest lead from several sources. Deteriorating lead-based paint in old housing, which was widely used before its ban in 1978 is considered to be a major source. In fact, Abelsohn & Sanborn, (2010), reported that lead-based paint accounts for seventy percent of children's exposure to lead. Another common source is lead contaminated soil. In a study by Lanphear at al. (1997), lead exposure in children through contaminated soil and house dust were examined and the authors suggested that hand-to-mouth behaviors resulted in children ingesting heavy metals.

Toys may also contain lead that can be ingested. Toys painted with lead-based paint or toys used outside in the contaminated soil can be sources of lead contamination (Abelsohn & Sanborn, 2010). Automobile exhaust is another source that contributes to the contamination of soil which in turn can contribute to the elevated BLLs, meaning levels ≥ 2.0 µg/dL, found in children. Deteriorating lead pipes can cause lead-contaminated water and can also contribute to elevated BLLs in children (Rossi, 2008).

Children might also inhale lead from a variety of sources for example, from lead fumes or dust containing lead (de Lurdes Dinis & Fiúza, 2011; Papanikolaou, 2005). Gasoline exhaust in the air can be a source of direct absorption of lead pollution through inhalation (Reyes, 2015). Inhalation of urban road dust is another source of lead contamination that can affect children, especially children that reside in rural communities with unpaved roads (Jiang, 2010). Inhalation of suspended lead-contaminated soil is of concern especially in urban areas where the soils are exposed and constantly eroding. Urban areas where drought conditions are frequent increase the possibility of this source of contamination (Schwarz, 2012).

1.1.3 Child Health Risks from Environmental Lead Exposure

1.1.3.1 Adverse Effects on Neurobehavior

The adverse effects that lead exposure has on the central nervous system have been an area of extensive study at all levels of exposure, from lowest to highest. There is strong evidence that levels as low as 5µg/dL are harmful for the developing brain. Even at lowest levels of exposure, lead exposure is associated with lower IQ scores, diminished memory, and diminished attention (Chiodo, 2004; Nigg, 2008; Sobin, 2009, 2011).

A study conducted by Canfield et al. (2003) measured cognitive impairment through BLLs and IQ scores on the Stanford-Binet Intelligence Scale in children aged 3-5 years. An association between an increase in lifetime average BLL concentration of 1 µg/dL and a decrease of 0.87 IQ points on the scale was identified. It was concluded that children with BLLs at or below 10µg/dL had a decrease in IQ, and children with BLLs below 10µg/dL had a greater decrease in IQ score.

A study by Sobin et al. (2015) tested children aged 5.1-11.8 in working memory, short-term memory, and motor dexterity. In this study ALAD2 and hPEPT2*2 genotypes influenced neurobehavioral outcomes differently. It was found that regardless of genotype as BLLs increased, working memory decreased.

In a case-control study, Wang et al. (2008) examined the association between ADHD and BLLs in Chinese children. Children aged 4-12 with a medical history of ADHD were compared to children randomly selected from outpatients admitted for acute upper respiratory infection. In children with BLLs <10 µg/dL but >5 µg/dL there was a 3.5-7.0 fold increase risk for ADHD.

1.1.3.2 Psychomotor coordination

Low-level lead exposure has been associated with impaired psychomotor coordination in children. For example, a study by Winneke et al. (1990) found deficits for tapping and pattern recognition with respect to BLLs lower than 10 µg/dL. Additionally, Despres et al. (2005), found that a small elevation in BLLs (4.1 µg/dL) during childhood was associated with lower fine-motor and visuo-motor function but unrelated to the overall motor coordination.

1.1.3.2 Kidney Damage

The kidney is made up of a million nephrons that are known to filter waste products and remove them from the body in the form of urine (NIH, 2014). It has been proposed that kidney's filtration rate of the urine may be disrupted as a result of exposure to low-levels of lead (de Burbure, 2005). There are very few studies examining the effects of low-level environmental heavy metal exposure on kidney, especially in children. In a study, conducted by de Burbure et al. (2005) the glomerulus (i.e. small blood vessels in the kidney) filtration rate in the kidney was examined. It was found that in children, at low levels of lead exposure the filtration rate of the glomerulus was decreased. This study suggested that lead impairs kidney function in children.

1.1.3.4 Blood Pressure

Hypertension in humans and animals is caused by exposures of low lead levels, due to the result of lead induced oxidative stress or increase of reactive oxygen species (Ahamed & Siddiqui, 2007; Gonick, 1997). In a longitudinal cohort study, Zhang et al. (2011) examined the association between blood pressure in children and prenatal lead exposure. Lead levels from the maternal tibia, maternal patella bone, and from the umbilical cord blood lead were measured. It was concluded that lead in the maternal tibia is a factor that predicts higher blood pressure in female children but not in male children. No association was found between patella and umbilical cord blood lead with blood pressure. This study suggested that sex-specific adaptive responses to lead may explain differences in blood pressure.

1.1.4 Cadmium

Cadmium is a heavy metal that is found naturally in the earth's crust (Schoeters, 2006) and the environment. Major sources of environmental cadmium contamination include industrial emissions, car and truck exhaust, waste incineration, non-ferrous metal production, mining, and battery manufacturing. Other sources include cadmium contaminated phosphate fertilizers and contaminated sewage sludge on farm land (Järup, 2009; Peters, 2010; Schoeters, 2006). Cadmium is also found in paint pigments, metal coatings, batteries, and plastics (Schoeters 2006; Tellez-Plaza, 2012).

Atmospheric deposition of cadmium is a major pathway of environmental contamination. Cadmium-polluted air may occur in the vicinity of some industrial activities. Cadmium can bind to air particles and is able to travel long distances, bind strongly to soil, and dissolve in water (Järup, 2009). Contamination of soils is caused by atmospheric deposition and this may lead to uptake by crops and vegetables grown for global consumption (Järup, 2009). Soil contamination of cadmium can further lead to the contamination of groundwater (Sethi, 2006).

1.1.5 Pathways of Cadmium Exposure in Children

Exposure to cadmium can occur via inhalation and/or ingestion. Inhalation of cadmium can occur from exposure to contaminated dust or fumes from industrial activities and from second hand cigarette smoking. Cadmium-contaminated dust is influenced by many factors such as city location, traffic emissions, heating with coal, and dampness of the home. According to Malara et al. (2004), it was found that baby teeth of children exposed to cigarette smoke had higher concentration of cadmium-to-calcium ratios, which indicated accumulation of these metals.

The major sources of cadmium exposure in children in the U.S. include the intake certain foods such as leafy vegetables, grains, and meat (Peters, 2010). Interestingly, a study conducted by Johri et al. (2010), showed that the levels of cadmium concentration in cereals and tubers were higher than in meat, fish, and fruit.

1.1.6 Child Health Risks from Environmental Cadmium Exposure

Studies have found detrimental effects of environmental cadmium contamination in the kidneys and bones of children.

1.1.6.1 Kidney Damage

Studies in adults have shown that kidneys affected by cadmium show signs of tubular proteinuria, which is an increase of urinary excretion of proteins and enzymes. Another effect seen in cadmium-exposed adult kidneys is tubular dysfunction. This leads to increased urinary excretion of proteins due to very low filtration rates (Swaddiwudhipong, 2015). It is likely that effects seen in adults will be exaggerated in children because developing organs are less able to efficiently excrete toxic substances. .

In a cross-sectional study by Swaddiwudhipong et al., (2015) the possible association between urinary cadmium excretion and renal dysfunction was examined in 594 elementary school children. Urinary excretion of calcium was measured in these children among other biomarkers such as ß2-microglobulin and total protein. It was concluded that mean levels of urinary calcium and ß2-microglobulin significantly increased with increased urinary cadmium.

