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MEMORY AND FINE MOTOR SKILL TEST PERFORMANCE
AMONG CHILDREN LIVING NEAR COAL ASH STORAGE SITES

By

Lindsay Koloff Tompkins
B.S., University of North Carolina, 2012

A Thesis
Submitted to the Faculty of the
School of Public Health and Information Sciences
of the University of Louisville
in Partial Fulfillment of the Requirements
for the Degree of

Master of Science
in Epidemiology

Department of Epidemiology and Population Health
University of Louisville
Louisville, Kentucky

August 2016

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ABSTRACT

MEMORY AND FINE MOTOR SKILL TEST PERFORMANCE AMONG CHILDREN LIVING NEAR COAL ASH STORAGE SITES

Lindsay Koloff Tompkins

August 2, 2016

Coal ash, a byproduct of coal combustion, is produced in 47 U.S. states and frequently contains heavy metals, some of which are known neurotoxins. An estimated 1.5 million children live near sites where coal ash is produced and stored, yet there have been no studies assessing coal ash exposure and children's neurobehavioral health.

This study is part of a larger cross-sectional study, Coal Ash and Neurobehavioral Symptoms in Children Aged 6-14 Years Old, and aimed to determine the relationship between children's memory and fine motor skill test performance and the proximity of the home to coal ash storage sites, the participants' heavy metal body burdens, and presence of fly ash in the home. Children aged 6 to 14 years who lived near coal ash storage sites in Louisville, Kentucky were recruited to participate. Participation involved the completion of a battery of neurobehavioral tests, the collection of toenails and fingernails, and air and lift sampling in the home.

Neurobehavioral test data and home distance to ash landfill were available for 55 participants, while nail analysis was available for 32 participants and fly ash data were available for 49 participants.

The results of this study were impacted by a small sample size; however, several patterns were identified. Though not significant, the odds of abnormal or low performance on five neurobehavioral tests were higher among those who lived closer to an ash landfill (OR range = 1.035-4.549). The presence of titanium, manganese, and strontium in nail samples were each significantly related to abnormal performance on certain neurobehavioral tests, while higher levels of zinc and copper were significantly related to abnormal or low test performance. Fly ash was confirmed in 42.9% of homes, and though not significant, the odds of abnormal or low performance on seven neurobehavioral tests were higher among those with fly ash in their homes (AOR range = 1.150-2.134). The relationship between memory and fine motor skill test performance should be further evaluated as the overarching study's sample size continues to grow.

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I. BACKGROUND AND SIGNIFICANCE

Coal Ash and Fly Ash

In 2014, coal-fired electric utilities in the United States generated approximately 130 million tons of coal combustion residuals, commonly known as coal ash (American Coal Ash Association [ACAA], 2015a). This coal ash was generated in all U.S. states except Rhode Island, Vermont, and Idaho (U.S. Energy Information Administration [EIA], 2016a). Coal is the primary energy source in the United States as a whole as well as the primary energy source for 24 states (EIA, 2016c). In 2014, while 62.4 million tons of coal ash were recycled and used in products such as concrete, roofing granules, and gypsum wallboard, much of the coal ash was disposed of in on- or off-site landfills or ponds (U.S. Department of Transportation, 2015; ACAA, 2015b; U.S. Environmental Protection Agency [EPA], 2015b). The United States Environmental Protection Agency (EPA) estimates that there are more than 310 active on-site landfills and over 735 active surface impoundments, or ponds, across the country, existing in every state except Rhode Island, Vermont, and Idaho (EPA, 2015b).

The properties of coal ash are dependent on several factors, including the composition of the coal burned, conditions during burning, and climate (Adriano, Page, Elseewi, Chang, & Straughan, 1980). Despite the differences in makeup, coal ash frequently contains heavy metals, radioactive elements, and polycyclic aromatic hydrocarbons (PAHs) (Brown, Jones, & BeruBe, 2011; el-Mogazi, Lisk,

& Weinstein, 1988; Roy, Thiery, Schuller, & Suloway, 1981; Roper, Stabin, Delapp, & Kosson, 2013; Tang et al., 2008). Coal ash consists of several different components, including bottom ash, boiler slag, synthetic gypsum, and fly ash. Bottom ash and boiler slag are comprised of heavier particles that fall to the bottom of the furnace or boiler during coal combustion (Liberda & Chen, 2013). Though bottom ash and boiler slag are similar in composition to fly ash, they are less likely to be inhaled due to their large size and have lower leaching characteristics (Liberda & Chen, 2013). In 2014, approximately 12.5 million tons of bottom ash were produced in the U.S., about 49% of which was reused (ACAA, 2015a). The remaining amount was stored in coal ash ponds or landfills. Synthetic gypsum, another form of coal ash, is produced in the chemical scrubbers of coal-fired power plants (Adriano et al., 1980; Liberda & Chen, 2013). These scrubbers remove sulfur dioxide from flue gas, and through a chemical reaction involving sulfur dioxide, a limestone or chemical slurry, and water, synthetic gypsum is produced (Adriano et al., 1980; Liberda & Chen, 2013). In 2014, approximately 34 million tons of synthetic gypsum was produced by coal-burning power plants in the U.S., and approximately 50% of the gypsum produced was reused while the remaining 50% was stored in coal ash ponds or landfills (ACAA, 2015a).

Fly Ash

The most common component of coal ash is fly ash (ACAA, 2015a). Fly ash is made up of small, spherical particles with diameters predominately $\leq 10 \mu\text{m}$ (PM_{10}) (Roy et al., 1981; Patra, Rautray, Tripathy, & Nayak, 2012). During

coal combustion, fine liquid droplets are released and carried away by flue glasses (Brown et al., 2011). As the particles rise through the smokestack, the liquid droplets undergo rapid solidification and small, glassy, perfectly spherical particles form (Brown et al., 2011). These small spherical particles are fly ash and often appear as tan or gray in color of fine to medium silt-size depending on the coal source (Brown et al., 2011; el-Mogazi et al., 1988; U.S. Department of Transportation, 2015). Fly ash particles collect in air pollution control devices and, after removal, are transported in trucks to ash ponds and landfills for storage. In 2014, 50.4 million tons of fly ash were produced, approximately 46% of which were reused while the other 54% were stored in landfills and ponds (ACAA, 2015a; ACAA, 2015b).

When fly ash is disposed of in ponds or landfills, the particles can be emitted into the air during the loading, unloading, and transportation processes. Wind conditions can exacerbate the number of fly ash particles that are made airborne. Once the particles are airborne, they can travel distances of up to hundreds of kilometers before settling (World Health Organization Europe, 2006). These migrating particles are often referred to as fugitive dust. Fugitive dust emissions are also related to the maintenance of ash landfills. For example, dry, uncovered landfills are more prone to emit fugitive dust than wet, covered landfills. For this reason, the EPA now mandates that ash ponds and landfill operators develop fugitive dust plans, including the installation of water spray systems, use of wind barriers, and covers for trucks transporting ash to ponds and landfills, in order to protect against fugitive dust emissions (EPA, 2015b).

The elemental composition of fly ash depends on the properties of the coal that was burned; however, the five most common elemental components of fly ash include silicon, aluminum, iron, calcium, and oxygen (Brown et al., 2011; Borm, 1997). Commonly found trace elements include nickel, vanadium, arsenic, beryllium, cadmium, copper, zinc, lead, mercury, selenium, radon, and molybdenum (Brown et al., 2011).

Storage and Disposal of Coal Ash

Until late 2014, the disposal of coal ash was not federally regulated (EPA, 2015a). Coal ash has been classified as a non-hazardous solid waste, and, under Subtitle D of the Resource Conservation and Recovery Act of 1976 (2009), can be stored in open-air impoundments and landfills (EPA, 2015a). On December 19, 2014, the EPA signed the Disposal of Coal Combustion Residuals from Electric Utilities Rule, which provides a set of requirements for the disposal of coal ash from coal-fired power plants, including technical requirements for coal ash storage landfills and ponds (EPA, 2015a; Hazardous and Solid Waste Management System, 2015). While coal ash is still not considered a hazardous waste, there are now federal regulations requiring a minimum set of criteria for new and existing ash ponds and landfills (Hazardous and Solid Waste Management System, 2015). These criteria include the installation of groundwater monitoring devices, design and operating rules, recordkeeping and Internet posting requirements, closure requirements, and post-closure care plans (Hazardous and Solid Waste Management System, 2015). New coal ash storage sites will face location restrictions and must meet design criteria (Hazardous and

Solid Waste Management System, 2015). Existing coal ash ponds or landfills that still receive coal ash and cannot meet the new criteria must retrofit or close (Hazardous and Solid Waste Management System, 2015). Ash ponds or landfills that no longer receive coal ash but still contain coal ash are still subject to these new regulations, unless a final cover system is installed within three years of the new rule's effective date (Hazardous and Solid Waste Management System, 2015). The effective date of this rule was October 19, 2015 (Hazardous and Solid Waste Management System, 2015).

Coal Ash and Fly Ash in Kentucky and Louisville

Kentucky has a long history of burning coal for energy. Kentucky ranks fifth in coal ash generation in the U.S., with annual generations exceeding 9 million tons (Evans, Becher, & Lee, 2011). In 2015, coal fueled 87% of Kentucky's net electricity generation (EIA, 2016b). Kentucky has the 3rd largest coal ash storage capacity in the country with a total of 43 ash ponds and at least 12 landfills (Evans et al., 2011). As of November 2015, Kentucky has 14 active coal-burning power plants (EIA, 2016d). Two of the power plants of great concern in Kentucky are located in Louisville along the Ohio River approximately 10 miles from one-another. The plants are operated by Louisville Gas & Electric (LG&E). These plants are surrounded by neighborhoods and schools and have been the source of many complaints regarding fly ash that escapes from the property's landfills and ponds. In total, the Louisville power plants have burned over 6 million tons of coal per year.

Cane Run

LG&E's Cane Run Generating Station opened in 1954 and occupies over 500 acres in west Louisville (LG&E, n.d.; LG&E, 2013). The Cane Run plant houses one large ash pond with a surface area of approximately 40 acres and a dam height of 12 feet (Adnams, Stellato, & Harris, 2010; E.ON U.S., n.d.). The pond is approximately 1,200 feet east of the Ohio River and opened in 1972 (Adnams et al., 2010). The pond stores bottom ash, fly ash, and other plant materials (Adnams et al., 2010). Prior to 1972, another ash pond existed in the area now occupied by the plant's landfill (Adnams et al., 2010). The EPA has given Cane Run's main ash pond a high hazard potential rating, meaning that failure of the structure "would probably result in loss of human life (EPA, 2009; Hazardous and Solid Waste Management System, 2015)." Four additional ponds are housed on the property, one of which, the Clearwell Pond, potentially contains coal ash (Adnams et al., 2010).

The plant's ash landfill opened in 1982 and stores a mixture of coal ash products (E.ON U.S., n.d.). It sits alongside the Ohio River. As of 2010, the landfill was estimated to have an elevation of at least 560 feet and a surface area of 110 acres (Adnams et al., 2010; E.ON U.S., n.d.).

LG&E's Cane Run Generating Station converted to natural gas in early July 2015 in part due to the cost involved in complying with the newest air pollution regulations (LG&E, n.d.; Bruggers, 2015). It was determined that building a new plant that burns natural gas would make the issue of compliance less expensive (Bruggers, 2015). Though the ash pond and landfill at Cane Run

no longer receive coal ash, they have not yet been completely capped or closed. In response to the EPA's Disposal of Coal Combustion Residuals from Electric Utilities Rule, the ash pond at Cane Run is scheduled to close by April 17, 2018 (Herron, 2015). This closure will involve the placement of a soil cover over the ash pond, the lining of a storm water pond, and the addition of drainage facilities, as well as other closure activities (Herron, 2015). Additionally, LG&E is planning to cap and close Cane Run's ash landfill, although its plan and timeline have not yet been posted (LG&E, n.d.).

Mill Creek

The Mill Creek Generating Station began operating in 1972 and sits on 544 acres in southwest Louisville alongside the Ohio River (LG&E, n.d.). Mill Creek is currently LG&E's largest coal-fired power plant with a generating capacity of 1,472 megawatts (LG&E, n.d.). This plant generates coal ash in the form of fly ash, bottom ash, boiler slag, and gypsum (LG&E, 2015). Any forms of coal ash that cannot be repurposed are disposed in the on-site ash ponds or on-site landfill (LG&E, 2015).

The Mill Creek plant is home to one large ash pond that opened around the same time as the plant began operating in 1972 (E.ON U.S., n.d.; Bowers & Cormier, 2009). Materials stored in the pond include fly ash, bottom ash, and gypsum (E.ON U.S., n.d.). The large ash pond covers a surface area of approximately 43 acres, with dikes on the north, east, and west sides. The pond's western dike barricades the pond from the Ohio River and sits approximately 77 feet above the normal surface of the river at its highest point

(Bowers & Cormier, 2009). The height of the northern dike varies, but is at its highest point where it meets the western dike, and the eastern dike ranges 18 feet near the northern dike to 10 feet near the south end of the pond (Bowers & Cormier, 2009). All of the dikes were constructed using the clay, sand, and silt that were excavated during pond construction (Bowers & Cormier, 2009). The southern side of the ash pond is completely incised below surrounding grades (Bowers & Cormier, 2009). The total storage capacity of the large ash pond is 6.914 million cubic yards (Zimmerman, 2016). As of October 13, 2015, the total volume of stored materials was estimated to be 6.251 million cubic yards, including an impounded water volume of 0.509 million cubic yards (Zimmerman, 2016). The EPA has given this ash pond a high hazard potential rating like that given to the ash pond at the Cane Run plant (EPA, 2009).

There are four other small ponds in addition to the large ash pond at the Mill Creek plant (Bowers & Cormier, 2009). Three of these ponds are used for sedimentation prior to discharge into the Ohio River, and they all contain flue gas emission controls residual, including gypsum (Bowers & Cormier, 2009).

The plant's ash landfill opened in 1982 (E.ON U.S., n.d.). As of November 2015, the landfill was estimated to have a maximum elevation of 598 feet and occupies a surface area of 206 acres (Holm, 2016; E.ON U.S., n.d.). In August 2015, the landfill was estimated to contain a total of 12.985 million cubic yards of coal ash (Holm, 2016). The landfill is not lined (Holm, 2016).

LG&E announced in January 2016 that it plans to close the ash ponds at the Mill Creek plant in response to the EPA's Disposal of Coal Combustion

Residuals from Electric Utilities Rule, but does not expect for this to be completed until 2020 (LG&E, n.d.). There are currently no plans to close the landfill at Mill Creek, as this landfill continues to receive coal ash from the Mill Creek plant, and LG&E states that this landfill meets new EPA regulations (LG&E, n.d.).

Coal Ash and Human Health

Humans may be exposed to coal ash through inhalation, skin absorption, and oral ingestion. The small size and shape of fly ash particles makes them particularly hazardous to human health when inhaled, as particles of this size are able to penetrate deeply into the lungs and make their way into the bloodstream (Roy et al., 1981; Oberdörster, Oberdörster, & Oberdörster, 2005). As particle size decreases, surface area and pollutant concentration increase (Spencer & Drake, 1987; Patra et al., 2012). Spencer and Drake (1987) found that the concentration of metals in fly ash can be two times higher than concentrations found in coal. Despite the potential for fly ash-sized particles to bypass the human body's natural barriers, the effects of chronic coal ash exposure have not been well studied. The studies that have explored this area are limited to animals, occupational exposures, effects of prenatal exposure, human cells, or are specific to PAHs.