In another cross-sectional study, Skroder et al., (2015), assessed the effects of cadmium exposure on kidney function in pre-school aged children. Exposure to cadmium was assessed by concentrations found in urine, and kidney function was assessed by glomerular filtration rate. As urinary cadmium increased, glomerular filtration rate decreased and the effects were more marked in female as compared to male children.

1.1.6.2 The Effect of Cadmium on Bone Reabsorption of Calcium

Studies have found that a secondary effect of kidney failure is diminished bone reabsorption of calcium. If arsenic disrupts kidney function, it might also reduce bone reabsorption of calcium. In a cross-sectional study by Sughis et al., (2011) the effects of environmental cadmium exposure and levels of bone reabsorption of calcium were examined in a sample of 155 elementary school children. In this study, the levels of urinary pyridinium (an organic compound) were measured, as a marker of decreased bone reabsorption of calcium. Cadmium in the urine was associated with higher excretion of calcium and urinary pyridinium suggesting that exposure to cadmium resulted in decreased bone reabsorption of calcium.

In bone, calcium is essential for children's development. Lack of bone calcium is associated with osteoporosis and fractures (NIH, 2015). Decreased bone reabsorption of calcium can lead to bone fragility and increased fracture risk (Järup, 2009). In the long-term, decreased bone reabsorption of calcium can lead to low bone mass and deterioration of bone tissue (osteoporosis). Decreased bone reabsorption of calcium in childhood might increase the likelihood of osteoporosis in later adulthood.

1.1.7 Mercury

Mercury occurs naturally in earth's crust (Holmes, 2009; Zahir, 2005) and enters the environment through natural processes such as off-gassing from the earth's crust, and also is emitted from various industrial sources such as coal smoke, metal smelting, waste disposal/incinerators, and chemical use.

Atmospheric pollution from mercury mainly originates from emissions of industrial sources. Coal smoke is the main source of mercury pollution (Tchounwou, 2012; Zahir, 2005). Once in the atmosphere mercury is able to travel with wind and ultimately pass into bodies of water. Additional mercury contamination of water can occur when polluted water produces acidic rain. Once mercury is in a body of water, it makes its way into marine life and eventually into humans (Zahir, 2005).

Other sources have been identified as contributing to mercury contamination such as breakage of mercury-containing instruments such as thermometers or sphygmomanometers, and theft of mercury from industries or schools. Minor contributions described by Holmes at al. (2009), include dental fillings which can contain up to 50% elemental mercury, residual vaccine preservative thiomersal (vaccine preservative), fluorescent light bulbs, beauty products, infant teething powders, and folk remedies.

1.1.8 Pathways of Mercury Exposure in Children

Children are exposed to mercury through ingestion and/or inhalation. Children might ingest mercury by the consumption of mercury-contaminated meat. Fish is the major source of mercury-contaminated meat (Zahir, 2005). Additionally, according to Holmes et al. (2009), red meat is a potential source of mercury contamination because of animal’s consumption of water, vegetables, and cereals contaminated with mercury. Prenatal exposure to methylmercury, the organic form of mercury, occurs when pregnant mothers eat fish during gestation (Counter & Buchanan, 2004; Tchounwou, 2012; Zahir, 2005).

Inhalation of mercury by children can occur through exposure to a vaporous form of mercury (Counter & Buchanan, 2004). It is believed children are at higher risk of inhaling mercury vapor in residential settings because families tend to have instruments in their houses that contain mercury (e.g. thermometers). Children can be exposed when an instrument containing mercury is broken in the residential area and is not cleaned appropriately. This is due to the fact that mercury vapor can be released from the liquid metallic on the floor close to the child's respiratory system, and children can easily get exposed to it while they walk or crawl (ATSDR, 2015; Counter & Buchanan, 2004).

1.1.9 Child Health Risks from Environmental Mercury Exposure

1.1.9.1 Adverse Effects on Neurobehavior

Several studies have shown an association between prenatal mercury exposure and neonatal motor function, behavior, and memory once the child reached preschool age. These studies included as a factor the amount of fish consumed by the mother during pregnancy.

A cohort study by Suzuki et al., (2010) examined the effects of methylmercury and maternal seafood intake on the Neonatal Behavioral Assessment Scale (NBAS). This test was administered three days after the child was born. Methylmercury was analyzed in maternal hair, and maternal seafood intake was estimated using a semi-quantitative food frequency questionnaire. It was concluded that low-levels of methylmercury in maternal hair affected motor function, and higher consumption of seafood resulted in a positive association between seafood consumption and motor behavior.

A cohort study by Sagiv et al., (2012) examined the effect of prenatal mercury exposure and maternal seafood intake on ADHD-related behaviors. Mercury exposure was assessed through maternal hair, the ADHD-related behaviors were assessed using a rating scale and two neuropsychological tests, and fish consumption data was collected through a questionnaire. It was concluded that higher levels of mercury in maternal hair were associated with a higher risk of children developing ADHD-related behaviors. On the other hand, maternal seafood consumption was associated with lowering risks of these behaviors, suggesting that the beneficial effects of seafood outweighed the potential risk of mercury exposure.

In a third cohort study, Oken et al. (2005) examined the associations of maternal hair mercury and seafood intake during pregnancy with infant cognition. Total mercury content was assessed through maternal hair, cognition was assessed using the visual recognition memory (VRM) paradigm, and fish consumption data was collected through a questionnaire. In this study, it was concluded that very low-levels of mercury exposure were associated with lower cognitive scores. Again, maternal fish consumption was associated with higher infant cognition scores.

In conclusion, the above-described studies identified a negative association between maternal hair mercury levels and children's neurobehavior. These studies also found that higher consumption of seafood from the mother during pregnancy protects the infants from neurobehavioral deficits.

1.2 Heavy Metal Contamination in Urban and Rural Settings

Environmental heavy metal contamination including lead, cadmium, and mercury is expected to be greater in urban than in rural settings. For example, in two studies, the levels of lead in the soil were compared between urban and rural settings. It was found that the soil in urban settings had higher contamination of lead as compared to that of rural settings (Aelion, 2013; Morrison, 2013). The authors suggested that sources contaminating the soil of urban settings might be lead emissions from cars, trucks and industrial facilities, weathering of lead-painted buildings, and concrete paved surfaces.

A study by McBride et al., (2014) examined concentrations of heavy metals including cadmium and lead, in soil of urban gardens in New York City. It was found that concentrations of cadmium were higher in the urban community soils than in the rural background. Background concentrations of cadmium in the Northeastern United States range from 0.1-0.3 mg/kg, and concentrations found in the urban soil at times exceeded 1.0 mg/kg.

Taken together, these results suggested that urban settings had higher levels of lead, cadmium and mercury as compared to rural settings. Studies have provided evidence that higher levels of heavy metals in urban settings may be due to their close proximity to source "hotspots."

1.3 Source Proximity and Urban Heavy Metal Contamination

Several studies have provided evidence that soils at a close distance to industrial facilities, as compared to those at a larger distance, have greater heavy metal contamination (Douay, 2013; Verner, 1996). For example, in a study by Wei et al. (2009), the spatial distribution of 6 heavy metals sources, including lead and cadmium were measured. High levels of lead and cadmium were present around smelter and mining facilities, most likely from airborne emissions (Wei, 2009).

In a similar study by Gamiño-Gutierrez et al. (2013), the levels of two heavy metals, including lead and arsenic, were examined in soil in Villa de la Paz, Mexico, and the BLLs of children living near heavy metal sources were measured. It was found that there were high concentrations of lead in the soil and that the source of soil contamination was from mining waste rock deposits near the city. Additionally, thirty-percent of the children tested had BLLs >10 µg/dL. As levels of lead in the soil increased, children's BLLs also increased (Gamiño-Gutierrez, 2013).