Occupational studies have found that power plant workers who were exposed to fly ash had significantly higher blood levels of arsenic and mercury compared to healthy controls (Zeneli, Sekovanic, Ajvazi, Kurti, & Daci, 2016). Workers handling fly ash were also found to have increased markers of oxidative

stress and DNA damage compared to workers in bottom ash plants (Liu, Shih, Chen, & Chen, 2008; Chen, Chen, & Chia, 2010). Animal studies have shown that coal ash particles can affect lung epithelial cells, neutrophils, and macrophages (Goldsmith et al., 1999; Smith, Veranth, Kodavanti, Aust, & Pinkerton, 2006), and immune effects were found after exposing human lymphocytes to 16 trace elements commonly found in fly ash (Shifrine, Fisher, & Taylor, 1984).

Two prospective cohort studies explored the effects of prenatal exposure to coal-burning pollutants on children's development in Tongliang, Chongqing, China (Tang et al., 2008; Perera et al., 2008; Tang et al., 2014). The first prospective cohort began while the power plant was still in operation (Tang et al., 2008). Nonsmoking mothers at least 20 years of age who were admitted to one of three nearby hospitals and who lived within 2.5 kilometers of the power plant and their newborns were eligible for enrollment in the cohort. Enrollment occurred from March-June 2002. Levels of PAH-DNA adducts, lead, and mercury were measured in umbilical cord blood. PAH-DNA adducts were used as a measure of PAH exposure. When the children were 2 years of age, developmental quotients in motor, adaptive, language, and social areas were obtained. Decrements in one or more of the developmental quotients were significantly associated with cord blood PAH-DNA adduct and lead levels. The increased adduct levels were associated with decreased language area, decreased motor area, and decreased average overall developmental quotients.

The coal-burning power plant in Tongliang, Chongqing, China closed in May 2004, which provided an opportunity to conduct a second cohort study using the methods employed in the initial cohort study and to compare the effects (Perera et al., 2008; Tang et al., 2014). The second cohort study had the same inclusion criteria and recruited participants from March-May 2005 (Perera et al., 2008). The same cord blood levels were obtained in addition to brain-derived neurotrophic factor, a protein involved in neuronal growth. Children in the second cohort were given the same developmental tests at 2 years of age (Tang et al., 2014). Compared to the first cohort, the second cohort had reduced PAH-DNA adducts and increased brain-derived neurotrophic factor levels (Tang et al., 2014). The brain-derived neurotrophic factor levels were positively associated with neurocognitive development (Tang et al., 2014). The significant associations between elevated PAH-DNA adducts and decreased motor area and overall development quotients found in the first cohort were not observed with the second cohort; however, the direction of the relationships remained the same (Perera et al., 2008). Taken together, these results suggest that the closure of the power plant was associated with neurodevelopmental benefits to children with prenatal exposures to coal-burning pollutants living within 2.5 kilometers of the plant.

Although the effects of coal ash exposure have not been well studied, numerous studies have evaluated the effects of exposure to the individual components of coal ash, including metals, and to airborne particulate matter in general. Arsenic, chromium (VI), and cadmium are metals commonly found in

coal ash (Adraino et al, 1980; el-Mogazi et al., 1988; Spencer & Drake, 1987) and are all classified as Group 1 carcinogens by the International Agency for Research on Cancer (IARC), indicating that there is sufficient evidence that they are carcinogenic to humans (IARC, 2012). Arsenic exposure is associated with vomiting, interruption of normal blood cell production, and changes in heart rhythm (Agency for Toxic Substances and Disease Registry [ATSDR], 2007a). Exposure to arsenic has been linked to skin, liver, bladder, and lung cancer (IARC, 2012). Nervous system and kidney damage can result from lead exposure (ATSDR, 2007b). Inhalation of chromium (VI), a heavy metal, has also been shown to cause lung cancer, and can lead to breathing problems such as shortness of breath, asthma, and wheezing (IARC, 2012; ATSDR, 2012b). Inhalation of high levels of cadmium, another heavy metal, can result in severe lung damage, and long-term exposure can lead to kidney disease and fragile bones; additionally, cadmium exposure has been linked to liver cancer and positive associations have also been found between cadmium exposure and kidney and prostate cancer (ATSDR, 2012a; IARC, 2012).

Other metals, such as aluminum, zinc, nickel, and strontium may also be found in coal ash (Adraino et al, 1980; el-Mogazi et al., 1988; Spencer & Drake, 1987). Studies involving humans exposed to high levels of aluminum have found respiratory problems and decreased performance on neurobehavioral tests (ATSDR, 2008; Riihimaki & Aitio, 2012). Excess zinc may cause nausea, vomiting, or stomach cramps (ATSDR, 2005b). Interestingly, zinc has also been associated with the production of proteins that aid in the heavy metal

detoxification of the body (Park, Liu, & Klaassen, 2001; Faber, Zinn, Kern, & Kingston, 2009). Low zinc levels in combination with increased levels of metals such as mercury and copper were found to be associated with autism spectrum disorders in previous studies (Bjorklund, 2013; Li, Yang, Bjorklund, Zhao, & Yin, 2014). Several nickel compounds are known carcinogens, and breathing nickel dust can lead to reduced lung function (ATSDR, 2005a). While little is known of nickel's affect on children, studies have indicated that nickel can be transferred from mother to infant through breast milk and can cross the placenta (ATSDR, 2005a). Children exposed to high levels of stable strontium may suffer from impaired bone growth, but little is known of other possible birth defects or developmental effects related to this exposure (ATSDR, 2004).

Airborne particulate matter has been linked to numerous health outcomes, such as chronic obstructive pulmonary disease (Schikowski et al., 2005), lung cancer (Pope et al., 2002; Vineis et al., 2007), premature mortality (Dockery et al., 1993; Pope et al., 1995), sleep disturbances (Zanobetti et al., 2010), and cardiovascular effects (Dockery, 2001) in adults. In children, particulate air pollution has been associated with asthma, reduced lung function, wheeze, airway hyperresponsiveness (Ostro, Lipsett, Mann, Braxton-Owens, & White, 2001; Yu, Sheppard, Lumley, Koenig, & Shapiro, 2000; Gehring et al., 2013; Jung et al., 2012; Jang, Yeum, & Son, 2003), and sleep disturbances (Abou-Khadra, 2013).

Neurotoxins

Coal ash frequently contains heavy metals, such as cadmium, lead, mercury, chromium VI, and manganese, all of which are known neurotoxins (Brown et al., 2011; Patra et al., 2012; Nodelman, Pisupati, Miller, & Scaroni, 2000). Fly ash particles are small enough to penetrate deeply into the lungs and access the bloodstream and thus pose a risk for bypassing the blood-brain barrier and coming into contact with cells in the brain (Roy et al., 1981; Oberdörster et al., 2005). Particles containing neurotoxins can induce neurotoxicity, which may result in developmental delays, cognitive deficits, changes in behavior, or other neurobehavioral impacts (Gottlieb, Gilbert, & Evans, 2010). Though many metals have been studied separately to determine their potential for neurotoxicity, it is unknown what effect concurrent exposure to multiple neurotoxins may have, though it has been speculated that such concurrent exposure may intensify known effects or induce new effects (Gottlieb et al., 2010).

Studies involving children and exposure to heavy metals have found reduced cognitive development and functioning, decreased general intelligence scores, and increased risk for learning disability (Liu & Lewis, 2014; Wright, Amarasiriwardena, Woolf, Jim, & Bellinger, 2006; Ciesielski, Weuve, Bellinger, Schwartz, Lanphear, & Wright, 2012). Molybdenum levels were found to be a predictor for learning disorders (Yousef, Eapen, Zoubeydi, Kosanovic, Mabrouk, & Adem, 2013), and cadmium levels were associated with cognitive delays in boys (Rodriguez-Barranco et al., 2014). Manganese and arsenic levels were inversely

correlated to scores on tests of memory (Wright et al., 2006). Lead exposure was related to deficits in fine motor skills, reaction time, and hand-eye coordination (Needleman, Schell, Bellinger, Leviton, & Allred, 1990). Studies in adults have shown that mercury, lead, and cadmium exposures are linked to problems with fine motor skills and memory (Gunther, Sietman, & Seeber, 1996; Chia, Chia, Ong, & Jeyaratnam, 1997; Grashow et al., 2013; Schwartz et al., 2005; Ciesielski, Bellinger, Schwartz, Hauser, & Wright, 2013;).

Coal Ash Exposure and Children

The EPA estimates that, out of the 6.08 million people residing near electric utility plants, 1.54 million, or 25.4%, of them are children (Hazardous and Solid Waste Management System, 2010). Children may be at greater risk for coal ash exposure than adults due to their behaviors, factors relating to their size, and their developing defense mechanisms (Salvi, 2007; Etzel, 1996; Kim, 2004; Gottlieb et al., 2010). Children are more likely to engage in hand-to-mouth behaviors, which put them at risk for the incidental ingestion of particles (Gottlieb et al., 2010). Play habits such as rolling or crawling on the floor or ground may also put children in contact with particles that have settled to the ground or have been brought indoors by foot traffic. Additionally, children are less likely to discontinue playing when they experience respiratory distress, increasing the number of particles inhaled. All of these behaviors make children more likely to come in contact with particles such as coal ash.

Children's size is also an important consideration when comparing their likelihood of coal ash exposure to that of adults. Landrigan et al. (2004) stresses

that children are not simply small adults. For example, children breathe in higher volumes of air per body weight than adults (Etzel, 1996; Kim, 2004; Salvi, 2007). Children are also closer to the floor due to their physical size than adults, putting them closer to the floor where particles have settled. Furthermore, children may be more sensitive to environmental pollutant exposures due to their developing defense mechanisms (Kim, 2004; Salvi, 2007). The majority of lung alveoli are formed after birth, with development continuing through adolescence (Dietert et al., 2000; Kim, 2004). The developing lung is more susceptible to damage by environmental toxicants than a fully developed adult lung (Dietert et al., 2000; Plopper & Fanucchi, 2000; Pinkerton & Joad, 2000; Kim, 2004).

II. HYPOTHESES AND AIMS

The overall goal of this study is to evaluate the neurobehavioral performance of children exposed to coal ash. This goal will be accomplished by 3 specific aims:

- 1) To determine the relationship between children's neurobehavioral performance, as measured by tests of memory and fine motor skills, and proximity of residence to coal ash storage sites.
- 2) To determine if children with greater heavy metal body burden perform poorer on neurobehavioral tests of memory and fine motor skills compared to children with lower heavy metal body burden.
- 3) To assess if children who have fly ash in their home perform poorer on neurobehavioral tests of memory and fine motor skills compared to children with no fly ash in their home.

Based on investigating these aims, there are three associated hypotheses:

1) Children living closer to coal ash storage sites will perform poorer on neurobehavioral tests of memory and fine motor skills than children living further from coal ash storage sites.

2) Children with greater heavy metal body burden will perform poorer on neurobehavioral tests of memory and fine motor skills than children with lower heavy metal body burden.

3) Children with fly ash found in their home will perform poorer on neurobehavioral tests of memory and fine motor skills than children with no fly ash found in their home.

III. METHODS

This thesis is a sub-study nested within a larger environmental epidemiologic study, Coal Ash and Neurobehavioral Symptoms in Children Aged 6-14 Years Old, funded by the National Institutes of Health, National Institute of Environmental Health Sciences (Grant: 5 R01 ES024757; PI: Kristina Zierold, PhD). The larger study aims to: 1) characterize indoor exposure from fly ash and heavy metals in homes of children residing near coal ash storage sites compared to children living further away from coal ash storage sites, 2) determine if the heavy metal body burden differs from children residing near coal ash storage sites compared to children living further away from storage sites, 3) assess if increased fly ash exposure and greater heavy metal body burden is associated with poorer neurobehavioral performance and more neurobehavioral symptoms, and 4) utilize mapping, spatial analysis and modeling applications of geographic information systems (GIS) for household recruitment, analysis of distance decay effects, surface interpolation of Aims 1 and 2 results, and fate and transport modeling of fly ash. The recruitment, consent, and data collection methods explained in this section are all original to the larger study. All participants signed informed written consent, and the study was approved by the University of Louisville Institutional Review Board for Human Subjects (IRB number: 14.1069).

Location and Population

Participants were recruited from areas within a 10-mile radius of either of the two coal ash storage sites at Cane Run and Mill Creek, located in southwest Louisville, Kentucky. The population includes children between the ages of 6 and 14 years and their parent or guardian, who have lived within the study area for at least two years. Children with genetic disorders known to cause neurobehavioral problems, such as Fragile X Syndrome, were excluded from the study. There are an estimated 11,568 children aged 5 to 16 years within the study area according to U.S. Census data (2012).

Recruitment and Consent

Recruitment efforts were stratified using a collection of buffer zones and quadrants surrounding the two plant locations with the use of a geographical information system (GIS). Five concentric buffer zones were drawn around a centroid located halfway between the two power plants, with each buffer representing a distance of 2 miles. For instance, buffer zone 1 included those living 0-2 miles from the plant, while buffer zone 5 included those living 8-10 miles from the plant. Each buffer zone was further divided into four wedges, labeled quadrants A-D. Sampling units used for recruitment were a combination of buffer zone and quadrant, and recruitment efforts spanned across buffers 1-5 and quadrants A-D. Recruitment efforts based on buffers and quadrants allow for the stratification of analysis on distance from plant, wind patterns, and possible exposure to fly ash from both plants.

Flyers and pamphlets describing the study and participant eligibility criteria were distributed door-to-door in neighborhoods within sampling units that were found to have large populations of children based on U.S. Census data. This door-to-door recruitment style involved members of the study team walking through target neighborhoods and talking to members of the community. Door-to-door recruitment methods were successful in previous studies in the same area of Louisville (Zierold & Sears, 2015). Those interested in participating in the study called either of the two phone numbers listed on the flyer or pamphlet.

In addition to door-to-door methods, mailings were also used for recruitment. Address lists for houses with children aged 7-15 years within specified zip codes in the study area were obtained from an Internet site that sells customized mailing lists (LeadsPlease.com). Items in the mailing included a flyer identical to those used for door-to-door recruitment and a letter describing the study purpose, participant eligibility, compensation, and contact information. Those interested in participating in the study called one of the three phone numbers listed on the letter.

Since weather patterns may affect exposure levels, as changes in wind and precipitation can impact fly ash movement, participants were enrolled in approximately equal numbers per season. Winter was defined as December 1 – February 28 (29 during leap year), Spring from March 1 – May 31, Summer from June 1 – August 31, and Fall from September 1 – November 30.

Consenting

Parents or other legal guardians and children were consented and assented in their homes. The study's background information, purpose, procedures, potential risks, benefits, compensation, confidentiality, and contact information were all discussed with the parents or guardians of the child. The parent or guardian was asked to sign two consent documents if they were interested in participating. The first document the parent or guardian signed concerned his or her own willingness to participate in the study. The second document gave permission for their child to participate in the study. Two copies of each document were signed, one for the research team and one for the parent or guardian. A subject assent was reviewed with each child and the details of their participation in the study were explained. The child and the parent or guardian were both asked to sign the assent if they wished to participate. All forms were signed by the investigator consenting the parents or legal guardians and by the principal investigator. The consenting and assenting process took 30-45 minutes.

Exposure Measurement and Analysis

Air Sampling

SKC Airchek XR5000 pumps connected to SKC Personal Modular Impactors were placed in the participants' households and allowed to run for seven days. The sampler was set in one of the household's main rooms, depending on which portion of the home was most often frequented by the child. This air sampling technique allows for the collection of PM₁₀ on a polycarbonate

membrane filter, which later undergoes gravimetric and elemental analysis. Polycarbonate filters were selected for use due to their smooth surface, precise pore size and distribution, chemical and biological inertness, strength, optical transparency, and ability to undergo scanning electron microscopy and Proton Induced X-Ray Emission (PIXE). The filters are weighed prior to sampler set-up and weighed again after sampler removal to determine the mass gained during sampling. The sampler's flow rate was set to 3 Liters/minute, the required flow rate for the use of the impactor chosen. The flow rate was set during sampler set-up, checked halfway through sampling, and checked again when the sampler was taken down.