In a study by Morrison et al. (2013), soil samples around the Westside Cooperative Organization community in Indianapolis, USA were examined. They examined whether hotspots existed in the community near the former industrial site (a "Superfund" site). Lead “hotspots” were located at the urban core, where the Superfund site was located, and also north from it. The authors concluded that people in communities living nearby this industrial source are at high risk of becoming contaminated through dust or soil (Morrison, 2013).

1.4 Factors that Increase Vulnerability to Heavy Metal Exposure

There are several factors that influence heavy metal exposure. These factors include age, gender and socioeconomic status.

1.4.1 Age

During childhood development, children are more likely to be exposed to heavy metals and when exposed, are more vulnerable to heavy metal absorption as compared to adults.

Young children and particularly toddlers appear to be most vulnerable to heavy metal exposure because as compared to older children and adults, they have engage in exploratory behavior that includes frequent hand to mouth movements, such as playing in dirt and putting objects and their hands in their mouths(Bose-O’Reilly, 2010; Goyer, 1972). In a study by Morrison et al. (2013), it was found that children aged 6-30 months had higher mean BLL, 3.14 µg/dL, than children aged 0-5 months, 2.11 µg/dL. This increase in BLLs was associated with an increase in mobility and hand-to mouth behaviors.

Similarly, Lanphear et al. (2002) conducted a longitudinal study examining BLLs in children. It was found that, when children were 6 months, they had mean BLLs of 2.9 µg/dL whereas when they were 24 months, they had mean BLLs of 7.5 µg/dL. This increase in BLLs was associated with standing upright, crawling, putting paint chips or soil into their mouths and mouthing interior windowsills, and soil ingestion.

Also, as compared to adults, children are more vulnerable to heavy metal absorption. This is due to many factors including differences in the gastro-intestinal tract that increase the rate of lead absorption (Bose-O'Reilly, 2010; Hou, 2013). Another factor is the developing nervous system in young children as it absorbs higher fractions of lead making them more vulnerable to neurologic effects (Flora, 2012). Also, a higher permeability of the blood-brain barrier causes heavy metals to accumulate in the brain of toddlers which can also lead to neurologic effects (Kostial, 1978).

1.4.2 Gender

Studies have provided evidence that male children have higher BLLs than female children. According to Vahter et al, (2007) BLL concentrations are influenced mostly from physiological factors. It is known that male children have higher hematocrit levels than female children due to higher blood hematocrit levels. In blood, lead is easily bound to erythrocytes. In the study by Morrison et al. (2013) BLLs were tested for children younger than 5 years old. It was found that female children had mean BLLs of 2.70µg/dL whereas male children had mean BLLs of 2.82µg/dL.

Studies examining the effects of δ-Aminolevulinic acid dehydratase single nucleotide polymorphism 2 (ALAD2) and peptide transporter 2*2 haplotype (hPEPT2*2) genes on lead blood burden have shown differences between male and female children. It was found that ALAD2 and hPEPT2*2 might be expected to exaggerate risks associated with low-level lead exposure in male children as lead blood burden increases. This result supports other suggestions that the effect of modifying hPEPT2*2 on lead blood burden is specific to male children (Sobin et al, 2009, 2011).

Additionally, in a study by Chlopicka et al. (1998) male and female BLLs and blood cadmium levels (BCL) were compared in children ages 8-15 years. For BLLs, it was found that female children had mean BLLs of 13.23±4.23 µg/dL whereas male children mean BLLs of

14.99±3.68 μg/dL. For BCL, it was found that female children had mean BCLs of 0.48±21 μg/dL whereas male children had mean BCLs of 0.55±0.24 μg/dL. The authors of these studies suggested that more studies need to be conducted in order to determine the specific behavioral and/or genetic factors that might explain gender differences in BLLs and BCLs.

1.4.3 Socioeconomic status

Children from lower socio-economic environments are more vulnerable to lead exposure as compared to children form high socio-economic environments. Socioeconomic status has most often been based on parental education, occupation and income (Adler, 2005).

With regard to education, Moralez et al. (2005) described how low and high education attainment from the head of the household is associated with different BLLs in Mexican-American children. When the household head had an educational attainment of 6 years or less the mean BLLs of children was 4.15μg/dL. In contrast, when the household head had an educational attainment of 13 years or more the mean BLLs of children was 2.37μg/dL.

Concerning parental occupation, a study by Shah et al. (2011), conducted in Pakistan, found that parental occupation in industrial sites resulted in higher lead and cadmium concentration in children's hair. It was suggested that this was because these families live in close proximity to the industrial sites where they are employed, thus increasing the likelihood of child heavy metal exposure.

With regard to income, several factors might contribute to higher heavy metal exposure. For example, low income is associated with decreased access to health care, decreased regularity of BLLs testing, lower quality of physical living condition, and poor nutrition (MMWR, 2000; Morrison, 2013).

Despite the fact that several components of socioeconomic status such as parental education, occupation and income play a role in understanding children heavy metal neurotoxicity, additional research needs to be conducted in order to understand the complexity and interactions of these factors (Bellinger, 2008).

1.5 Goal of this study

Historically, the U.S. Mexico border region that includes El Paso, Texas was known to have heavy metal contamination as a result of several factors including close proximity to a large smelting plant located within one mile of downtown El Paso, industry pollution from Mexican industry operating across the Rio Grande river, and contaminants typically found in old, un-renovated housing. The prevalence of child lead poisoning has dropped dramatically in the region and nationwide however our laboratory's studies have suggested that over 50% of children living in a historically contaminated low-income neighborhood (Sobin et al., 2009, 2011, 2015) have elevated ($\geq$2.0 μg/dL) blood lead, suggesting that lead contamination continues in this urban center long after the original source of contamination was removed. Whether low-level heavy metal exposure is ubiquitous among lowest-income children is not known. The goal of this study was to compare whether children in a historically contaminated urban downtown area had significantly increased levels of lead exposure as compared to children in a demographically similar rural area approximately 20 miles north of the urban center. For contrast to lead, levels of cadmium, mercury and iron were also measured and compared.

It was predicted that children in the historically contaminated urban setting would have significantly higher blood lead levels as compared to children in a rural community living approximately 20 miles north of downtown El Paso.

Methods

2.1 Study Population

Sampling took place in two settings in the El Paso, Texas border region and included one urban setting and one rural setting. Children were recruited from elementary schools located in either downtown El Paso or towns approximately 20 miles north of downtown El Paso in a sparsely populated rural area. All of the methods described were fully approved by the University of Texas Institutional Review Board, by the El Paso Independent School District Research Board, and by the Canutillo Independent School District Board and Superintendent.

2.2 Study Participants

Recruitment took place with the permission in each school district from the school district superintendent, the school board, school principals, school nurses and school staff. Parents were recruited for child participation during parent-teacher conferences and during school health fairs.

Inclusion criteria for participation included children who were currently enrolled at one of the three participating elementary school located in the areas of interest, had no history of being diagnosed with heavy metal poisoning, and was healthy. Exclusion criteria included having any kind of cognitive impairments or mental disability or refusal to participate.

Participation was on a volunteer basis. The details of the study were explained to children's parents who completed written informed consent prior to child testing. Up to two children per household were allowed to participate. Child assent was obtained immediately before child testing occurred, typically one to three weeks after obtaining parental consent.

Participants were compensated with a 5 dollar gift card (per children) for completing the first phase of the study which included the initial recruitment, signed consent, and health questionnaire form completion. At the end of the study, another 5 dollar gift card was given for completing the final phase of the study, which included the child testing.

Testing was done during the school day, specifically during Physical Education classes. During testing days, the parent liaisons at each school called for the participating children during the gym period, and brought them to the testing room in groups of approximately eight children. The physical education period lasted 45 minutes and testing of all children was done during that period. Once all children had completed the testing, they were returned to their respective classes.