While the sampler was present in the participants' homes, the parent or guardian was asked to complete a daily activity diary of activities that occurred indoors, such as cooking, candle burning, or the use of fans, to gather information on other potential causes of changes in air quality.

The filters were analyzed by PIXE to determine the elements in the PM₁₀, and Scanning Electron Microscopy with Energy-Dispersive X-ray Spectroscopy (SEM/EDX) to determine the presence or absence of fly ash.

Lift Samples

Lift samples were taken from three or four locations in each child's room using Stick-to-It Lift Tape (SKC, Inc). This technique involved applying a Stick-to-It Lift Tape to a location of interest in the child's room in order to peel off particles for analysis. In this study, lift samples were collected in order to determine the presence of fly ash. Preferable locations for lift sampling included the windowsill,

bedpost, nightstand, dresser, and the child's favorite toy. The location of each sample was documented.

Lift samples were first analyzed by Optical Microscopy (OM). If fly ash was found on the sample, the fly ash particles were further analyzed by Scanning Electron Microscopy and Energy-Dispersive X-Ray Spectroscopy (SEM/EDX) to determine the elements in the fly ash.

Nail Clippings

The children who participated in the study were asked to collect fingernail and toenail clippings over the course of several months, until a cleaned nail mass of ≥ 150 mg was obtained. Nails were collected due to their ability to act as biomarkers for long-term exposure to heavy metals present within the body. Nail clippings were stored in plastic containers labeled with the participants' identification numbers in a desiccator. The nail samples were cleaned with acetone, twice rinsed with deionized water, and allowed to air dry before final nail weights were taken. For analysis, nails were frozen and ground into a fine powder. The nail powder was used to create a disc using a neutral binding agent. The disc was then placed in a slide with a circle cutout of 3/8-inch diameter. The slides were analyzed using PIXE, described below, to determine the elements present.

PIXE

Proton Induced X-Ray Emission (PIXE) analysis was used to determine the elemental concentrations of children's nail clippings and of the filters from air samplers that were placed in the participants' households. This analytic

technique is non-destructive and allows for the simultaneous analysis of 72 inorganic elements from sodium to uranium on the periodic table (Elemental Analysis, Inc. [EAI], n.d.). PIXE analysis can be applied to solid, liquid, and thin film sample types (EAI, n.d.).

PIXE uses an X-Ray spectrographic technique (EAI, n.d.). X-Rays are generated in response to the sample being bombarded by energetic protons. The samples are placed in a sealed chamber and are positioned so that a proton beam is focused on the center of the sample. The thin proton beam required for PIXE analysis is produced in a large accelerator tube leading up to the sample chamber. Electrons are stripped from elements in the presence of an electromagnetic field, leaving positively charged particles. These positively charged particles form a beam, which can be finely focused and adjusted by the technician operating the machine.

When the proton beam bombards the sample, the protons cause the inner shell electrons of atoms within the sample to become excited and displaced. The inner shell electrons then fall back into place following proton excitation. The expulsion of electrons and re-filling of their vacancies results in the production of X-Rays, and the number of X-Rays emitted is related to the mass of the element in the sample that is being analyzed (EAI, n.d.). Each element has a unique X-Ray energy (EAI, n.d.).

After a sample is analyzed using PIXE, a report is produced listing the elements detected, the mass fraction for each of the elements detected, and the margin of error associated with the analysis for each elemental value provided in

the report. An analytical chemist who is an expert on analyzing PIXE reports then uses the details provided in the report and the spectra produced to determine which elements are present in the sample and which elements reported were artifactual findings. A final report of the elements found in the sample and their mass fractions and concentrations is then produced. In this study, mass fractions for nail samples and concentrations for filters were included in the final PIXE report.

Optical Microscopy and SEM-EDX

Optical Microscopy (OM) was used to analyze all lift tape samples that were collected from the child's bedroom. OM was performed on each of the samples collected to evaluate for the presence of fly ash. The use of OM allows for the detailed observation and photography of small particles such as fly ash. Fly ash appears as perfectly spherical, smooth particles when viewed under a microscope, which is a unique characteristic. Images of particles found during OM were then sent to the study's principal investigator. The principal investigator then determined if any of the particles appeared to be fly ash based on their morphology and size. Those that visually appeared to be fly ash were then sent for SEM/EDX analysis.

SEM provided detailed, high-resolution images on a sub-micron scale of the particles on the lift samples and filters from the air samplers through the use of a focused electron beam. The electron beam detects electron signals. Additionally, an Energy Dispersive X-Ray Analyzer (EDX) was used to determine

the elemental composition of the particles on the lift samples and polycarbonate filters.

Assessment of Neurobehavioral Performance

Neurobehavioral performance was assessed in all children using four types of tests: the Beery-Buktenica Developmental Test of Visual-Motor Integration (Beery VMI), the Purdue Pegboard Test, the Object Memory Test, and the Behavioral Assessment and Research System (BARS). These tests offer a range of information on the participants' short and long-term memory, fine motor skills, and response speed.

Beery VMI

The first test given to the participants during neurobehavioral performance testing was the Beery VMI, 6th edition, full form (Beery, Buktenica, & Beery, 2010). This test assesses fine motor skills and visual-motor integration and has been standardized on children and adolescents aged 2-18 years (Beery et al., 2010). Participants were given a packet containing 24 geometric images with blank space provided below each image. The Beery VMI generally begins with 6 additional blank spaces, which are used to imitate marks and drawings and to engage in spontaneous and contained scribbling; however, these initial six tasks are not used in this study. The test scoring criteria allow credit to be awarded for the initial six imitations, scribbles, and drawings as long as the seventh test item, the first copy of a geometric image, is completed successfully. Therefore, the participants in this study were only asked to copy the 24 geometric images within the Beery VMI's full form.

Each participant was given a pencil without an eraser and was asked to copy each image in the blank space below to the best of their ability. The images increase in complexity as the packet progresses. If the participant incorrectly copies three images in a row, the test is concluded. The test administration time ranges from 5-15 minutes. The VMI was hand scored using the scoring criteria and sample drawings provided in the Beery VMI testing manual (Beery et al., 2010). The raw scores range from 0 to 30, with 7 points awarded for the successful copying of the first geometric image and an additional point awarded for the successful copying of each image thereafter. Scoring was terminated when three images in a row were given no score due to being incorrectly copied. The raw scores were then converted to standard scores based on the participant's age in years and months. Standard scores below an 85 are poorer than expected for participants at any age; therefore, standard scores below an 85 were considered to be indicative of a problem with fine motor skills and visual-motor integration.

Purdue Pegboard

The next test in the neurobehavioral testing sequence was the Purdue Pegboard Test. This test is used to measure fine motor speed and dexterity and can be used with children and adolescents aged 5-16 years (Costa, Scarola, & Rapin, 1964; Gardner & Broman, 1979). The test utilizes a standardized pegboard with two columns of peg holes down the center of the board and cradles with pegs at the top of the board (Tiffin & Asher, 1948). The participants were asked to pick up the pegs one at a time and place them in the holes of the

board, either with their right hand, left hand, or both hands simultaneously.

Testing began with a round using the participant's dominant hand. Before each round, the participant was allowed to practice placing 3-4 pegs. During the right- and left-handed rounds, the participant was asked to pick up one peg at a time, using only the designated hand, and to place that peg in the respective column on the board. The participant was given 30 seconds, timed using a stopwatch, to place as many pegs as possible with both the left and right hands. The final round involves placing pegs with both hands simultaneously. The participant was again instructed to only pick up one peg per hand at a time. The participant was given 30 seconds to place as many pegs with both hands as possible. The numbers of pegs placed with the dominant, non-dominant, and both hands simultaneously were individually recorded and compared to age (in years and months) and gender-based norms (Gardner & Broman, 1979). Percentiles were determined using the Purdue Pegboard User's Manual. A percentile below 40% was considered to be below average and indicative of a problem with the participant's fine motor speed and dexterity.

Object Memory

The final tabletop test, the Object Memory test, measures short and long-term memory. During the test, participants were given a card with pictures of 20 common, everyday objects, such as a boat, a ring, and a cup. The test proctor stated the name of each object while pointing to it during the participant's first encounter with the images. The participant was then given 45 seconds, timed using a stopwatch, to study the images before the card was removed and

participants were asked to recall as many of the images as possible in a 45-second time limit. The participant was then shown the card again for 20 seconds and allowed to review the images. The card was again removed and the participant was asked to recall the images for a second time for a period of 40 seconds. This sequence, including 20 seconds of review and 40 seconds of recall, occurred one final time prior to moving on to the computerized testing. After the computerized testing was completed, the proctor asked the participant to recall the images one final time, this time without allowing the participant to first review the card. The participant was given 45 seconds for recall. The three recall trials conducted before the computerized testing are indicative of the participant's short-term memory, while the final trial conducted after the completion of the computerized testing was indicative of the participant's long-term memory.

The maximum raw score from each trial is 20, with one point awarded for the correct recall of each object. If the participant clearly remembered the object, but did not recall the object's name as it was presented, such as a recall of "robin" instead of "bird," the response was scored as correct. Incorrect responses or objects not named received a score of 0. The raw scores from the initial 3 trials, the short-term memory trials, were summed for a maximum raw score of 60. The final trial, the long-term memory trial, remained on a scale from 0 to 20. T-scores for both short and long-term memory were calculated for each participant based on their age in years and months. A t-score of less than 40 was considered to be out-of-normal range and indicative of a problem.

BARS

BARS consists of a battery of computerized tests that were designed to detect neurotoxicity among workers (Anger et al., 1996; Rohlman et al., 2000a; Rohlman et al., 2003; Farahat, Rohlman, Storzbach, Ammerman, & Anger, 2003). BARS testing has been adapted for use among children and adolescents (Dahl et al., 1996; Otto, Skalik, House, & Hudnell, 1996; Rohlman et al., 2000b). The equipment needed in order to conduct BARS testing includes a laptop with BARS software installed and a special keyboard with nine buttons that is placed over a laptop during the testing (Anger et al., 1996). The keys are numbered 1 through 9, and the participants use only this keyboard to complete the tests. Two of the BARS tests were selected for use in this study. These are Simple Digit Span Test and Finger Tapping. Before each new test begins, a practice trial round will first occur to ensure that the participant understands the test's instructions.

Simple Digit Span

This test presented the participants with a series of numbers (1 through 9) one at a time. The participant was then asked to recall the sequence in order by typing it in using the keyboard. The test was two-part in that initially the participant was asked to recall the sequence in the order in which it was presented; however, during the latter half of the test, participants were asked to recall the sequence in reverse order, starting with the last number that appeared on screen (Anger et al., 1996). The longest span the participant was asked to

recall was 9 digits and the shortest span was 3 digits. This test measured memory and attention.

Finger Tapping

This BARS test instructed participants to press a key on the keyboard using their index finger as quickly as possible until the test was over. As the participant taps the key, the height of a dark bar on the screen increases in order to show the participant their progress. The participant is asked to press the number 9 key with their right index finger and the number 1 key with their left index finger. Participants completed two separate trials, one for each finger, each of 30-second duration, with a 15-second break between trials. This test measured fine motor speed.

Questionnaires

The children's parents or guardians were also asked to complete several questionnaires and forms: the Child Behavior Checklist (CBCL), a Home Cleaning Questionnaire, an Environmental Health History, a Child Respiratory Health Questionnaire, and a Child Health History Form. The CBCL is a commonly used checklist that provides information on the child's behavioral, emotional, and social functioning. The CBCL produces a measure of behavioral and emotional problems and t-scores are calculated using standardized norms based on age and gender. A t-score ≥ 70 required further assessment by the study's child psychologist. The follow-up assessment consisted of a Structured Clinical Interview for the Diagnosis of DSM Disorders (SCID). If a child was

diagnosed with a disorder, he/she was given referrals for physicians, therapists, or centers that may help the child and family.

The Home Cleaning Questionnaire asks multiple-choice questions regarding how frequently certain cleaning tasks are performed in the home. Questions focus on dusting, vacuuming, frequency of cleaning the home and child's room in general, and wet versus dry cleaning methods.

The Environmental Health History covers topics such as demographics, home characteristics, child behaviors such as where the child plays, cleaners used, pesticide use, food and water, hobbies and occupations of household members, questions concerning pregnancy, and address history.

The Child Respiratory Health Questionnaire asks questions concerning the child's past respiratory conditions. Such conditions include coughing, wheezing, shortness of breath, chest tightness, asthma, bronchitis, and pneumonia.

The Child Health History Form was completed with assistance from a community nurse who visited the participants' homes. The form asks questions regarding the child's age, sex, race, disease history, medical problems, hospitalizations, medications, immunization history, the child's mother's pregnancy, the child's milestones, behaviors, and family medical history. The community nurse also takes and documents the child's height, weight, blood pressure, pulse, and respirations.

Responses to questions from each of these questionnaires will be considered during statistical analysis.

Pediatric Environmental Home Assessment

In addition to the aforementioned questionnaires, a nurse made visits to each participant's home to complete a Pediatric Environmental Home Assessment and to collect information for the Pediatric Health History Form. The home assessment covers topics relating to other sources within the home that could be contributing to the child's health. Such sources include the age of the home, presence of lead paint, asbestos, radon, environmental tobacco smoke, mold, and pets. The home's cleanliness and condition were assessed, with special attention paid to the child's room. The presence of other environmental concerns within the home will be taken into consideration during statistical analysis.

Analytic Methods Used to Answer Specific Aims and to Test Hypotheses

This section will cover the methods that were used to analyze the data by specific aim. However, several of these methods pertain to all of the following aims and will be discussed before proceeding to the methods used for individual aims.

Two decisions that were made affected the analysis of all aims. These involved participants' ages and grades. Participants' dates of birth were collected at the time of neurobehavioral testing. Using the date of birth and date of neurobehavioral testing, participants' ages for use in these analyses were calculated in both months and years. A participant's age was not rounded up. Participants' ages were given in the number of years or months that they had

already completed. For example, a participant aged 106.5 months was documented as 106 months old instead of 107 months old.

One participant had missing information on their grade in school, but did have a date of birth listed, which was used to approximate their age and associated grade.

In addition, two variables were created for use in multiple aims: socioeconomic status (SES) and presence/absence of lead-based paint. SES was based on the median household income of a participant's block group using data from the U.S. Census/American Community Survey (2010-2014), obtained through American FactFinder. The potential presence of lead-based paint was determined using responses on the Environmental Health History form. Twenty-eight percent of participants responded that they were unsure if their homes had lead paint, yet 62% of participants who responded to the question inquiring on the year their home was built (N=45) reported having homes built before 1978. The Centers for Disease Control and Prevention warns that all houses built prior to 1978 are likely to contain at least some lead-based paint (CDC, 2014). For this reason, a new dichotomous variable was created to differentiate between participants with homes built before or after 1978.

One participant was found to live outside the study area. This participant's data are included in this thesis, but will be removed in future analysis.

A final detail important to all aims is that one participant was not able to complete the Purdue Pegboard non-dominant and both hand tests due to a hand

injury. However, they were able to complete the dominant hand Purdue Pegboard test as well as all other neurobehavioral tests.

A total of twelve neurobehavioral test scores were analyzed in each aim: the Beery VMI score; Purdue Pegboard dominant, non-dominant, and both hands scores; immediate and delayed Object Memory scores; preferred, non-preferred, left, and right hand BARS Finger Tapping scores; and forward and reverse BARS Simple Digit Span scores.

Methods for Aim 1

AIM 1: To determine the relationship between children's neurobehavioral performance, as measured by tests of memory and fine motor skills, and proximity of residence to coal ash storage sites.

a. Geographical Information System (GIS)

A geographical information system (GIS), ArcGIS version 10.2.2 by Esri, was used to calculate the distance between the participants' homes and both the Cane Run and Mill Creek ash landfills. Two Topologically Integrated Geographic Encoding and Referencing (TIGER) Line Shapefiles available from the U.S. Census Bureau, year 2015, were downloaded. Participants in this study predominately lived in Jefferson County, Kentucky; however, two participants resided in Bullitt County, Kentucky. Since the necessary shapefiles included county-level data, shapefiles for both Jefferson and Bullitt County were downloaded. Each shapefile contained the street and address information for its county. These shapefiles were necessary for geocoding the participants' home addresses in ArcGIS.

To prepare the participants' addresses for use in ArcGIS, a Microsoft Excel spreadsheet was created. Participant numbers, street addresses, cities, states, and zip codes were each given their own column in the spreadsheet.

In addition to the county shapefiles containing street locations and participants' home addresses, the latitude and longitude of an approximated centroid for each plant's ash landfill were required. These latitudes and longitudes were approximated by a grant co-investigator, who has expertise in geography and GIS applications, using Google Maps' "Earth" view, which provided a satellite image of the area. The satellite image of the ash landfills allowed the study's geographer to approximate each ash landfill's center and obtain that center's latitude and longitude. The coordinates selected for Cane Run's ash landfill centroid were 38.175573, -85.894129 and the coordinates for Mill Creek's ash landfill centroid were 38.044100, -85.907309. Each ash landfill's coordinates were entered into a separate Microsoft Excel spreadsheet to prepare for use in ArcGIS.

A new ArcGIS session was started and the map layer was projected to the North Kentucky state plane in US feet (NAD_1983_2011_StatePlane_Kentucky_North_FIPS_1601_Ft_US). To the session the following were added: the Jefferson County streets shapefile, the Bullitt County streets shapefile, the Excel spreadsheet containing the participants' addresses, the Excel spreadsheet with Cane Run's ash landfill centroid coordinates, and the Excel spreadsheet with Mill Creek's ash landfill centroid coordinates.

The “Display XY Data” option was selected for both of the ash landfill centroid spreadsheets to create a point at the location of each landfill on the map. The ash landfill point shapefiles and county street shapefiles were then exported using the same coordinate system as the data frame. The Excel file containing the participants’ addresses was exported to a dBase table.

Address locators were then created for both of the county street shapefiles using the street address, city, state, and zip code. Address matching was performed. Bullitt County addresses matched at 100%. Jefferson County had one address that did not match with a match success of 98.1%. The address that did not match did have a suggested address; however, upon further investigation, the suggested address was directly across the street from the unmatched address in a residential neighborhood. The suggested address location was determined to be close enough to the actual address location due to their close proximity, so the suggested address was used instead. After this change was made, 100% of the participants’ addresses matched. The new shapefiles containing the address-matched points were then exported using the same coordinate system as the data frame.

To calculate the distances between each participant’s home and each ash landfill, the “Near” command in ArcToolbox was used. The address-matched shapefile was used for the “input” category and the plant shapefile was used for the “near” category. This was performed for each address-matched shapefile and plant shapefile combination, for a total of four times. Each attribute table produced, which contained the distances in feet, was then exported to an Excel

file for further analysis. Additionally, a map was created to show the locations of participants' homes and their proximity to the two ash landfills. Jefferson County and Bullitt County TIGER/Line shapefiles from the U.S. Census Bureau were used to create this map. Street networks were not included for privacy.

b. Statistical Analysis

Statistical analysis was performed using SAS software, Version 9.4 (SAS Institute Inc., Cary, NC, USA). Univariate analysis was performed using data from each of the neurobehavioral tests individually to assess characteristics including distribution, central tendency, and dispersion. These analyses were performed overall and by sex and age groups (ages 6-8, 9-11, and 12-14). The results of the neurobehavioral tests with standardized norms (Beery VMI, Purdue Pegboard, and Object Memory) were analyzed in standardized score and dichotomized (normal versus abnormal score) form. The results of the BARS tests that do not have standardized forms (Tapping and Simple Digit Span) were analyzed in continuous and dichotomized form. For BARS tests that were normally distributed, the mean was used as the cut point for above average and below average scores. BARS tests that were not normally distributed were divided using the median score. Distances from participants' homes to each ash landfill were analyzed in continuous form in miles and dichotomized form. The dichotomous variables were created by dividing the distributions using their means since these distributions were normally distributed. Because the Cane Run and Mill Creek ash landfill distances only take a participants' distance from one plant into account, an overall variable indicating a participant's closest

proximity to either ash landfill was created. The lesser of the two landfill distances (in miles) for each participant was taken to create this new variable. Since this variable was not normally distributed, the median was used to create a dichotomized variable. Information on normality and variable forms used in analyses are listed in Table 1.

Table 1. Variables Used in Aim 1

Neurobehavioral Test	Normally Distributed (Yes/No)	Form for Analysis
Beery VMI	No	Continuous; Dichotomous (normal vs. abnormal)
Purdue Pegboard <i>Dominant Hand</i> <i>Non-Dominant Hand</i> <i>Both Hands</i>	No No No	Continuous; Dichotomous (normal vs. abnormal)
Object Memory <i>Immediate</i> <i>Delayed</i>	Yes Yes	Continuous; Dichotomous (normal vs. abnormal)
BARS Tapping <i>Right Hand</i> <i>Left Hand</i> <i>Preferred Hand</i> <i>Non-Preferred Hand</i>	Yes Yes Yes No	Continuous (all) Dichotomous (above vs. below mean for normally distributed; above vs. below median for non-normally distributed)
Simple Digit Span <i>Forward</i> <i>Reverse</i>	No No	Continuous; Dichotomous (above vs. below median)
Distances from Ash Landfills	Normally Distributed (Yes/No)	Form for Analysis
Distance from Cane Run	Yes	Continuous; Dichotomous (above vs. below mean)
Distance from Mill Creek	Yes	Continuous; Dichotomous (above vs. below mean)
Minimum Distance to Either Plant	No	Continuous; Dichotomous (above vs. below median)

Comparisons of the test outcomes and plant distances by sex and age groups were analyzed in accord with their form (continuous or dichotomous) and the normality of their distribution. Fisher's Exact p-values were calculated for

dichotomous variables with expected cell counts of five or fewer. For larger expected cell counts under the same conditions, Chi-square p-values were calculated. Wilcoxon Rank-Sum tests were used when continuous variables with non-normal distributions were compared between two groups. For comparisons under the same conditions involving more than two groups, a Kruskal Wallis test was performed. For comparisons of normally distributed continuous variables across two groups, two-sample unpaired t-tests were conducted, and for more than two groups, one-way ANOVA was used. In the case of normally distributed continuous variable comparisons across more than two groups with unequal variances, Welch's test was conducted.

Bivariate analysis using the test scores and the participants' distance from each plant were also performed. T-tests comparing mean Cane Run and Mill Creek distances were performed using each dichotomized testing score described in Table 1.

Finally, logistic regression was conducted using the dichotomized minimum distance to either plant variable as the predictor and dichotomized test scores as the outcomes. Potential covariates considered for model inclusion were participant's age (in months), sex, the median income of the participant's block group (obtained through the American Community Survey 2014 data), living in a home built before 1978, exposure to tobacco smoke in the home, and a family history of a learning disability. Covariates were only considered for inclusion in final models if univariate Wald Chi-square p-values were significant ($p < 0.05$).

Methods for Aim 2

AIM 2: To determine if children with greater heavy metal body burden perform poorer on neurobehavioral tests of memory and fine motor skills compared to children with lower heavy metal body burden.

Statistical Analysis

Metals present in nail samples were obtained through reports from Elemental Analysis, Inc., the lab that conducted the PIXE analysis.

Concentrations of elements were reported in a mixture of ppm and mass fraction units. All concentrations were converted to ppm for analysis. If an element did not exceed the test's limit of detection, the participant's nail concentration of the element was recorded as 0 ppm. Heavy metals that were found in nails of some but not all participants were dichotomized for their presence or absence.

Descriptive statistics were calculated for each of the heavy metals found in the participants' nails. Additional metals that may not be considered heavy metals were included if they were present in this population's nails and were potentially associated with neurobehavioral outcomes.

The relationship between heavy metal body burden and neurobehavioral performance was assessed. The dichotomized score (normal versus abnormal or above median/mean versus below median/mean) of each test's results were individually used in analysis. Fisher's Exact p-values were calculated for dichotomous variables with expected cell counts of five or fewer. For larger expected cell counts under the same conditions, Chi-square p-values were calculated. Wilcoxon Rank-Sum tests were used when continuous metal

concentrations with non-normal distributions were compared between two dichotomized test score groups. For comparisons of normally distributed continuous metal concentrations across two test score groups, two-sample unpaired t-tests were conducted.

Methods for Aim 3

AIM 3: To assess if children who have fly ash in their home perform poorer on neurobehavioral tests of memory and fine motor skills compared to children with no fly ash in their home.

a. Statistical Analysis

The presence or absence of fly ash was analyzed as a dichotomous variable. The presence or absence of fly ash was determined by SEM/EDX on the polycarbonate filters and OM and SEM/EDX on the lift samples. However, only a positive presence of fly ash on the lift tapes through SEM/EDX resulted in a classification of fly ash presence in this thesis. This is because although OM indicates that fly ash visually appears to be present on samples, SEM/EDX is needed to confirm that the elemental make-up of these particles is indicative of fly ash. Positive identification through SEM/EDX of fly ash on either of these samples resulted in a categorization of a participant's home's fly ash presence.

The relationship between the presence of fly ash in the home and neurobehavioral performance was assessed using Fisher's Exact or Chi-square tests depending on sample size. Fisher's Exact was used if a comparison had an expected cell count of less than 5. Chi-square tests were used for larger cell counts. The dichotomized score (normal versus abnormal or above median/mean

versus below median/mean) of each test's results was used in analysis.

Finally, logistic regression was conducted using fly ash presence as the predictor and dichotomized test scores as the outcomes. Potential covariates considered for model inclusion were participant's age (in months), sex, the median income of the participant's block group (obtained through the American Community Survey 2014 data), living in a home built before 1978, exposure to tobacco smoke in the home, and a family history of a learning disability (self-reported by parent or guardian on the Pediatric Health History form). Covariates were only considered for inclusion in final models if univariate Wald Chi-square p-values were significant ($p < 0.05$).

b. Geographical Information System (GIS)

Continuing with Aim 1's ArcGIS session, a map was produced to depict the proximity of participants' homes with and without fly ash to the two ash landfills and to determine if a visual pattern between proximity and fly ash presence existed. The same shapefiles and address locators were used to produce this map. This time, however, participants' addresses were divided between two spreadsheets. One spreadsheet had the participant numbers and addresses for participants with fly ash in their homes. The other spreadsheet had this same information for participants who did not have fly ash in their homes. Each spreadsheet was added to the ArcGIS session, exported to a dBase file, and geocoded using the address locators used for Aim 1. The locations of homes with fly ash present were marked with green circles while the locations of homes without fly ash were marked with red circles.

IV. RESULTS

Aim 1 Results

The demographics of the population can be found in Tables 2 and 3. Aim 1 had the largest population of all of the three aims with 55 participants. The participants were almost evenly divided by sex (49.1% female). The female population tended to be younger than the male population and less racially diverse. Overall, of the participants, 76.1% were white, 10.9% African-American, 2.2% Asian, and 10.9% biracial.

Table 2. Demographics of Population Used for Aim 1 by Sex*

	Male N=28	Female N=27	Total N=55
Age (in years)			
<i>Min</i>	7	6	6
<i>Q1</i>	10	7	8
<i>Median</i>	12	10	11
<i>Q3</i>	13.5	12	13
<i>Max</i>	14	14	14
<i>Mean</i>	11.5	9.7	10.6
<i>SD</i>	2.2	2.4	2.5
<i>Mode</i>	12	7	12
<i>Range</i>	7	8	8
<i>IQR</i>	3.5	5	5
Age (in months)			
<i>Min</i>	89	74	74
<i>Q1</i>	129	94	106
<i>Median</i>	147.5	121	138
<i>Q3</i>	168	144	161
<i>Max</i>	178	178	178
<i>Mean</i>	144.4	120.6	132.7
<i>SD</i>	27.2	29.7	30.6
<i>Mode</i>	130	86	178
<i>Range</i>	89	104	104
<i>IQR</i>	39	50	55
Grade			
<i>Kindergarten</i>	0.0% (0)	3.7% (1)	1.8% (1)
<i>1st grade</i>	0.0% (0)	14.8% (4)	7.3% (4)
<i>2nd grade</i>	10.7% (3)	11.1% (3)	10.9% (6)
<i>3rd grade</i>	3.6% (1)	14.8% (4)	9.1% (5)
<i>4th grade</i>	7.1% (2)	14.8% (4)	10.9% (6)
<i>5th grade</i>	14.3% (4)	7.4% (2)	10.9% (6)
<i>6th grade</i>	14.3% (4)	18.5% (5)	16.4% (9)
<i>7th grade</i>	21.4% (6)	3.7% (1)	12.7% (7)
<i>8th grade</i>	10.7% (3)	7.4% (2)	9.1% (5)
<i>9th grade</i>	17.9% (5)	3.7% (1)	10.9% (6)
Race (missing = 9)			
<i>White/Caucasian</i>	72.0% (18)	81.0% (17)	76.1% (35)
<i>Black/African American</i>	16.0% (4)	4.8% (1)	10.9% (5)
<i>Asian</i>	0.0% (0)	4.8% (1)	2.2% (1)
<i>American Indian/Alaskan Native</i>	0.0% (0)	0.0% (0)	0.0% (0)
<i>Hispanic</i>	0.0% (0)	0.0% (0)	0.0% (0)
<i>Biracial</i>	12.0% (3)	9.5% (2)	10.9% (5)
* Numbers may not add to 100 due to rounding.			

Table 3. Demographics of Population Used for Aim 1 by Age Group*

	Ages 6-8 N=14	Ages 9-11 N=17	Ages 12-14 N=24	Total N=55
Sex				
<i>Male</i>	21.4% (3)	47.1% (8)	70.8% (17)	50.9% (28)
<i>Female</i>	78.6% (11)	52.9% (9)	29.2% (7)	49.1% (27)
Race (missing = 9)				
<i>White/Caucasian</i>	63.6% (7)	78.6% (11)	81.0% (17)	76.1% (35)
<i>Black/African American</i>	18.2% (2)	7.1% (1)	9.5% (2)	10.9% (5)
<i>Asian</i>	0.0% (0)	7.1% (1)	0.0% (0)	2.2% (1)
<i>American Indian/Alaskan Native</i>	0.0% (0)	0.0% (0)	0.0% (0)	0.0% (0)
<i>Hispanic</i>	0.0% (0)	0.0% (0)	0.0% (0)	0.0% (0)
<i>Biracial</i>	18.2% (2)	7.1% (1)	9.5% (2)	10.9% (5)
*Numbers may not add to 100 due to rounding.				