All forms and materials were available in Spanish and English versions. Researchers participating in this study were bilingual and interacted with parents and children in their preferred language throughout the course of the study.

2.3 Study Design

This study was part of a larger child health study examining low-level heavy metal in children in the El Paso border region. This was an observational study of very low-income Hispanic children residing in two different settings (urban and rural) and used convenience sampling. The sample for this study consisted of 111 children living in the rural setting, matched by age and gender to 111 children from the downtown urban setting. Identical data were collected from each sample.

2.4 IRB approval

Institutional Review Board (IRB) approval was obtained prior to data collection (IRB Protocols # 564493-1 and #79085-14). Informed parental consent was obtained for child participation prior to the study and written assent from each child was obtained immediately prior to blood collection and anthropometric measurements. All workers and volunteers participating in this study completed required human subjects training

2.5 Data Collection

2.5.1 Rural School District

In the school district located in the rural area, each child began each testing session with anthropometric measurements. The child's waist, hip, and height were measured and recorded in centimeters. The child's weight was also measured and recorded in pounds. Waist and hips were measured with a standard tape measurer; for hips, measurements were taken over the clothes around the broadest point of the buttocks. For waist measurements, children were measured approximately at the level of the navel, or at the smallest part of the waist. Using the height and weight measurements and converting them to inches and pounds respectively, BMIs were calculated.

Blood pressure was measured using an electronic sphygmomanometer specialized for children. The child sat on a chair and the cuff was placed on their upper left arm. Both systolic and diastolic measurements were automatically calculated and recorded.

Blood samples were collected once the child's anthropometric measures were taken. Blood collection procedure was the same for both school districts. Each child cleaned their hands with antiseptic foam soap. Fingers of the left hand were then wiped with towelettes specially formulated to remove lead, cadmium, and arsenic from the skin. It can also remove nickel and silver (D-Wipe™, Esca-Tech, Inc. Milwaukee, WI, USA). Saf-T-Pro™ 1.8 mm lancets were used to prick the forth finger of the left hand. A total of 50 microliters were collected from each child. Samples remained at room temperature for about 1-3 hours, and were later refrigerated at 4ºC.

Blood analysis was done by the chemistry laboratory at the New Mexico State University, Las Cruces. A total of 50 microliters were collected from each child to be analyzed though Inductive-Coupled Plasma Mass Spectrometry (ICP-MS) and tested for lead, cadmium, mercury, arsenic, and iron in whole blood. The quantity of lead, cadmium, and mercury in blood was determined in micrograms per deciliter (μg/dL).

2.5.2 Urban School District

Similarly, children in the urban school district began each testing session with anthropometric measurements. In this case, children were only measured for height in centimeters and weight in kilograms. Using the height and weight measurements and converting them to inches and pounds respectively, BMIs were calculated.

Blood collection procedure for both rural and urban children was similar. The child's hand was cleaned with antiseptic foam soap then fingers from the left hand were wiped with towelettes formulated to remove heavy metals from the skin. Saf-T-Pro™ 1.8 mm lancets were used to prick the forth finger of the left hand.

2.6 Statistical Analyses

All variables were examined for outliers and distribution properties. Descriptive statistics were calculated for demographic and clinical characteristics. All of the rural setting children were used in this analysis since fewer children were tested, and the 111 children from the urban setting were selected for inclusion based on gender and age match to the children in the rural setting. The values were examined and compared to determine whether the two schools located 20 miles north of El Paso are similar enough to be combined. Pre-test were conducted to determine if the two schools were not significantly different. If not significantly different they were combined and the values represented the rural location for the primary analyses.

A general linear model (regression) was used to examine if geographic location predicts blood lead levels in children, controlling for gender and age. For comparison purposes blood cadmium and mercury levels were also compared in secondary analyses. Depending on the outcome of the primary analyses, additional secondary analyses may be conducted to examine differences in other physiological characteristics of children in the two locations.

Results

This study included a total of 222 children, 111 children from a rural setting and 111 children from the downtown urban setting. Fewer children were available for testing in the rural settings, thus, to maximize our samples, all of the rural setting children were used. One hundred eleven children from the urban setting were then selected for inclusion based on a gender and age match (within 1 year) to the rural children. The 111 children from the rural setting were from two elementary schools (Rural 1, n = 39 and Rural 2, n = 72).

Table 1 shows the demographic and clinical characteristics of the analyzed sample of 222 children by site. Mean ages for Rural 1, 2, and Urban were 7.97 ± 1.77, 7.86 ± 1.88, and 8.01 ± 1.77, respectively. Children living in the urban setting had a slightly higher mean weight (lbs.) when compared to children living in the rural sites; mean height (in.) was similar across all sites. Higher mean BMIs were seen in children living in the urban setting 18.64 ± 5.02 when compared to rural sites, 17.99 ± 3.97 in Rural 1 and 17.54 ± 3.98 in Rural 2, but this difference was not statistically significant. The majority of the children's mothers and fathers in all three sites identified themselves as either Hispanic or from Mexican descent. Across all sites the highest percentage of parent's highest education level completed was high school. For all sites, a high percentage of household income included incomes of ≤10K per year or > 10K and ≤ 20K per year. The mean number of persons living in households was also similar across all sites, 5.13±1.26 Rural 1, 5.34±1.56 Rural 2, and Urban, 5.00±1.65. According to the 2014 U.S. Federal Poverty Level for 2014, for a family of 4 it is $24,250.

The mean BLL values of females and males of either rural or urban settings did not exceed the current threshold of concern in children of 5.0µg/dL (CDC, 2015). When separated by sites, Urban had the highest mean value of lead exposure with 2.86±1.29 µg/dL compared to

1.18±1.32 µg/dL and 1.07±0.84 µg/dL in Rural 1 and Rural 2 respectively. The same trends were found for cadmium and mercury, with mean levels being higher in the urban setting. Mean levels found in the urban setting did not exceed the allowable levels for cadmium (0.5µg/dL) or mercury (0.9µg/dL). It was found that mean iron levels in children living in the urban setting were lower 5511.72 ± 742.02 than children living in the rural setting with Rural 1 having mean iron levels of 11827.14 ± 2785.10 and Rural 2 mean iron levels of 10582.82 ± 2377.99. None of the children in this sample met criteria for anemia, based on iron levels tested for this study.

In order to determine whether findings from the two rural settings could be combined for the location comparison models, one-way ANOVA analyses were conducted comparing child blood lead, cadmium, and mercury levels controlling for age and gender. As shown in Table 2, no statistical differences between the two rural sites for lead (F (1, 109 = 0.26, *p* = .61); for cadmium (F (1, 109 = 0.84, *p* = .36); or for mercury (F (1, 109 = 1.17, *p* = .28) were found. Based on these findings, the two rural sites were combined for all further analyses.

Table 3 summarizes the Type III fixed effects and parameter estimates for associations between child blood lead levels and geographic location, controlling for gender, age. Location was a strong predictor of BLL (F (1,221) = 126.02, *p* = 0.00). In this model the effects of age (F (1, 221) = 1.80, *p* = 0.18), and gender (F (1, 221) = .740, *p* = 0.39) were not significant predictors. The interaction of location and gender was also not significant (F (1, 221) = 0.120, *p* = 0.73). The non-significant effects were dropped from the model and the model was re-calculated predicting child BLL from only the location factor. In the reduced model, location was a significant predictor of child BLL (F (1, 221) = 125.12, *p* = 0.00).

Table 4 summarizes the Type III fixed effects and parameter estimates for associations between child blood cadmium levels, controlling for gender, age and living in rural and urban settings. No effects in this model predicted child blood cadmium levels.