Test Performance Results by Sex and Age Group

Tables 4 through 16 report neurobehavioral performance by gender. Wilcoxon Rank-Sum tests and Kruskal Wallis tests were used to compare test scores between sex and age groups, respectively, for scores with non-normal distributions. Two-sample unpaired t-tests and ANOVA were used to compare normally distributed test scores between sex and age groups, respectively. In the event of heteroscedasticity, Welch's test was used in place of ANOVA. Fisher's Exact and Chi-square p-values were calculated for dichotomized score outcomes (normal versus abnormal for standardized tests and above versus below median/mean for non-standardized tests depending on the normality of the distribution) across sex and age groups.

Females and younger participants had higher median scores on the Beery VMI than males and older participants, though this difference was not significant ($p > 0.05$; Tables 4 and 5). The same relationship was observed for dominant hand, non-dominant hand, and both hands median performance on the Purdue Pegboard Test (Tables 6-9) and again for Object Memory immediate and

delayed score means (Tables 10 and 11), although these relationships were not significant.

Table 4. Beery VMI Scores by Sex

Scores	Male N=28	Female N=27	Total N=55	P-value
Standard Scores				0.2314 ^a
<i>Min</i>	46	58	46	
<i>Q1</i>	87	88	88	
<i>Median</i>	94	97	96	
<i>Q3</i>	101	108	101	
<i>Max</i>	116	117	117	
<i>Mean</i>	92.5	96.4	94.4	
<i>SD</i>	14.0	13.7	13.9	
<i>Mode</i>	87	88	98	
<i>Range</i>	70	59	71	
<i>IQR</i>	14	20	13	
Dichotomized*				1.0000 ^b
<i>Normal</i>	82.1% (23)	85.2% (23)	83.6% (46)	
<i>Abnormal</i>	17.9% (5)	14.8% (4)	16.4% (9)	
* Numbers may not add to 100 due to rounding. ^a Wilcoxon Rank-Sum P-value ^b Fisher's Exact P-value				

Table 5. Beery VMI Scores by Age Group

Scores	Ages 6-8 N=14	Ages 9-11 N=17	Ages 12-14 N=24	Total N=55	P-value
Standard Scores					0.2950 ^a
<i>Min</i>	84	75	46	46	
<i>Q1</i>	88	94	85	88	
<i>Median</i>	95.5	97	93.5	96	
<i>Q3</i>	108	103	99.5	101	
<i>Max</i>	116	117	116	117	
<i>Mean</i>	97.6	97.8	90.2	94.4	
<i>SD</i>	10.7	10.2	16.7	13.9	
<i>Mode</i>	88	97	98	98	
<i>Range</i>	32	42	70	71	
<i>IQR</i>	20	9	14.5	13	
Dichotomized*					0.3794 ^b
<i>Normal</i>	92.9% (13)	88.2% (15)	75.0% (18)	83.6% (46)	
<i>Abnormal</i>	7.1% (1)	11.8% (2)	25.0% (6)	16.4% (9)	
* Numbers may not add to 100 due to rounding. ^a Kruskal Wallis P-value ^b Fisher's Exact P-value					

Table 6. Standardized Purdue Pegboard Scores by Sex

Scores	Male N=28	Female N=27	Total N=55	P-value
Dominant Hand				0.5957 ^a
<i>Min</i>	10	10	10	
<i>Q1</i>	20	10	10	
<i>Median</i>	30	50	40	
<i>Q3</i>	50	60	60	
<i>Max</i>	70	80	80	
<i>Mean</i>	33.9	39.3	36.5	
<i>SD</i>	19.5	26.4	23.1	
<i>Mode</i>	10	10	10	
<i>Range</i>	60	70	70	
<i>IQR</i>	30	50	50	
Non-dominant Hand (missing=1)				0.1289 ^a
<i>Min</i>	10	10	10	
<i>Q1</i>	10	10	10	
<i>Median</i>	10	20	20	
<i>Q3</i>	40	50	50	
<i>Max</i>	60	90	90	
<i>Mean</i>	24.8	34.4	29.6	
<i>SD</i>	18.7	24.7	22.2	
<i>Mode</i>	10	10	10	
<i>Range</i>	50	80	80	
<i>IQR</i>	30	40	40	
Both Hands (missing=1)				0.1993 ^a
<i>Min</i>	10	10	10	
<i>Q1</i>	10	10	10	
<i>Median</i>	20	40	25	
<i>Q3</i>	40	60	50	
<i>Max</i>	70	90	90	
<i>Mean</i>	27.4	36.7	32.0	
<i>SD</i>	19.1	25.1	22.6	
<i>Mode</i>	10	10	10	
<i>Range</i>	60	80	80	
<i>IQR</i>	30	50	40	
^a Wilcoxon Rank-Sum P-value				

Table 7. Dichotomized Purdue Pegboard Scores by Sex*

	Male N=28	Female N=27	Total N=55	P-value
Dominant Hand				0.4985 ^a
<i>Normal</i>	46.4% (13)	55.6% (15)	50.9% (28)	
<i>Abnormal</i>	53.6% (15)	44.4% (12)	49.1% (27)	
Non-dominant Hand (missing=1)				0.1628 ^a
<i>Normal</i>	29.6% (8)	48.2% (13)	38.9% (21)	
<i>Abnormal</i>	70.4% (19)	51.9% (14)	61.1% (33)	
Both Hands (missing=1)				0.1688 ^a
<i>Normal</i>	33.3% (9)	51.9% (14)	42.6% (23)	
<i>Abnormal</i>	66.7% (18)	48.2% (13)	57.4% (31)	
* Numbers may not add to 100 due to rounding.				
^a Chi-Square P-value				

Table 8. Standardized Purdue Pegboard Scores by Age Group

Scores	Ages 6-8 N=14	Ages 9-11 N=17	Ages 12-14 N=24	Total N=55	P-value
Dominant Hand					0.1025 ^a
<i>Min</i>	10	10	10	10	
<i>Q1</i>	30	10	10	10	
<i>Median</i>	50	20	25	40	
<i>Q3</i>	70	50	50	60	
<i>Max</i>	80	70	70	80	
<i>Mean</i>	49.3	32.9	31.7	36.5	
<i>SD</i>	25.6	22.0	20.4	23.1	
<i>Mode</i>	50	10	10	10	
<i>Range</i>	70	60	60	70	
<i>IQR</i>	40	40	40	50	
Non-dominant Hand (missing=1)					0.1653 ^a
<i>Min</i>	10	10	10	10	
<i>Q1</i>	20	10	10	10	
<i>Median</i>	40	10	20	20	
<i>Q3</i>	50	30	40	50	
<i>Max</i>	90	80	60	90	
<i>Mean</i>	38.6	24.7	27.8	29.6	
<i>SD</i>	23.5	22.4	20.7	22.2	
<i>Mode</i>	10, 50	10	10	10	
<i>Range</i>	80	70	50	80	
<i>IQR</i>	30	20	30	40	
Both Hands (missing=1)					0.2862 ^a
<i>Min</i>	10	10	10	10	
<i>Q1</i>	20	10	10	10	
<i>Median</i>	40	20	20	25	
<i>Q3</i>	60	60	40	50	
<i>Max</i>	70	90	70	90	
<i>Mean</i>	39.3	31.8	27.8	32.0	
<i>SD</i>	21.3	27.2	19.3	22.6	
<i>Mode</i>	60	10	10	10	
<i>Range</i>	60	80	60	80	
<i>IQR</i>	40	50	30	40	
^a Kruskal Wallis P-value					

Table 9. Dichotomized Purdue Pegboard Scores by Age Group*

	Ages 6-8 N=14	Ages 9-11 N=17	Ages 12-14 N=24	Total N=55	P-value
Dominant Hand					0.1940 ^a
<i>Normal</i>	71.4% (10)	47.1% (8)	41.7% (10)	50.9% (28)	
<i>Abnormal</i>	28.6% (4)	52.9% (9)	58.3% (14)	49.1% (27)	
Non-dominant Hand (missing=1)					0.1611 ^a
<i>Normal</i>	57.1% (8)	23.5% (4)	39.1% (9)	38.9% (21)	
<i>Abnormal</i>	42.9% (6)	76.5% (13)	60.9% (14)	61.1% (33)	
Both Hands (missing=1)					0.4284 ^a
<i>Normal</i>	57.1% (8)	35.3% (6)	39.1% (9)	42.6% (23)	
<i>Abnormal</i>	42.9% (6)	64.7% (11)	60.9% (14)	57.4% (31)	
* Numbers may not add to 100 due to rounding.					
^a Chi-Square P-value					

Table 10. Object Memory Scores by Sex

Scores	Male N=28	Female N=27	Total N=55	P-value
Standard Scores				
Immediate				0.4518 ^a
<i>Min</i>	26	36	26	
<i>Q1</i>	43	43	43	
<i>Median</i>	45.5	47	46	
<i>Q3</i>	51.5	54	53	
<i>Max</i>	60	64	64	
<i>Mean</i>	46.5	48.0	47.3	
<i>SD</i>	7.5	7.2	7.3	
<i>Mode</i>	43	56	43	
<i>Range</i>	34	28	38	
<i>IQR</i>	8.5	11	10	
Delayed				0.4381 ^a
<i>Min</i>	29	33	29	
<i>Q1</i>	39.5	44	42	
<i>Median</i>	47.5	48	48	
<i>Q3</i>	52	53	52	
<i>Max</i>	64	70	70	
<i>Mean</i>	46.8	48.5	47.6	
<i>SD</i>	8.1	7.9	8.0	
<i>Mode</i>	46, 52	44, 49	49	
<i>Range</i>	35	37	41	
<i>IQR</i>	12.5	9	10	
Dichotomized*				
Immediate				1.0000 ^b
<i>Normal</i>	89.3% (25)	88.9% (24)	89.1% (49)	
<i>Abnormal</i>	10.7% (3)	11.1% (3)	10.9% (6)	
Delayed				0.1430 ^b
<i>Normal</i>	75.0% (21)	92.6% (25)	83.6% (46)	
<i>Abnormal</i>	25.0% (7)	7.4% (2)	16.4% (9)	
* Numbers may not add to 100 due to rounding.				
^a Two-Sample Unpaired T-test P-value				
^b Fisher's Exact P-value				

Table 11. Object Memory Scores by Age Group

Scores	Ages 6-8 N=14	Ages 9-11 N=17	Ages 12-14 N=24	Total N=55	P-value
Standard Scores					
Immediate					0.0635 ^a
Min	40	39	26	26	
Q1	44	44	40.5	43	
Median	51	47	43.5	46	
Q3	56	49	50.5	53	
Max	64	58	60	64	
Mean	50.9	47.4	45.1	47.3	
SD	7.5	5.5	7.8	7.3	
Mode	56	41, 45, 47, 48	43	43	
Range	24	19	34	38	
IQR	12	5	10	10	
Delayed					0.7788 ^a
Min	38	36	29	29	
Q1	40	44	41	42	
Median	45.5	47	49	48	
Q3	56	52	52	52	
Max	70	61	64	70	
Mean	48.5	48.1	46.8	47.6	
SD	9.3	6.6	8.3	8.0	
Mode	40	46	49, 52	49	
Range	32	25	35	41	
IQR	16	8	11	10	
Dichotomized Scores*					
Immediate					0.1286 ^b
Normal	100.0% (14)	94.1% (16)	79.2% (19)	89.1% (49)	
Abnormal	0.0% (0)	5.9% (1)	20.8% (5)	10.9% (6)	
Delayed					0.8966 ^b
Normal	85.7% (12)	88.2% (15)	79.2% (19)	83.6% (46)	
Abnormal	14.3% (2)	11.8% (2)	20.8% (5)	16.4% (9)	
* Numbers may not add to 100 due to rounding.					
^a One-way ANOVA P-value					
^b Fisher's Exact P-value					

Performance on BARS Tapping and Simple Digit Span, which are not standardized using sex or age norms, yielded different age and sex relationships (Tables 12-16). Comparisons of the median non-preferred Tapping scores and mean right and left hand Tapping scores by sex were significant ($p < 0.05$; Table 12). Mean preferred hand Tapping score differences by sex approached significance ($p = 0.0656$). The performance on each Tapping test also

significantly differed by age group ($p < 0.0001$; Tables 13 and 14). Unlike the results of other tests, BARS Simple Digit Span scores did not significantly differ by sex ($p > 0.05$; Table 15), although median scores were significantly different by age group for both forward and reverse tests ($p < 0.05$; Table 16).

Table 12. BARS Tapping Scores by Sex

Scores	Male N=28	Female N=27	Total N=55	P-value
Preferred Hand				0.0656 ^a
Min	76	85	76	
Q1	123	107	118	
Median	137	129	133	
Q3	153	134	146	
Max	168	164	168	
Mean	135.9	125.7	130.9	
SD	21.9	18.3	20.7	
Mode	123, 137, 151	134	134	
Range	92	79	92	
IQR	30	27	28	
Non-preferred Hand				0.0053 ^b
Min	59	51	51	
Q1	74.5	64	69	
Median	88	75	80	
Q3	101.5	85	95	
Max	188	141	188	
Mean	92.4	77	84.9	
SD	26.7	18.4	24.1	
Mode	82	64, 75	75, 82	
Range	129	90	137	
IQR	27	21	26	
Right Hand				0.0083 ^a
Min	107	103	103	
Q1	126	115	120	
Median	140	129	134	
Q3	155.5	135	151	
Max	188	164	188	
Mean	141.5	128	134.9	
SD	19.9	16.3	19.3	
Mode	137, 151	134	134	
Range	81	61	85	
IQR	29.5	20	31	
Left Hand				0.0022 ^a
Min	59	51	51	
Q1	74.5	64	69	
Median	85	75	78	
Q3	100	85	94	
Max	123	103	123	
Mean	86.9	74.7	80.9	
SD	15.3	12.8	15.3	
Mode	82	64, 75, 85	75, 82	
Range	64	52	72	
IQR	25	21	25	
^a Two-Sample Unpaired T-test P-value		^b Wilcoxon Rank-Sum P-value		

Table 13. BARS Tapping Scores by Hand Preference and Age Group

Scores	Ages 6-8 N=14	Ages 9-11 N=17	Ages 12-14 N=24	Total N=55	P-value
Preferred Hand					<0.0001 ^a
Min	103	76	103	76	
Q1	107	126	134	118	
Median	113	132	140.5	133	
Q3	120	135	155.5	146	
Max	129	157	168	168	
Mean	113.9	128.8	142.3	130.9	
SD	8.9	21.7	17.9	20.7	
Mode	107	134	103, 123, 134, 137, 151	134	
Range	26	81	65	92	
IQR	13	9	21.5	28	
Non-preferred Hand					<0.0001 ^b
Min	51	65	72	51	
Q1	60	75	82	69	
Median	64	78	94	80	
Q3	68	88	102	95	
Max	73	116	188	188	
Mean	63.3	83.1	98.7	84.9	
SD	5.5	13.8	27.0	24.1	
Mode	64	75	82, 85, 94, 102	75, 82	
Range	22	51	116	137	
IQR	8	13	20	26	
^a Welch's Test P-value					
^b Kruskal Wallis P-value					

Table 14. BARS Tapping Scores by Hand and Age Group

Scores	Ages 6-8 N=14	Ages 9-11 N=17	Ages 12-14 N=24	Total N=55	P-value
Right Hand					<0.0001 ^a
Min	103	110	123	103	
Q1	107	126	137	120	
Median	113	132	147.5	134	
Q3	120	135	159	151	
Max	129	157	188	188	
Mean	113.9	132.6	148.7	134.9	
SD	8.9	13.9	14.9	19.3	
Mode	107	134	134, 137, 151	134	
Range	26	47	65	85	
IQR	13	9	22	31	
Left Hand					<0.0001 ^b
Min	51	65	72	51	
Q1	60	75	82	69	
Median	64	77	94	78	
Q3	68	85	102	94	
Max	73	97	123	123	
Mean	63.3	79.2	92.3	80.9	
SD	5.5	8.0	12.6	15.3	
Mode	64	75	82, 85, 94, 102, 103	75, 82	
Range	22	32	51	72	
IQR	8	10	20	25	
^a One-way ANOVA P-value					
^b Welch's Test P-value					