Table 5 summarizes the Type III fixed effects and parameter estimates for associations between child blood mercury levels, controlling for gender, age and living in rural and urban Settings. The effect of location was not significant for predicting child blood mercury levels (F (1, 140) = 2.61, p = 0.11). Interestingly, mercury level was predicted by age (F (1,140) = 4.67, p = 0.03). Children's gender was not a significant predictor (F (1, 140) = 1.40, p = 0.24). The interaction between location and gender also was not significant (F (1, 140) = 0.35, p = 0.55).

Multiple linear regression analyses were also conducted to predict blood lead, cadmium, or mercury levels based on location, age, and gender (Table 6) (with children from two rural sites combined). Consistent with the ANOVA results, the regression equation predicting BLL from location was significant (F (3, 218) = 125.13, p <0.000), with an R^2 of 0.363. Only the location of the school was a significant predictor of BLL in children with a *p-value* of .000. In other words children living in the urban setting had significantly higher BLLs than children living in the rural area.

Consistent with the ANOVA models, the regression analyses predicting cadmium and mercury from location, controlling for age and gender, were not significant (cadmium, F (3, 217) = 1.23, p = 0.27, R^2 = 0.015; (mercury, F (3, 137) = 3.36, p = 0.069, R^2 of 0.024).

Table 1

Clinical and Demographic Characteristics of Children in Urban and Rural Settings and Parent's Demographic Characteristics (N = 222)

	Rural 1		Rural 2		Urban	
	Females	Males	Females	Males	Females	Males
Variable	n=12 (30.8%)	n=27 (69.2%)	n=42 (58.3%)	n=30 (41.7%)	n=54 (48.6%)	n=57 (51.4%)
Age (SD)	8.20 (±1.78)	7.86 (±1.79)	8.07 (±1.88)	7.56 (±1.88)	8.18 (±1.79)	7.85 (±1.75)
Weight lbs. (SD)	70.17 (±21.42)	65.76 (±27.09)	65.36 (±27.13)	64.50 (±26.23)	68.21 (±22.32)	70.59 (±25.64)
Height in. (SD)	51.24 (±4.85)	50.03 (±5.07)	50.05 (±5.15)	50.12 (±4.81)	51.49 (±6.06)	50.39 (±4.18)
BMI (SD)	18.43 (±3.77)	17.80 (±4.11)	17.62 (±3.78)	17.43 (±4.32)	17.90 (±2.87)	19.35 (±6.37)
Pb µg/dL (SD) (222/222)	1.00 (±0.94)	1.25 (±1.47)	1.00 (±0.80)	1.17 (±0.90)	2.81 (±1.20)	2.91 (±1.38)
Cd µg/dL (SD) (222/222)	0.038 (±0.023)	0.042 (±0.073)	0.029 (±0.052)	0.033 (±0.056)	0.041 (±0.060)	0.047 (±0.086)
Hg µg/dL (SD) (141/222)	0.025(±0.005)	0.037 (±0.037)	0.037 (±0.017)	0.042 (±0.022)	0.049 (±0.11)	0.075 (±0.17)
Fe µg/dL (SD) (222/222)	11156.90 (±826.87)	12125.02 (±3278.4)	10216.04 (±2120.9)	11096.3 (±2649.05)	5564.12 (±840.02)	5522.90 (±705.93)
	Total Rural 1		Total Rural 2		Total Urban	
	n=39 (17.6%)		n=72 (32.4%)		n=111 (50.0%)	
Age (SD)	7.97 (±1.77)		7.86 (±1.88)		8.01 (±1.77)	
Weight lbs (SD)	67.12 (±25.28)		65.00 (±26.58)		69.43 (±24.00)	
Height in. (SD)	50.41 (±4.97)		50.08 (±4.97)		50.93 (±5.19)	
BMI (SD)	17.99 (±3.97)		17.54 (±3.98)		18.64 (±5.02)	
Pb µg/dL (SD) (222/222)	1.18 (±1.32)		1.07 (±0.84)		2.86 (±1.29)	
Cd µg/dL (SD) (222/222)	0.041 (±0.062)		0.031 (±0.053)		0.044 (±0.074)	
Hg µg/dL (SD) (141/222)	0.033 (±0.032)		0.039 (±0.019)		0.064 (±0.15)	
Fe µg/dL (SD) (222/222)	11827.14 (±2785.10)		10582.82 (±2377.99)		5511.72 (±742.03)	
Household Size	5.13 (±1.26)		5.34 (±1.56)		5.00(±1.65)	

Table 1 (Continued)

	Rural 1		Rural 2		Urban	
	Females	Males	Females	Males	Females	Males
Variable	n=12 (30.8%)	n=27 (69.2%)	n=42 (58.3%)	n=30 (41.7%)	n=54 (48.6%)	n=57 (51.4%)
Mother Ethnicity (200/222)						
Hispanic (%)	7 (58.3%)	14 (51.9%)	21 (61.8%)	21 (70.0%)	28 (57.1%)	23 (47.9%)
Mexican (%)	3 (25.0%)	7 (25.9%)	10 (29.4%)	4 (13.3%)	18 (36.7%)	18 (37.5%)
Other (%)	2 (16.7%)	8 (29.6%)	3 (8.8%)	5 (16.7%)	3 (6.1%)	7 (14.6%)
Mother Education Level Completed (199/222)						
Graduated high school (%)	5 (41.7%)	12 (44.4%)	3 (8.8%)	9 (30.0%)	11 (22.9%)	16 (33.3%)
Completed some college (%)	4 (33.3%)	7 (25.9%)	13 (38.2%)	9 (30.0%)	6 (12.5%)	4 (8.3%)
Other (%)	3 (24.9%)	8 (29.6%)	18 (53.0%)	12 (40.0%)	31 (64.6%)	28 (58.4%)
Father Ethnicity (175/222)						
Hispanic (%)	4 (33.3%)	12 (46.2%)	20 (60.6%)	20 (69.0%)	19 (48.7%)	18 (50.0%)
Mexican (%)	6 (50.0%)	8 (30.8%)	8 (24.2%)	6 (20.7%)	17 (43.6%)	14 (38.9%)
Other (%)	2 (16.7%)	6 (23.1%)	5 (15.2%)	3 (10.3%)	3 (7.7%)	2 (11.1%)
Father Education Level Completed (175/222)						
Graduated high school (%)	4 (33.3%)	13 (50.0%)	9 (27.2%)	5 (17.9%)	9 (26.5%)	7 (19.5%)
Completed some college (%)	4 (33.3%)	3 (11.5%)	2 (6.1%)	5 (17.9%)	5 (14.7%)	5 (13.9%)
Other (%)	4 (33.3%)	10 (38.5%)	22 (66.7%)	18 (64.3%)	20 (58.8%)	29 (80.6%)
Income (189/222)						
= 10K (%)	1 (10.0%)	1 (4.0%)	8 (24.3%)	5 (17.9%)	20 (43.5%)	28 (59.6%)
> 10K and = 20K (%)	6 (60.0%)	13 (52.0%)	15 (45.5%)	11 (39.3%)	18 (39.1%)	12 (25.5%)
> 20K and = 30K (%)	1 (10.0%)	5 (20.0%)	5 (15.2%)	3 (10.7%)	3 (6.5%)	6 (12.8%)
Other (%)	2 (20.0%)	6 (24.0%)	5 (15.2%)	9 (32.1%)	5 (10.9%)	1 (2.1%)

Table 2

One-Way Analysis of Variance of Blood Lead, Cadmium, and Mercury Levels Comparing Two Rural Settings

Metal	Source	df	SS	MS	F	*p*
Pb	Between groups	1	0.28	0.282	0.26	0.61
	Within groups	109	117.0	1.07		
	Total	110	117.3			
Cd	Between groups	1	0.003	0.003	0.84	0.36
	Within groups	109	0.4	0.003		
	Total	110	0.35			
Hg	Between groups	1	0.001	0.001	1.17	0.28
	Within groups	109	0.07	0.001		
	Total	110	0.07			

Table 3

Type III Fixed Effects and Parameter Estimates for Associations between Child Blood Lead Levels, Controlling for Gender and Age, Living in Rural and Urban Settings (N = 222)

Type III fixed effect				*Solutions for fixed effects*					
	F	*p*			Est	SE	DF	t-value	*p*
Full Model				*Intercept*	3.29	0.39	1	8.38	0.00
Age	1.80	0.18		Age	-0.059	0.044	1	-1.34	0.18
Location	126.01	**0.00**		Location Urban	1.75	0.25	1	-6.93	**0.00**
Gender	0.74	0.39		Location Rural	0.00	-	-	-	-
Location x Gender	0.12	0.73		Gender Male	0.081	0.22	1	0.37	0.72
				Gender Female	0.00	-	-	-	-
				Location Urban x Gender Male	0.11	0.341	1	0.35	0.73
				Location Urban x Gender Female	0.00	-	-	-	-
				Location Rural x Gender Male	0.00	-	-	-	-
				Location Rural x Gender Female	0.00	-	-	-	-
Reduced Model				*Intercept*	2.86	0.12	1	23.83	0.00
Location	125.12	**0.00**		Location	1.72	0.17	1	-10.12	**0.00**

Table 4

Type III Fixed Effects and Parameter Estimates for Associations between Child Blood Cadmium Levels, Controlling for Gender and Age, Living in Rural and Urban Settings (N = 222)

Type III fixed effect				*Solutions for fixed effects*					
	F	*p*			Est	SE	DF	t-value	*p*
Full Model				*Intercept*	0.065	0.022	1	2.93	0.00
Age	1.42	0.24		Age	-0.003	0.002	1	-1.19	0.24
Location	1.32	0.25		Location Urban	-0.1	0.013	1	-0.8	0.43
Gender	0.38	0.54		Location Rural	0.00	-	-	-	-
Location x Gender	0.00	0.99		Gender Male	0.01	0.013	1	0.439	0.66
				Gender Female	0.00	-	-	-	-
				Location Urba x Gender Male	-0.00007	0.018	1	-0.004	0.99
				Location Urban x Gender Female	0.00	-	-	-	-
				Location Rural x Gender Male	0.00	-	-	-	-
				Location Rural x Gender Female	0.00	-	-	-	-

Table 5

Type III Fixed Effects and Parameter Estimates for Associations between Child Blood Mercury Levels, Controlling for Gender and Age, Living in Rural and Urban Settings (N = 222)

Type III fixed effect				*Solutions for fixed effects*					
	F	*p*			Est	SE	DF	t-value	*p*
Full Model				*Intercept*	-0.008	0.033	1	-0.23	0.82
Age	4.67	**0.03**		Age	0.007	0.003	1	2.16	**0.03**
Location	2.61	0.11		Location Urban	-0.015	0.022	1	-0.69	0.49
Gender	1.40	0.24		Location Rural	0.00	-	-	-	-
Location x Gender	0.35	0.55		Gender Male	0.03	0.026	1	0.99	0.32
				Gender Female	0.00	-	-	-	-
				Location Urban x Gender Male	-0.017	0.029	1	-0.59	0.55
				Location Urban x Gender Female	0.00	-	-	-	-
				Location Rural x Gender Male	0.00	-	-	-	-
				Location Rural x Gender Female	0.00	-	-	-	-

Table 6

Blood Lead, Cadmium, and Mercury Levels Regressed Hierarchically on Gender, Age, and Living in Rural and Urban Settings

		Model 1			Model 2			Model 3		
Metal	Variable	B	SE B	ß	B	SE B	ß	B	SE B	ß
Pb	Location	0.88	0.079	0.6	0.88	0.078	0.61	0.88	0.078	0.60
	Age				-0.063	0.044	-0.077	-0.059	0.044	-0.073
	Gender							-0.014	0.16	-0.047
	R2		0.36			0.40			0.37	
	F for change in R2		125.13			2.08			0.74	
	p-value		0.00			0.15			0.39	
Cd	Location	0.005	0.004	0.075	0.005	0.004	0.078	0.005	0.004	0.08
	Age				-0.003	0.002	-0.085	-0.003	0.002	-0.081
	Gender							-0.006	0.009	-0.042
	R2		0.006			0.01			0.015	
	F for change in R2		1.23			1.60			0.38	
	p-value		0.27			0.21			0.54	

Table 6 (Continued)

		Model 1				Model 2				Model 3		
	Variable	B	SE B	ß		B	SE B	ß		B	SE B	ß
Hg	Age	0.007	0.003	0.183		0.007	0.003	0.176		0.007	0.003	0.183
	Location					0.025	0.14	0.145		0.024	0.014	0.141
	Gender									-0.012	0.12	-0.086
	R2		0.033				0.054				0.062	
	F for change in R2		4.81				3.05				1.06	
	p-value		0.03				0.083				0.305	

Discussion

4.1 Summary of Major Findings

Historically, the border town of El Paso, Texas was known to have heavy metal contamination as a result of several factors including close proximity to a large smelting plant located within one mile of downtown El Paso and industry pollution from Mexican industry operating across the Rio Grande River. While there has been much progress in reducing child lead poisoning, the problem of early chronic low-level exposure continues. It is important to determine whether children in a region with historical contamination are at ongoing risk for low-level lead exposure.

The main goal of the present study was to compare the blood lead levels of children living in the historically contaminated region (downtown El Paso, TX) to those living in a demographically similar but geographically distinct rural area. In the present study, 111 children in the urban setting, living in the zip codes historically considered at "high risk" for lead exposure, where compared to children living in a rural setting north of El Paso. It was found that children living in the urban setting had significantly higher BLLs (2.86, ±1.29), than children living 20 miles north of El Paso (1.11±1.03). For comparison, cadmium and mercury blood levels were also measured and were not found to be significantly elevated in urban children. Additionally, it was shown that gender and age were not a contributing factor to these models. Only the location of the children, whether it be the urban or rural setting was a predictor of the children's BLLs.

4.2 History of Lead Contamination in the El Paso, Texas Urban Setting

A major source of historical contamination in the downtown El Paso border region was a smelting plant located within one mile of downtown El Paso. The smelter was constructed in 1887 and lead smelting was the primary function of this facility when copper smelting was also initiated (lead smelting continued until 1985). In the beginning of the 1950s the smelting plant initiated a cadmium roasting unit. The 828 foot- high stack that would become the emblem of the smelting plant was built in 1967 (Texas Department of Health, 2001).

Shortly after the stack was built, the El Paso City-County Health Department discovered that large quantities of lead and other metals were being discharged by this ore smelter. For more than one hundred years the smelter had been contaminating the air and soil with various smelter associated elements (Romero, 1984). According to this discovery, only between the years of 1969 and 1971, 1,116 tons of lead, 12 tons of cadmium, and 1.2 tons of arsenic were released by the smelter.

In 1979 the smelting plant spent $90 million in renovations to improve emission quality, but even then 96 tons of lead per year was being emitted until lead smelting was stopped in 1985; copper smelting was suspended in 1999. In 2005 the smelting plant filed for bankruptcy and in 2009 permanent closure of the site was announced (Darby, 2012). The smelter plant was then purchased by a mining company which later became engaged in the largest environmental bankruptcy in United States history (Blumenthal, 2009).

4.2.1 Early Environmental Sampling and Blood Testing in the Urban Setting of El Paso

The fact that this study found children in downtown El Paso continue to have significantly higher concentrations of blood lead as compared to children in nearby rural area is perhaps not surprising. There is a great deal of evidence regarding the historical contamination of downtown El Paso. In 1971, before any kind of testing was started, a public health director estimated that about 2,700 persons between the ages of one and nineteen had BLLs $\geq$ 40µg/dL and that all residents living within a four mile radius of the smelter plant were affected (Romero, 1984). Initial studies focused on soils in “Smeltertown”, that is, the smelter company town located adjacent to the smelter, and in directly surrounding areas. High BLLs were found in children and adults living in Smeltertown, but high BLLs were also found in children living in different parts of El Paso (Landrigan, 1975).