Table 15. BARS Simple Digit Span Scores by Sex

Scores	Male N=28	Female N=27	Total N=55	P-value
Forward				0.9792 ^a
<i>Min</i>	3	3	3	
<i>Q1</i>	4	4	4	
<i>Median</i>	5	5	5	
<i>Q3</i>	6	6	6	
<i>Max</i>	7	8	8	
<i>Mean</i>	5	5.1	5.0	
<i>SD</i>	1.0	1.6	1.3	
<i>Mode</i>	5	5	5	
<i>Range</i>	4	5	5	
<i>IQR</i>	2	2	2	
Reverse				0.4373 ^a
<i>Min</i>	0	0	0	
<i>Q1</i>	3	3	3	
<i>Median</i>	3	3	3	
<i>Q3</i>	4	4	4	
<i>Max</i>	7	7	7	
<i>Mean</i>	3.4	3.3	3.3	
<i>SD</i>	1.5	1.9	1.7	
<i>Mode</i>	3	3	3	
<i>Range</i>	7	7	7	
<i>IQR</i>	1	1	1	
^a Wilcoxon Rank-Sum P-value				

Table 16. BARS Simple Digit Span Scores by Age Group

Scores	Ages 6-8 N=14	Ages 9-11 N=17	Ages 12-14 N=24	Total N=55	P-value
Forward					0.0018 ^a
Min	3	3	3	3	
Q1	3	5	5	4	
Median	4	5	5	5	
Q3	5	6	6.5	6	
Max	6	8	8	8	
Mean	4.0	5.2	5.5	5.0	
SD	1.0	1.2	1.3	1.3	
Mode	3, 4	5	5	5	
Range	3	5	5	5	
IQR	2	1	1.5	2	
Reverse					0.0062 ^a
Min	0	0	0	0	
Q1	0	3	3	3	
Median	3	3	4	3	
Q3	3	4	4.5	4	
Max	4	7	7	7	
Mean	2.2	3.6	3.8	3.3	
SD	1.5	1.6	1.7	1.7	
Mode	3	3	3, 4	3	
Range	4	7	7	7	
IQR	3	1	1.5	1	
^a Kruskal Wallis P-value					

Distance from Ash Landfills by Sex and Age Group

A map of the participants' distances from the coal ash landfills is shown in Figure 1. Tables 17 through 21 report distance from the ash landfill by gender and age group. Two-sample unpaired t-tests and ANOVA were used to compare participants' mean home distance from ash landfills between sex and age groups, respectively. Fisher's Exact and Chi-square p-values were calculated for dichotomized ash landfill distances (closer versus further from mean distance for each ash landfill and distances from either ash landfill) across sex and age groups.

Participants' mean distances from each ash landfill did not significantly differ by sex or age ($p > 0.05$; Tables 17-21). The same was true for distance from either ash landfill by sex or age group, with the exception of living five miles or closer compared to more than five miles from either landfill by age group, which was significant ($p = 0.0316$).

Figure 1.

Table 17. Distance from Ash Landfills by Sex

Distance in Miles	Male N=28	Female N=27	Total N=55	P-value
Distance from Cane Run				0.5815 ^a
<i>Min</i>	0.5	0.5	0.5	
<i>Q1</i>	3.1	2.2	2.8	
<i>Median</i>	5.3	4.2	5.0	
<i>Q3</i>	6.5	6.6	6.6	
<i>Max</i>	9.2	15.5	15.5	
<i>Mean</i>	5.1	4.7	4.9	
<i>SD</i>	2.2	3.3	2.8	
<i>Mode</i>	.	.	.	
<i>Range</i>	8.6	15.0	15.0	
<i>IQR</i>	3.4	4.4	3.8	
Distance from Mill Creek				0.1679 ^a
<i>Min</i>	1.0	1.0	1.0	
<i>Q1</i>	3.6	3.8	3.8	
<i>Median</i>	4.8	7.2	6.5	
<i>Q3</i>	7.6	9.1	9.0	
<i>Max</i>	12.6	17.7	17.7	
<i>Mean</i>	5.6	7.0	6.3	
<i>SD</i>	3.3	3.8	3.6	
<i>Mode</i>	.	.	.	
<i>Range</i>	11.7	16.7	16.8	
<i>IQR</i>	4.0	5.3	5.2	
Nearest Landfill Distance				0.4437 ^b
<i>Min</i>	0.5	0.5	0.5	
<i>Q1</i>	2.5	1.1	1.7	
<i>Median</i>	3.4	2.8	3.1	
<i>Q3</i>	4.4	4.0	4.2	
<i>Max</i>	5.7	15.5	15.5	
<i>Mean</i>	3.2	3.3	3.2	
<i>SD</i>	1.4	2.9	2.2	
<i>Mode</i>	.	.	.	
<i>Range</i>	5.1	15.0	15.0	
<i>IQR</i>	1.9	2.8	2.5	
^a Two-Sample Unpaired T-test P-value				
^b Wilcoxon Rank-Sum P-value				

Table 18. Dichotomized Distance from Ash Landfills by Sex*

Distance in Miles	Male N=28	Female N=27	Total N=55	P-value
Distance from Cane Run				0.5042 ^a
≤ 4.9 miles	42.9% (12)	51.9% (14)	47.3% (26)	
> 4.9 miles	57.1% (16)	48.2% (13)	52.7% (29)	
Distance from Mill Creek				0.2238 ^a
≤ 6.3 miles	57.1% (16)	40.7% (11)	49.1% (27)	
> 6.3 miles	42.9% (12)	59.3% (16)	50.9% (28)	
Nearest Landfill Distance				0.6875 ^a
≤ 3.1 miles	46.4% (13)	51.9% (14)	49.1% (27)	
> 3.1 miles	53.6% (15)	48.2% (13)	50.9% (28)	
Distance from Either Landfill				0.6088 ^b
≤ 1 mile	7.1% (2)	11.1% (3)	9.1% (5)	
> 1 mile	92.9% (26)	88.9% (24)	90.9% (50)	
Distance from Either Landfill				0.3217 ^a
≤ 2 miles	21.4% (6)	33.3% (9)	27.3% (15)	
> 2 miles	78.6% (22)	66.7% (18)	66.7% (40)	
Distance from Either Landfill				0.6875 ^a
≤ 3 miles	46.4% (13)	51.9% (14)	49.1% (27)	
> 3 miles	53.6% (15)	48.2% (13)	50.9% (28)	
Distance from Either Landfill				0.5889 ^a
≤ 4 miles	71.4% (20)	77.8% (21)	74.6% (41)	
> 4 miles	28.6% (8)	22.2% (6)	25.5% (14)	
Distance from Either Landfill				0.2516 ^b
≤ 5 miles	92.9% (26)	81.5% (22)	87.3% (48)	
> 5 miles	7.1% (2)	18.5% (5)	12.7% (7)	
Distance from Either Landfill				0.4909 ^b
≤ 6 miles	100.0% (28)	96.3% (26)	98.2% (54)	
> 6 miles	0.0% (0)	3.7% (1)	1.8% (1)	
Distance from Either Landfill				0.4909 ^b
≤ 7 miles	100.0% (28)	96.3% (26)	98.2% (54)	
> 7 miles	0.0% (0)	3.7% (1)	1.8% (1)	
Distance from Either Landfill				0.4909 ^b
≤ 8 miles	100.0% (28)	96.3% (26)	98.2% (54)	
> 8 miles	0.0% (0)	3.7% (1)	1.8% (1)	
Distance from Either Landfill				0.4909 ^b
≤ 9 miles	100.0% (28)	96.3% (26)	98.2% (54)	
> 9 miles	0.0% (0)	3.7% (1)	1.8% (1)	
Distance from Either Landfill				0.4909 ^b
≤ 10 miles	100.0% (28)	96.3% (26)	98.2% (54)	
> 10 miles	0.0% (0)	3.7% (1)	1.8% (1)	
* Numbers may not add to 100 due to rounding.				
^a Chi-Square P-value				
^b Fisher's Exact P-value				

Table 19. Distance from Ash Landfills by Age Group

Distance in Miles	Ages 6-8 N=14	Ages 9-11 N=17	Ages 12-14 N=24	Total N=55	P-value
Distance from Cane Run					0.9912 ^a
<i>Min</i>	0.7	0.5	0.5	0.5	
<i>Q1</i>	2.9	2.2	2.9	2.8	
<i>Median</i>	4.0	5.3	5.0	5.0	
<i>Q3</i>	8.1	5.7	6.7	6.6	
<i>Max</i>	9.1	15.5	9.2	15.5	
<i>Mean</i>	5.0	4.9	4.9	4.9	
<i>SD</i>	2.7	3.5	2.4	2.8	
<i>Mode</i>	.	.	.	.	
<i>Range</i>	8.5	14.9	8.6	15.0	
<i>IQR</i>	5.2	3.5	3.8	3.8	
Distance from Mill Creek					0.4781 ^a
<i>Min</i>	1.0	1.1	1.0	1.0	
<i>Q1</i>	3.2	4.0	3.0	3.8	
<i>Median</i>	5.8	7.1	5.7	6.5	
<i>Q3</i>	7.2	8.8	9.9	9.0	
<i>Max</i>	10.5	17.7	12.6	17.7	
<i>Mean</i>	5.3	6.9	6.3	6.3	
<i>SD</i>	3.1	3.7	3.8	3.6	
<i>Mode</i>	.	.	.	.	
<i>Range</i>	9.5	16.6	11.7	16.8	
<i>IQR</i>	4.0	4.8	6.9	5.2	
Nearest Landfill Distance					0.4151 ^b
<i>Min</i>	0.7	0.5	0.5	0.5	
<i>Q1</i>	1.1	1.7	2.1	1.7	
<i>Median</i>	3.0	3.8	3.0	3.1	
<i>Q3</i>	3.6	5.2	4.2	4.2	
<i>Max</i>	4.4	15.5	5.4	15.5	
<i>Mean</i>	2.7	4.0	3.0	3.2	
<i>SD</i>	1.3	3.4	1.4	2.2	
<i>Mode</i>	.	.	.	.	
<i>Range</i>	3.8	15.0	4.8	15.0	
<i>IQR</i>	2.5	3.4	2.1	2.5	
^a One-way ANOVA P-value					
^b Kruskal-Wallis P-value					

Table 20. Dichotomized Distance from Ash Landfills by Age Group*

Distance in Miles	Ages 6-8 N=14	Ages 9-11 N=17	Ages 12-14 N=24	Total N=55	Chi-square P-value
Distance from Cane Run					0.6635
≤ 4.9 miles	57.1% (8)	41.2% (7)	45.8% (11)	47.3% (26)	
> 4.9 miles	42.9% (6)	58.8% (10)	54.2% (13)	52.7% (29)	
Distance from Mill Creek					0.7124
≤ 6.3 miles	50.0% (7)	41.2% (7)	54.2% (13)	49.1% (27)	
> 6.3 miles	50.0% (7)	58.8% (10)	45.8% (11)	50.9% (28)	
Nearest Landfill Distance					0.7124
≤ 3.1 miles	50.0% (7)	41.2% (7)	54.2% (13)	49.1% (27)	
> 3.1 miles	50.0% (7)	58.8% (10)	45.8% (11)	50.9% (28)	
* Numbers may not add to 100 due to rounding.					

Table 21. Dichotomized Distance from Either Ash Landfill by Age Group*

Distance in Miles	Ages 6-8 N=14	Ages 9-11 N=17	Ages 12-14 N=24	Total N=55	Fisher's Exact P-value
Distance from Either Landfill					0.8489
≤ 1 mile	7.1% (1)	5.9% (1)	12.5% (3)	9.1% (5)	
> 1 mile	92.9% (13)	94.1% (16)	87.5% (21)	90.9% (50)	
Distance from Either Landfill					1.0000
≤ 2 miles	28.6% (4)	29.4% (5)	25.0% (6)	27.3% (15)	
> 2 miles	71.4% (10)	70.6% (12)	75.0% (18)	72.7% (40)	
Distance from Either Landfill					0.7124 ^a
≤ 3 miles	50.0% (7)	41.2% (7)	54.2% (13)	49.1% (27)	
> 3 miles	50.0% (7)	58.8% (10)	45.8% (11)	50.9% (28)	
Distance from Either Landfill					0.4175
≤ 4 miles	85.7% (12)	64.7% (11)	75.0% (18)	74.6% (41)	
> 4 miles	14.3% (2)	35.3% (6)	25.0% (6)	25.5% (14)	
Distance from Either Landfill					0.0316
≤ 5 miles	100.0% (14)	70.6% (12)	91.7% (22)	87.3% (48)	
> 5 miles	0.0% (0)	29.4% (5)	8.3% (2)	12.7% (7)	
Distance from Either Landfill					0.5636
≤ 6 miles	100.0% (14)	94.1% (16)	100.0% (24)	98.2% (54)	
> 6 miles	0.0% (0)	5.9% (1)	0.0% (0)	1.8% (1)	
Distance from Either Landfill					0.5636
≤ 7 miles	100.0% (14)	94.1% (16)	100.0% (24)	98.2% (54)	
> 7 miles	0.0% (0)	5.9% (1)	0.0% (0)	1.8% (1)	
Distance from Either Landfill					0.5636
≤ 8 miles	100.0% (14)	94.1% (16)	100.0% (24)	98.2% (54)	
> 8 miles	0.0% (0)	5.9% (1)	0.0% (0)	1.8% (1)	
Distance from Either Landfill					0.5636
≤ 9 miles	100.0% (14)	94.1% (16)	100.0% (24)	98.2% (54)	
> 9 miles	0.0% (0)	5.9% (1)	0.0% (0)	1.8% (1)	
Distance from Either Landfill					0.5636
≤ 10 miles	100.0% (14)	94.1% (16)	100.0% (24)	98.2% (54)	
> 10 miles	0.0% (0)	5.9% (1)	0.0% (0)	1.8% (1)	
* Numbers may not add to 100 due to rounding.					
^a Chi-Square P-value					

Test Scores and Distance from Ash Landfills

Tables 22 - 33 report the dichotomized test scores and distances from the landfills. Two-sample unpaired t-tests were used to compare participants' mean home distance from ash landfills between participants with normal and abnormal or above and below mean/median test scores. Satterthwaite t-tests were used in cases of unequal variances. Fisher's Exact and Chi-square p-values were calculated for dichotomized ash landfill distances (closer versus further from mean distance for each ash landfill or distances from either ash landfill) between dichotomized performance levels on tests.

There was no significant difference between Beery VMI dichotomized performance based on living nearer or further from Cane Run or Mill Creek ($p > 0.05$; Table 22). The association between Beery VMI dichotomized performance based on living nearer or further from either as landfill approached significance ($p = 0.0776$), but did not reach significance at $\alpha=0.05$. Although these results were not significant, the majority (66.7%) of those with abnormal scores lived 4.9 miles (mean distance) or closer to Cane Run. Additionally, 77.8% of those with abnormal VMI scores lived within 3 miles of either ash landfill. The mean distances from Cane Run and Mill Creek did not significantly differ between normal or abnormal scoring groups ($p > 0.05$).