After the discovery of heavy metal emissions, especially lead, various studies were conducted to determine air quality, soil contamination, and BLLs in the population residing near the smelter. For example, twenty-four hour high-volume air samples to determine the amounts of lead and other heavy metals suspended in the atmosphere were collected throughout two time periods, one in 1971 and again between July 1972 and June 1973. The highest concentrations of metallic wastes in the air were found directly downwind of the smelter. Throughout both time periods of the study it was also found that metal concentrations in the air decreased as distance from the smelter plant increased. In 1971 the mean lead level was 92 µg/m3of air. Between 1972 and 1973 the mean lead level was 43 µg /m3 well above the limit for airborne lead content which is currently 0.15 µg /m3 of air (Landrigan, 1975; MMWR, 1997; NAAQS, 2014).

During the same time air samples were being collected, soil samples at 99 sites in El Paso were also being collected. Samples were taken at the surface and at depths of 2.5, 5.0 and 7.5 cm. Within the city of El Paso, the highest levels were found in within 200 m of the smelter and lead concentration was highest at the surface in 1972. Lead surface levels decreased as distance increased, but levels remained above background levels as far as 10 km from the smelter. When the soil samples were tested again in 1973 it was found that the extensive distributions for all metals sampled were unchanged (Landrigan, 1975; MMWR, 1997).

Once environmental contamination was examined, specifically in the air and soil, studies began to measure BLLs in the population. In a study by Landrigan et al. (1972), 758 children, aged one to 19 living in close proximity to the smelter plant were tested for lead and surveyed.

The area surveyed was divided along census-tract boundaries into three strata, roughly within a one mile radius from the smelter and were designated area I, II, and III. Area I included Smeltertown. It was found that area I had significantly higher BLLs than area II and III with levels as high as 40 to 59 µg/dL. Landrigan et al. concluded that the one mile radius area of the smelter plant was the principle source of lead contamination for the region. Blood lead levels measured in these studies would be way above the current threshold designated by the CDC of 5.0µg/dL.

In an epidemiologic follow-up study by Morse et al. in 1977 children living within one mile of the smelter were surveyed. Venous blood specimens were obtained from 140 children aged 1 through 18 years old. Mean BLL this time was 20.0µg/dL, with some children still having BLLs above 40µg/dL. One hundred thirty-seven children examined lived between 0.5 to 1.0 miles from the smelter. When comparing the blood lead results for these 137 children with the results obtained by Landrigan et al. (1972) in 96 children, mean BLLs had decreased from 31.2µg/dL to 20.2µg/dL. The principle finding in this follow-up study was that BLLs in children living within 1.0 miles from the smelter plant had decreased significantly from 1972 to 1977. Although the smelter plant was no longer operating, pollutants emitted from the plant, remain in the region's soil, and it could as well be in the bodies of residents that still live in the vicinity of it (Ketterer, 2006).

4.2.2 Recent Environmental Sampling and Blood Testing in Urban Setting of El Paso

Recent studies that have focused more on the environmental aspect of contamination from the smelting plant have also concluded that lead concentrations in the soil are higher near the smelter plant.

A study by Pingitore et al., (2005), analyzed heavy metal concentration in the surrounding areas of the smelting plant using an atomic emission spectrometer. The highest levels of lead and cadmium, among other heavy metals, were found in the downtown region and on the west side of the Franklin Mountains. It was also noted that the concentrations of lead and cadmium among other heavy metals, found to be highest in the area surrounding the smelting plant, and decreased with distance from it. It was concluded that these high levels of heavy metals found in the downtown region appeared to be associated with the location of the smelter plant.

In 2001, a comprehensive study of lead levels in the soil throughout El Paso was conducted by the University of Texas of El Paso and the Texas Tech Health Sciences Center. It was found that in the peripheral areas the lowest concentrations of lead were encountered. Although old neighborhoods and houses were sampled, all soil samples were below 50 parts per million. The highest concentrations of lead in the soil found were in excess of 150 parts per million and were located in the downtown area. According to the study, the elevated values can be attributed to the smelter plant since it had been in operation for more than one hundred years. These elevated levels could also be attributed to urban congestion, such as vehicular emissions from a nearby highway, a major railway system, and construction using lead-based paint (ATSDR, 2004).

Since the first study by Landrigan et al. 1972 examining soils in the proximity of the smelting plant, other studies have also been able to identify the pattern of contamination with lead and cadmium. The spatial pattern of contamination has also been repeatedly identified by these studies, which shows that concentrations were higher near the smelter plant, while decreasing when moving away from it (Ketterer, 2006).

According to the Texas Department of Health, data obtained for 1997-1999 from the Texas Childhood Lead Surveillance Program for El Paso County found that out of the 2,628 children 117(4.5%) of the children living in zip codes considered “high risk” for lead exposure had BLL >10µg/dL. These were higher BLLs than what was found in the rest of El Paso County, outside of the “high risk” area in downtown. This study also identified an odds ratio 4.5 for the relationship between a 500 parts per million increase in soil lead and blood lead level >10 µg/dL (ATSDR, 2004).

The most recent study to measure BLLs in children living near the smelting plant was from Sobin et al. (2009). Testing was done in children residing in zip codes located in downtown El Paso that are considered “high risk” for lead exposure. This study designated children with BLLs ≥4.0 µg/dL as “exposed” children and children with BLLs 3.2≤ µg/dL as “unexposed” children. It was found that the average of the children designated “exposed” had mean BLLs of 4.9µg/dL and children designated “unexposed” had a mean BLL of 2.8µg/dL. This study suggests that over 50% of children living in this historically contaminated neighborhood have BLLs ≥2.0 µg/dL.

These studies show that although levels of heavy metal contamination in the downtown area are not as high as when the smelter plant was open, there are still contamination sources that are affecting children. This is reflected by the significantly higher BLLs found in children living in the urban setting.

4.3 Identification of Other Point-Sources of Heavy Metals in Urban Setting

Although identifying the specific sources of heavy metal contamination was not an aim in this study, past studies have tried to examine which heavy metal sources contribute to exposure in children living in the downtown area. According to the CDC, lead-based paint remains the most common source of exposure for children and according to the city census data, the "high risk" zip code of interest for this study has almost 80% of houses that were built before 1978, when lead-based paint was finally banned (CDC, 2015; Census, 2013).

The Texas Department of Health, in an effort to determine if lead-based paint was a major contributor in the "high risk" area, performed a regression analysis of the percentage of children with BLLs > 10µg/dL with the median year the house was built. The data used was from the Texas Childhood Lead Surveillance Program for El Paso County. It was concluded in this study that the percentage of children who had elevated BLLs (>10µg/dL) increased as the median age of the houses increased. Other potential sources that could be contributing to lead exposure in children includes lead in soil, old water pipes, lead from food stored in glazed pottery, or home remedies (ATSDR, 2004).

4.4 Differences in Blood Lead Levels are Due to Geographical Location

Having matched the participating children on gender and age, and all children had very similar sociodemographics such as ethnicity, income and household size (see Table 1). It was concluded that the significant differences in BLL were explained by whether the child was living in the rural or urban setting. In this way, the findings suggest that downtown El Paso continues to represent a "hot spot" for continuing exposure

4.5 The Problem of Child Low-Level Heavy Metal Exposure Persists

Although the prevalence of child lead poisoning and overall BLLs have decreased in the United States over the past four decades, high levels persist in low socioeconomic communities. Over half of the children living in the urban area have elevated (≥2.0 µg/dL) BLLs, even after the smelter plant, which is believed to be the major source of contamination has been shut down for almost 10 years.