Table 22. Beery VMI Scores by Distance to Ash Landfill*

	Normal Scores N=46	Abnormal Scores N=9	Total N=55	Fisher's Exact p-value
Distance from Cane Run				0.2808
≤ 4.9 miles	43.5% (20)	66.7% (6)	47.3% (26)	
> 4.9 miles	58.5% (26)	33.3% (3)	52.7% (29)	
Distance from Mill Creek				0.4688
≤ 6.3 miles	52.2% (24)	33.3% (3)	49.1% (27)	
> 6.3 miles	47.8% (22)	66.7% (6)	50.9% (28)	
Nearest Landfill Distance				0.0776
≤ 3.1 miles	43.5% (20)	77.8% (7)	49.1% (27)	
> 3.1 miles	56.5% (26)	22.2% (2)	50.9% (28)	
	Mean (sd)	Mean (sd)	Two-Sample Unpaired T-test p-value	
Distance from Cane Run	5.1 (2.7)	3.9 (2.9)	0.2326	
Distance from Mill Creek	6.1 (3.5)	7.4 (4.2)	0.3209	
	Sum of Scores	Sum of Scores	Wilcoxon Rank-Sum Test p-value	
Nearest Landfill Distance	1383.0	157.0	0.0361	

* Numbers may not add to 100 due to rounding.

Those with abnormal Purdue Pegboard dominant hand scores were more likely to live closer to Cane Run (63.0%), while those with normal dominant hand scores were more likely to live further from Cane Run (Table 23). This association was statistically significant ($p = 0.0315$). Comparisons between mean distances from Cane Run among normal and abnormal dominant hand scores found the same, with abnormal scorers having a lower mean distance than normal scorers. This finding was significant ($p=0.0316$). The opposite relationship was observed with dominant hand scores and distance to Mill Creek, with the majority (60.7%) of normal scorers residing closer to Mill Creek and abnormal scorers (63.0%) residing further from Mill Creek. This relationship was not significant ($p > 0.05$). There was no relationship between the dominant hand scores and distance to either ash pile. No significant differences or patterns

emerged when assessing the Purdue Pegboard non-dominant and both hand scores in relation to ash pile distance (Tables 24 and 25).

Table 23. Purdue Pegboard Dominant Hand Scores by Distance to Ash Landfills*

	Normal Scores N=28	Abnormal Scores N=27	Total N=55	Chi- Square p-value
Distance from Cane Run ≤ 4.9 miles > 4.9 miles	32.1% (9) 67.9% (19)	63.0% (17) 37.0% (10)	47.3% (26) 52.7% (29)	0.0315
Distance from Mill Creek ≤ 6.3 miles > 6.3 miles	60.7% (17) 39.3% (11)	37.0% (10) 63.0% (17)	49.1% (27) 50.9% (28)	0.0791
Nearest Landfill Distance ≤ 3.1 miles > 3.1 miles	50.0% (14) 50.0% (14)	48.2% (13) 51.9% (14)	49.1% (27) 50.9% (28)	0.8908
	Mean (sd)	Mean (sd)	Two-Sample Unpaired T-test p-value	
Distance from Cane Run	5.7 (3.1)	4.1 (2.2)	0.0316	
Distance from Mill Creek	5.6 (4.0)	7.0 (3.1)	0.1498	
	Sum of Scores	Sum of Scores	Wilcoxon Rank-Sum Test p-value	
Nearest Landfill Distance	761.0	779.0	0.7048	
* Numbers may not add to 100 due to rounding.				

Table 24. Purdue Pegboard Non-Dominant Hand Scores by Distance to Ash Landfills*

	Normal Scores N=21	Abnormal Scores N=33	Total N=54	Chi- Square p-value
Distance from Cane Run ≤ 4.9 miles > 4.9 miles	47.6% (10) 52.4% (11)	48.5% (16) 51.5% (17)	48.2% (26) 51.9% (28)	0.9505
Distance from Mill Creek ≤ 6.3 miles > 6.3 miles	38.1% (8) 61.9% (13)	54.6% (18) 45.5% (15)	48.2% (26) 51.9% (28)	0.2382
Nearest Landfill Distance ≤ 3.1 miles > 3.1 miles	47.6% (10) 52.4% (11)	48.5% (16) 51.5% (17)	48.2% (26) 51.9% (28)	0.9505
	Mean (sd)	Mean (sd)	Two-Sample Unpaired T-test p-value	
Distance from Cane Run	5.1 (3.3)	4.7 (2.4)	0.5965	
Distance from Mill Creek	7.3 (4.1)	5.8 (3.1)	0.1429	
	Sum of Scores	Sum of Scores	Wilcoxon Rank-Sum Test p-value	
Nearest Landfill Distance	608.0	877.0	0.5945	
* Numbers may not add to 100 due to rounding.				

* Numbers may not add to 100 due to rounding.

Table 25. Purdue Pegboard Both Hands Scores by Distance to Ash Landfills*

	Normal Scores N=23	Abnormal Scores N=31	Total N=54	Chi- Square p-value	
Distance from Cane Run ≤ 4.9 miles > 4.9 miles	43.5% (10) 56.5% (13)	51.6% (16) 48.4% (15)	48.2% (26) 51.9% (28)	0.5541	
Distance from Mill Creek ≤ 6.3 miles > 6.3 miles	43.5% (10) 56.5% (13)	51.6% (16) 48.4% (15)	48.2% (26) 51.9% (28)		
Nearest Landfill Distance ≤ 3.1 miles > 3.1 miles	52.2% (12) 47.8% (11)	45.2% (14) 54.8% (17)	48.2% (26) 51.9% (28)		0.6101
	Mean (sd)	Mean (sd)	Two-Sample Unpaired T-test p-value		
Distance from Cane Run	5.0 (3.5)	4.7 (2.2)	0.7694		
Distance from Mill Creek	6.9 (4.1)	6.0 (3.2)	0.3486		
	Sum of Scores	Sum of Scores	Wilcoxon Rank-Sum Test p-value		
Nearest Landfill Distance	601.0	844.0	0.5876		
* Numbers may not add to 100 due to rounding.					

* Numbers may not add to 100 due to rounding.

Six participants (10.9%) scored abnormally on the immediate Object Memory test. The majority (66.7%) of these abnormal scores were from participants living within 4.9 miles of Cane Run (Table 26). There was not a significant association between dichotomized test scores and landfill distances ($p > 0.05$). A t-test comparing the mean distances from Cane Run between normal and abnormal scorers approached significance ($p = 0.0736$), but was not significant at $\alpha=0.05$.

Table 26. Object Memory Immediate Scores by Distance to Ash Landfills*

	Normal Scores N=49	Abnormal Scores N=6	Total N=55	Fisher's Exact p-value
Distance from Cane Run ≤ 4.9 miles > 4.9 miles	44.9% (22) 55.1% (27)	66.7% (4) 33.3% (2)	47.3% (26) 52.7% (29)	0.4060
Distance from Mill Creek ≤ 6.3 miles > 6.3 miles	49.0% (24) 51.0% (25)	50.0% (3) 50.0% (3)	49.1% (27) 50.9% (28)	1.0000
Nearest Landfill Distance ≤ 3.1 miles > 3.1 miles	49.0% (24) 51.0% (25)	50.0% (3) 50.0% (3)	49.1% (27) 50.9% (28)	1.0000
	Mean (sd)	Mean (sd)	Two-Sample Unpaired T-test p-value	
Distance from Cane Run	5.1 (2.7)	3.0 (2.5)	0.0736	
Distance from Mill Creek	6.2 (3.7)	6.9 (2.4)	0.6674	
	Sum of Scores	Sum of Scores	Wilcoxon Rank-Sum Test p-value	
Nearest Landfill Distance	1396.0	144.0	0.5258	
* Numbers may not add to 100 due to rounding.				

Nine participants (16.4%) scored abnormally on the delayed Object Memory test. There were no significant associations between plant distances and dichotomized scores ($p > 0.05$), though most (66.7%) of the abnormal scorers resided within 6.3 miles of Mill Creek (Table 27).

Table 27. Object Memory Delayed Scores by Distance to Ash Landfills*

	Normal Scores N=46	Abnormal Scores N=9	Total N=55	Fisher's Exact p-value
Distance from Cane Run				1.0000
≤ 4.9 miles	47.8% (22)	44.4% (4)	47.3% (26)	
> 4.9 miles	52.2% (24)	55.6% (5)	52.7% (29)	
Distance from Mill Creek				0.2955
≤ 6.3 miles	45.7% (21)	66.7% (6)	49.1% (27)	
> 6.3 miles	54.4% (25)	33.3% (3)	50.9% (28)	
Nearest Landfill Distance				1.0000
≤ 3.1 miles	50.0% (23)	44.4% (4)	49.1% (27)	
> 3.1 miles	50.0% (23)	55.6% (5)	50.9% (28)	
	Mean (sd)	Mean (sd)	Two-Sample Unpaired T-test p-value	
Distance from Cane Run	5.0 (2.8)	4.5 (2.5)	0.6237	
Distance from Mill Creek	6.5 (3.8)	5.4 (2.4)	0.4078	
	Sum of Scores	Sum of Scores	Wilcoxon Rank-Sum Test p-value	
Nearest Landfill Distance	1279.0	261.0	0.8467	

* Numbers may not add to 100 due to rounding.

The mean scores for the BARS Tapping preferred, right, and left hand tests were 130.9, 134.9, and 80.9, respectively. The median score for the BARS Tapping non-preferred hand test was 80. Dichotomized preferred hand, non-preferred hand, and left hand BARS Tapping performance was not significantly associated with distance from an ash landfill (Tables 28-30). While performance on the right hand test also was not significantly associated with plant distance, mean distance of those scoring below average on this test was lower than the mean distance of above average scorers ($p = 0.0622$; Table 31).

Table 28. BARS Tapping Preferred Hand Scores by Distance to Ash Landfills*

	Above Average Scores N=29	Below Average Scores N=26	Total N=55	Chi- Square p-value
Distance from Cane Run ≤ 4.9 miles > 4.9 miles	44.8% (13) 55.2% (16)	50.0% (13) 50.0% (13)	47.3% (26) 52.7% (29)	0.7013
Distance from Mill Creek ≤ 6.3 miles > 6.3 miles	44.8% (13) 55.2% (16)	53.9% (14) 46.2% (12)	49.1% (27) 50.9% (28)	0.5042
Nearest Landfill Distance ≤ 3.1 miles > 3.1 miles	55.2% (16) 44.8% (13)	42.3% (11) 57.7% (15)	29.1% (27) 50.9% (28)	0.3407
	Mean (sd)	Mean (sd)	Two-Sample Unpaired T-test p-value	
Distance from Cane Run	6.9 (4.3)	5.6 (2.6)	0.1544 ^a	
Distance from Mill Creek	5.0 (3.1)	4.7 (2.4)	0.7202	
	Sum of Scores	Sum of Scores	Wilcoxon Rank-Sum Test p-value	
Nearest Landfill Distance	787.0	753.0	0.6796	

* Numbers may not add to 100 due to rounding.

^a Satterthwaite t-test used due to unequal variances.

Table 29. BARS Tapping Non-Preferred Hand Scores by Distance to Ash Landfills*

	Above Median Score N=28	Below Median Score N=27	Total N=55	Chi- Square p-value
Distance from Cane Run ≤ 4.9 miles > 4.9 miles	46.4% (13) 53.6% (15)	48.2% (13) 51.9% (14)	47.3% (26) 52.7% (29)	0.8984
Distance from Mill Creek ≤ 6.3 miles > 6.3 miles	46.4% (13) 53.6% (15)	51.9% (14) 48.2% (13)	49.1% (27) 50.9% (28)	0.6875
Nearest Landfill Distance ≤ 3.1 miles > 3.1 miles	57.1% (16) 42.9% (12)	40.7% (11) 59.3% (16)	49.1% (27) 50.9% (28)	0.2238
	Mean (sd)	Mean (sd)	Two-Sample Unpaired T-test p-value	
Distance from Cane Run	4.6 (2.6)	5.2 (3.0)	0.4676	
Distance from Mill Creek	6.3 (3.5)	6.2 (3.8)	0.9244	
	Sum of Scores	Sum of Scores	Wilcoxon Rank-Sum Test p-value	
Nearest Landfill Distance	742.0	798.0	0.4847	
* Numbers may not add to 100 due to rounding.				

Table 30. BARS Tapping Left Hand Scores by Distance to Ash Landfills*

	Above Average Scores N=26	Below Average Scores N=29	Total N=55	Chi- Square p-value	
Distance from Cane Run ≤ 4.9 miles > 4.9 miles	46.2% (12) 53.9% (14)	48.3% (14) 51.7% (15)	47.3% (26) 52.7% (29)	0.8750	
Distance from Mill Creek ≤ 6.3 miles > 6.3 miles	46.2% (12) 53.9% (14)	51.7% (15) 48.3% (14)	49.1% (27) 50.9% (28)		
Nearest Landfill Distance ≤ 3.1 miles > 3.1 miles	53.9% (14) 46.2% (12)	44.8% (13) 55.2% (16)	49.1% (27) 50.9% (28)		0.5042
	Mean (sd)	Mean (sd)	Two-Sample Unpaired T-test p-value		
Distance from Cane Run	4.7 (2.5)	5.1 (3.0)	0.5466		
Distance from Mill Creek	6.4 (3.5)	6.1 (3.8)	0.7871		
	Sum of Scores	Sum of Scores	Wilcoxon Rank-Sum Test p-value		
Nearest Landfill Distance	729.0	811.0	0.9933		
* Numbers may not add to 100 due to rounding.					

Table 31. BARS Tapping Right Hand Scores by Distance to Ash Landfills

	Above Average Scores N=25	Below Average Scores N=30	Total N=55	Chi- Square p-value
Distance from Cane Run ≤ 4.9 miles > 4.9 miles	48.0% (12) 52.0% (13)	46.7% (14) 53.3% (16)	47.3% (26) 52.7% (29)	0.9214
Distance from Mill Creek ≤ 6.3 miles > 6.3 miles	40.0% (10) 60.0% (15)	56.7% (17) 43.3% (13)	49.1% (27) 50.9% (28)	0.2183
Nearest Landfill Distance ≤ 3.1 miles > 3.1 miles	48.0% (12) 52.0% (13)	50.0% (15) 50.0% (15)	49.1% (27) 50.9% (28)	0.8826
	Mean (sd)	Mean (sd)	Two-Sample Unpaired T-test p-value	
Distance from Cane Run	5.0 (3.2)	4.8 (2.4)	0.7796	
Distance from Mill Creek	7.3 (4.2)	5.4 (2.9)	0.0622	
	Sum of Scores	Sum of Scores	Wilcoxon Rank-Sum Test p-value	
Nearest Landfill Distance	734.0	806.0	0.5712	

The median scores for the BARS Forward and Reverse Simple Digit Span were 5 and 3, respectively. The BARS Simple Digit Span performance was not significantly associated with ash landfill distance (Tables 26 and 27). However, the majority (61.1%) of below median forward test scorers lived within 5 miles of Cane Run and the majority (71.4%) of below median reverse test scorers lived within 3 miles of either ash landfill.

Table 32. BARS Forward Simple Digit Span Scores by Distance to Ash Landfills*

	Above Median Score N=37	Below Median Score N=18	Total N=55	Chi- Square p-value
Distance from Cane Run ≤ 4.9 miles > 4.9 miles	40.5% (15) 59.5% (22)	61.1% (11) 38.9% (7)	47.3% (26) 52.7% (29)	0.1516
Distance from Mill Creek ≤ 6.3 miles > 6.3 miles	48.7% (18) 51.4% (19)	50.0% (9) 50.0% (9)	49.1% (27) 50.9% (28)	0.9251
Nearest Landfill Distance ≤ 3.1 miles > 3.1 miles	48.7% (18) 51.4% (19)	50.0% (9) 50.0% (9)	49.1% (27) 50.9% (28)	0.9251
	Mean (sd)	Mean (sd)	Two-Sample Unpaired T-test p- value	
Distance from Cane Run	5.0 (2.9)	4.8 (2.5)	0.8210	
Distance from Mill Creek	6.4 (3.7)	6.1 (3.6)	0.7510	
	Sum of Scores	Sum of Scores	Wilcoxon Rank-Sum Test p-value	
Nearest Landfill Distance	1079.0	461.0	0.4492	
* Numbers may not add to 100 due to rounding.				