It is known that chronic low-level heavy metal exposure is of great concern, especially for lead, as many, many child studies have shown. Increasing numbers of studies suggest that low-level environmental lead exposure yielding child BLLs as low as 2.5μg/dL are associated with poorer memory, attention, lower IQ and reduced academic achievement (Canfield, 2003; Chiodo, 2004). Organ systems can also be affected at very low-levels of lead exposure (Basgen, 2013). Studies also suggested that low–level environmental cadmium and mercury exposure can cause damage on organ systems and can also cause neurocognitive deficits. The mean BLL identified in the children living in the urban area was 2.8μg/dL. Children in this urban setting should be routinely screened for neurocognitive and behavioral deficits.

In C57BL/6J mice studies, it has been shown that very low-levels of lead exposure can cause deficits in recognition memory. This effect was seen in levels as low as 2.02 μg/dL (Flores-Montoya et al. 2015), levels lower than the mean BLL found in the current study in urban children. One way in which early low-level lead exposure affects the brain is by the disruption of the hippocampus/dentate gyrus regions, which are critical regions for memory and learning. Lead is able to affect different kind of brain cells such as microglia (Sobin, 2013); and astroglia and oligodendroglia which provide protection to the brain (Sanders, 2009). Another effect found in very low-level lead exposure in animal studies is glomerular hypertrophy. This means that there is a disruption in the kidney structure associated with early stage kidney disease. These effects were seen in mice studies in levels as low as 2.4 and 4.7μg/dL, (Bergen et al. 2013) again, levels that were seen in children living in the urban area.

One reason why lead, cadmium, and mercury, along with other heavy metals, could still be present in the soil after years of the smelting plant being shut down is because they are known to be non-biodegradable. Once the soil has been contaminated, it remains a long-term source of heavy metal exposure (Tangahu et al., 2011). Various studies have determined that there are differences in retention and mobility between heavy metals, especially lead and cadmium since they are frequently found together in regions with high smelting or mining activities (Rodriguez-Maroto et al., 2003).

There are several factors that affect the mobility of heavy metals in the soil, these include pH, soil nature, contaminant concentration, presence of other chemicals, and organic matter content (Ahmadipour, 2014; Machado, 2012). Studies have determined that cadmium had a higher mobility potential in various soil samples than lead and also had a lower retention time than lead. According to Machado et al. (2012), cadmium concentrations, although still being a matter of concern, seem less problematic because of the higher mobility of cadmium. Meanwhile, mercury in the soil is regarded as highly immobile and strongly retained in various soil samples (Liao, 2009).

Throughout the years BLLs have decreased dramatically, especially in children living in the urban area, but the levels seen in the current study are of concern since neurocognitive deficits and organ system damage can be present at very low levels.

4.6 Limitations

Although the aims of the study were accomplished, some limitations are important to consider. The most important limitation in this study was that dietary intake was not considered or addressed. It is known that intake of contaminated food is a source of heavy metal ingestion, especially for mercury in fish (Zahir, 2005). It is also known that foods rich in selenium (e.g. eggs, poultry, and mushrooms) and vitamin E can counteract the toxicity of heavy metals. Selenium is known to counteract toxicity of cadmium, inorganic mercury, methylmercury and vitamin E is known to be more effective against lead toxicity (Whanger, 1992). Another limitation was that mercury levels were not obtained for all children in the urban setting since testing for mercury in ICP-MS is a very expensive procedure.

4.7 Future Research

Several follow up studies need to be conducted to replicate and expand on the findings in this study. Children must be retested to determine whether lead, cadmium, and/or mercury levels are consistent with the current findings. Exposure sources for these three heavy metals especially in the urban setting must be identified. Also, effective approaches for community education regarding heavy metal contamination and childhood exposures are needed.

It is important to retest children at least every 6 months to determine if there is any seasonal variability in blood lead, cadmium, and mercury levels. It may be possible that seasonality, or wind patterns during the year can have an effect on child blood lead and cadmium levels.

While it is widely believed that the smelting plant was the main contributor of historical heavy metal air and soil contamination in the urban area, there are other point sources that could also be contributing to current low-level lead exposure in children. It has been well documented that lead-based paint is major contributor of lead contamination in the children. It is essential to identify specific sources in order to address the potential for chronic heavy metal exposure. Exposure sources for cadmium are equally important to identify. Although cadmium levels found in the children’s blood were very low it is important to avoid contamination from any identified source. Also, very low levels of mercury exposure were detectable in children’s blood and were significantly associated with age, so identification of mercury exposure is necessary to determine if the exposure was an acute exposure (occurred over a short period of time) or if it was a one-time exposure.

It is equally important to be able to educate the community about the possible health effects associated with heavy metals. Parents expressed their concern when blood lead, cadmium, and arsenic results of their children were given and would ask questions about what could be done to reduce those levels. Providing this information at regular intervals throughout the school year could be done through various community-based workshops including parents as well as their children. From the environmental perspective, regularly testing soil for heavy metal contamination could be valuable. For example, the implementation of soilSHOPs can greatly benefit vulnerable communities.

Both the rural and urban communities in El Paso, especially the urban community, are in great need of having the sources of exposure identified. It is an environmental injustice that children living in downtown El Paso continue to be exposed to heavy metals (Darby, 2012). Moreover, there is a marked disparity between the chronic low-level contamination and contamination mandates. The low-income communities living near the historical smelting plant site are the ones suffering the consequences of this injustice.

Conclusion

Although the prevalence of lead poisoning has decreased significantly, lead exposure is still present as was seen in children living in the urban setting. Children in the urban setting had significantly higher BLLs than children in the rural setting. Based on our findings, the mean BLLs found in the rural and urban settings were below the current threshold of 5.0μg/dL, but some children in both the urban and rural area had BLLs above the "threshold of concern". It is known that levels below the threshold can cause neurocognitive deficits and organ system damage. While the smelter plant located one mile from the urban setting has been shut down, continuing contamination exists from that source and from other point-sources primarily affecting children.

Furthermore, increased efforts should be made to monitor children's blood lead, cadmium, and mercury in the rural and urban communities. Especially in the urban area, efforts should also be made to identify potential contamination sources that could increase heavy metal exposure in children. Finally, more community-based approaches should be taking part in both the rural and urban settings to educate parents and children about the potential effects heavy metals can cause and identifying potential sources of contamination.

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Curriculum Vita

Juan M. Alvarez was born in El Paso, Texas. The first son of Juan M. Alvarez and Veronica Alvarez, he graduated from Americas High School, El Paso, Texas, in the spring of 2008 and entered The University of Texas at El Paso in the fall. While pursuing a bachelor's degree in Biomedical Sciences, he worked as a student assistant for the College of Science and as a research assistant for the Clinical Laboratory Sciences Department. He received his bachelor's degree in the spring of 2012 and began to pursue a Master's of Public Health at The University of Texas at El Paso. While pursuing the master's degree, he attended the Society for Neuroscience in fall of 2014 in Washington D.C. and presented the study *"A study of the object-in-place visual recognition paradigm for measuring memory impairment in young C57BL6J mice with early chronic low-level lead exposure".* He also interned with the National Center for Environmental Health (NCEH) and with the Agency for Toxic Substances and Disease Registry (ATSDR) during the summer of 2015 in Region 2, New York and New Jersey. During this time he was co-author of the publication "*Olfactory recognition memory is disrupted in young mice with chronic low-level lead exposure"* in the journal of *Neurotoxicology and Teratology.*

Juan plans to work for the Centers for Disease Control and Prevention in Region 2 in an ORISE fellowship and work with the Hispanic community in New Jersey in New York.

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