Table 33. BARS Reverse Simple Digit Span Scores by Distance to Ash Landfills

	Above Median Score N=48	Below Median Score N=7	Total N=55	Fisher's Exact p-value
Distance from Cane Run				0.6957
≤ 4.9 miles	45.8% (22)	57.1% (4)	47.3% (26)	
> 4.9 miles	54.2% (26)	42.9% (3)	52.7% (29)	
Distance from Mill Creek				1.0000
≤ 6.3 miles	50.0% (24)	42.9% (3)	49.1% (27)	
> 6.3 miles	50.0% (24)	57.1% (4)	50.9% (28)	
Nearest Landfill Distance				0.2516
≤ 3.1 miles	45.8% (22)	71.4% (5)	49.1% (27)	
> 3.1 miles	54.2% (26)	28.6% (2)	50.9% (28)	
	Mean (sd)	Mean (sd)	Two-Sample Unpaired T-test p-value	
Distance from Cane Run	4.9 (2.8)	4.6 (3.0)	0.7748	
Distance from Mill Creek	6.3 (3.6)	5.8 (4.0)	0.7053	
	Sum of Scores	Sum of Scores	Wilcoxon Rank-Sum Test p-value	
Nearest Landfill Distance	1420.0	120.0	0.0566	

Logistic Regression

Tables 34 through 57 report the results of logistic regression modeling with dichotomized test scores, dichotomized distance to the nearest ash landfill, and variables potentially associated with test scores. Possible covariates were included in the modeling step if their univariate Wald Chi-square p-values were less than 0.05. Few of the potential covariates were significant in univariate analyses; therefore, half of the models are simple.

None of the logistic regression models involving the nearest landfill distance variable reached statistical significance at $\alpha=0.05$. However, the odds of abnormal VMI performance (OR = 4.549), below median reverse SDS scores (OR = 2.954), and abnormal Purdue Pegboard non-dominant hand scores (OR = 1.035) were higher in those living closer to the ash landfills than those living further from the ash landfills in unadjusted models. Among adjusted

models, the odds of abnormal Purdue Pegboard dominant hand scores (AOR = 1.186) and below median BARS forward SDS scores (AOR = 1.170) were higher in those living closer to the ash landfills than those living further from the ash landfills.

Logistic regression analysis also provided the opportunity to compare the odds of below mean/median scores on the BARS test between males and females when the univariate Wald Chi-square p-values were significant. The odds of below median performance on the BARS Tapping test with the non-preferred hand (OR = 5.937) and below average performance on the BARS Tapping right (OR = 5.143) and left (OR = 4.275) hand tests were higher in females than males. However, upon further analysis, these associations are confounded by age. The odds of below mean or median performance on all of the BARS tests except for the reverse Simple Digit Span test were significantly lower in older participants than in younger participants.

Table 34. Variables Potentially Associated with VMI Scores

Variable	Chi-square p-value
Age (in months)	0.3864
Sex	0.7607
Median Income	0.0767
Pre-1978 Home	0.9445
Environmental Tobacco Smoke Exposure	0.4670
Family History of Learning Disability	0.9197

Table 35. Logistic Regression for VMI Scores

Model Variables*	OR	95% CI
Nearest Landfill Distance	4.549	(0.851, 24.308)
* No adjustments for age, sex, median income, home age, tobacco smoke, or family history of learning disability since these variables were not significant in univariate analyses.		

Table 36. Variables Potentially Associated with Purdue Pegboard Dominant Hand Scores

Variable	Chi-square p-value
Age (in months)	0.1747
Sex	0.4991
Median Income	0.5814
Pre-1978 Home	0.0272
Environmental Tobacco Smoke Exposure	0.9407
Family History of Learning Disability	0.5480

Table 37. Logistic Regression for Purdue Pegboard Dominant Hand

Model Variables*	OR	95% CI
Nearest Landfill Distance	0.929	(0.322, 2.674)
Pre-1978 Home	0.231	(0.063, 0.848)
Nearest Landfill Distance + Pre-1978 Home	1.186	(0.333, 4.228)
* No adjustments for age, sex, median income, tobacco smoke, or family history of learning disability since these variables were not significant in univariate analyses.		

Table 38. Variables Potentially Associated with Purdue Pegboard Non-Dominant Hand Scores

Variable	Chi-square p-value
Age (in months)	0.0610
Sex	0.1660
Median Income	0.7261
Pre-1978 Home	0.2227
Environmental Tobacco Smoke Exposure	0.0925
Family History of Learning Disability	0.9638

Table 39. Logistic Regression for Purdue Pegboard Non-Dominant Hand

Model Variables*	OR	95% CI
Nearest Landfill Distance	1.035	(0.346, 3.095)
* No adjustments for age, sex, median income, home age, tobacco smoke, or family history of learning disability since these variables were not significant in univariate analyses.		

Table 40. Variables Potentially Associated with Purdue Pegboard Both Hands Scores

Variable	Chi-square p-value
Age (in months)	0.2490
Sex	0.1716
Median Income	0.3269
Pre-1978 Home	0.0585
Environmental Tobacco Smoke Exposure	0.6470
Family History of Learning Disability	0.9638

Table 41. Logistic Regression for Purdue Pegboard Both Hands

Model Variables*	OR	95% CI
Nearest Landfill Distance	0.755	(0.256, 2.226)
* No adjustments for age, sex, median income, home age, tobacco smoke, or family history of learning disability since these variables were not significant in univariate analyses.		

Table 42. Variables Potentially Associated with Immediate Object Memory Scores

Variable	Chi-square p-value
Age (in months)	0.0323
Sex	0.9624
Median Income	0.4418
Pre-1978 Home	0.6008
Environmental Tobacco Smoke Exposure	0.5112
Family History of Learning Disability	0.7718

Table 43. Logistic Regression for Immediate Object Memory Scores

Model Variables*	OR	95% CI
Nearest Landfill Distance	1.042	(0.191, 5.676)
Age (in months)	1.056	(1.005, 1.110)
Nearest Landfill Distance + Age (in months)	0.772	(0.120, 4.983)
* No adjustments for sex, median income, home age, tobacco smoke, or family history of learning disability since these variables were not significant in univariate analyses.		

Table 44. Variables Potentially Associated with Delayed Object Memory Scores

Variable	Chi-square p-value
Age (in months)	0.6767
Sex	0.4670
Median Income	0.8483
Pre-1978 Home	0.7633
Environmental Tobacco Smoke Exposure	0.4670
Family History of Learning Disability	0.7933

Table 45. Logistic Regression for Delayed Object Memory Scores

Model Variables*	OR	95% CI
Nearest Landfill Distance	0.800	(0.190, 3.364)
* No adjustments for age, sex, median income, home age, tobacco smoke, or family history of learning disability since these variables were not significant in univariate analyses.		

Table 46. Variables Potentially Associated with BARS Preferred Hand Tapping Scores

Variable	Chi-square p-value
Age (in months)	0.0001
Sex	0.2291
Median Income	0.9048
Pre-1978 Home	0.8484
Environmental Tobacco Smoke Exposure	0.8231
Family History of Learning Disability	0.0926

Table 47. Logistic Regression for BARS Preferred Hand Tapping Scores

Model Variables*	OR	95% CI
Nearest Landfill Distance	0.596	(0.205, 1.734)
Age (in months)	0.947	(0.921, 0.974)
Nearest Landfill Distance + Age (in months)	0.518	(0.132, 2.027)
* No adjustments for sex, median income, home age, tobacco smoke, or family history of learning disability since these variables were not significant in univariate analyses.		

Table 48. Variables Potentially Associated with BARS Non-Preferred Hand Tapping Scores

Variable	Chi-square p-value
Age (in months)	<0.0001
Sex	0.0027
Median Income	0.1891
Pre-1978 Home	0.8484
Environmental Tobacco Smoke Exposure	0.1730
Family History of Learning Disability	0.2550

Table 49. Logistic Regression for BARS Non-Preferred Hand Tapping Scores

Model Variables*	OR	95% CI
Nearest Landfill Distance	0.516	(0.176, 1.506)
Age (in months)	0.937	(0.907, 0.968)
Sex	5.937	(1.854, 19.014)
Sex + Age (in months)	3.357	(0.777, 14.510)
Nearest Landfill Distance + Age (in months)	0.368	(0.083, 1.641)
Nearest Landfill Distance + Sex	0.389	(0.114, 1.332)
Nearest Landfill Distance + Age (in months) + Sex	0.281	(0.055, 1.428)
* No adjustments for median income, home age, tobacco smoke, or family history of learning disability since these variables were not significant in univariate analyses.		

Table 50. Variables Potentially Associated with BARS Right Hand Tapping Scores

Variable	Chi-square p-value
Age (in months)	0.0001
Sex	0.0050
Median Income	0.6644
Pre-1978 Home	0.4214
Environmental Tobacco Smoke Exposure	0.3487
Family History of Learning Disability	0.6358

Table 51. Logistic Regression for BARS Right Hand Tapping Scores

Model Variables*	OR	95% CI
Nearest Landfill Distance	1.083	(0.375, 3.133)
Age (in months)	0.931	(0.897, 0.966)
Sex	5.143	(1.617, 16.355)
Sex + Age (in months)	2.630	(0.590, 11.727)
Nearest Landfill Distance + Age (in months)	1.547	(0.353, 6.779)
Nearest Landfill Distance + Sex	0.995	(0.314, 3.151)
Nearest Landfill Distance + Age (in months) + Sex	1.414	(0.313, 6.397)
* No adjustments for median income, home age, tobacco smoke, or family history of learning disability since these variables were not significant in univariate analyses.		

Table 52. Variables Potentially Associated with BARS Left Hand Tapping Scores

Variable	Chi-square p-value
Age (in months)	0.0001
Sex	0.0118
Median Income	0.4357
Pre-1978 Home	0.9672
Environmental Tobacco Smoke Exposure	0.0909
Family History of Learning Disability	0.1695

Table 53. Logistic Regression for BARS Left Hand Tapping Scores

Model Variables*	OR	95% CI
Nearest Landfill Distance	0.696	(0.241, 2.016)
Age (in months)	0.939	(0.909, 0.970)
Sex	4.275	(1.379, 13.252)
Sex + Age (in months)	2.015	(0.484, 8.399)
Nearest Landfill Distance + Age (in months)	0.674	(0.165, 2.746)
Nearest Landfill Distance + Sex	0.604	(0.192, 1.906)
Nearest Landfill Distance + Age (in months) + Sex	0.614	(0.145, 2.590)
* No adjustments for median income, home age, tobacco smoke, or family history of learning disability since these variables were not significant in univariate analyses.		

Table 54. Variables Potentially Associated with BARS Forward Simple Digit Span Scores

Variable	Chi-square p-value
Age (in months)	0.0006
Sex	0.5045
Median Income	0.8004
Pre-1978 Home	0.6372
Environmental Tobacco Smoke Exposure	0.9155
Family History of Learning Disability	0.7716

Table 55. Logistic Regression for BARS Forward Simple Digit Span Scores

Model Variables*	OR	95% CI
Nearest Landfill Distance	1.056	(0.342, 3.257)
Age (in months)	0.958	(0.934, 0.982)
Nearest Landfill Distance + Age (in months)	1.170	(0.311, 4.398)
* No adjustments for sex, median income, home age, tobacco smoke, or family history of learning disability since these variables were not significant in univariate analyses.		

Table 56. Variables Potentially Associated with BARS Reverse Simple Digit Span Scores

Variable	Chi-square p-value
Age (in months)	0.1457
Sex	0.6495
Median Income	0.3405
Pre-1978 Home	0.6008
Environmental Tobacco Smoke Exposure	0.5760
Family History of Learning Disability	0.2162

Table 57. Logistic Regression for BARS Reverse Simple Digit Span Scores

Model Variables*	OR	95% CI
Nearest Landfill Distance	2.954	(0.521, 16.754)
* No adjustments for age, sex, median income, home age, tobacco smoke, or family history of learning disability since these variables were not significant in univariate analyses.		

Aim 2 Results

The demographics of the population can be found in Tables 58 and 59. Aim 2 had the smallest population of all of the three aims with 32 participants. The participants were almost evenly divided by sex (46.9% female). The female population tended to be younger than the male population. Overall, of the participants, 75% were white, 12.5% African-American, 3.1% Asian, and 9.4% biracial. Over half of the population (53.1%) was between 12 and 14 years old.

Table 58. Demographics of Population Used for Aim 2 by Sex*

	Male N=17	Female N=15	Total N=32
Age (in years)			
<i>Min</i>	7	6	6
<i>Q1</i>	11	8	8.5
<i>Median</i>	12	10	12
<i>Q3</i>	14	13	13
<i>Max</i>	14	14	14
<i>Mean</i>	11.7	10.1	11.0
<i>SD</i>	2.5	2.6	2.7
<i>Mode</i>	14	10	14
<i>Range</i>	7	8	8
<i>IQR</i>	3	5	4.5
Age (in months)			
<i>Min</i>	89	83	83
<i>Q1</i>	142	96	109
<i>Median</i>	151	121	144.5
<i>Q3</i>	169	161	166
<i>Max</i>	178	178	178
<i>Mean</i>	147.5	127.3	138.0
<i>SD</i>	30.5	8.2	32.2
<i>Mode</i>	165, 178	161	178
<i>Range</i>	89	95	95
<i>IQR</i>	27	65	57
Grade			
<i>Kindergarten</i>	0.0% (0)	0.0% (0)	0.0% (0)
<i>1st grade</i>	0.0% (0)	6.7% (1)	3.1% (1)
<i>2nd grade</i>	17.7% (3)	20.0% (3)	18.8% (6)
<i>3rd grade</i>	0.0% (0)	13.3% (2)	6.3% (2)
<i>4th grade</i>	0.0% (0)	13.3% (2)	6.3% (2)
<i>5th grade</i>	5.9% (1)	6.7% (1)	6.3% (2)
<i>6th grade</i>	17.7% (3)	13.3% (2)	15.6% (5)
<i>7th grade</i>	23.5% (4)	6.7% (1)	15.6% (5)
<i>8th grade</i>	11.8% (2)	13.3% (2)	12.5% (4)
<i>9th grade</i>	23.5% (4)	6.7% (1)	15.6% (5)
Race			
<i>White/Caucasian</i>	70.6% (12)	80.0% (12)	75.0% (24)
<i>Black/African American</i>	17.7% (3)	6.7% (1)	12.5% (4)
<i>American Indian/Alaskan Native</i>	0.0% (0)	0.0% (0)	0.0% (0)
<i>Asian</i>	0.0% (0)	6.7% (1)	3.1% (1)
<i>Hispanic</i>	0.0% (0)	0.0% (0)	0.0% (0)
<i>Biracial</i>	11.8% (2)	6.7% (1)	9.4% (3)
* Numbers may not add to 100 due to rounding.			

Table 59. Demographics of Population Used for Aim 2 by Age Group*

	Ages 6-8 N=8	Ages 9-11 N=7	Ages 12-14 N=17	Total N=32
Sex				
<i>Male</i>	37.5% (3)	28.6% (2)	70.6% (12)	53.1% (17)
<i>Female</i>	62.5% (5)	71.4% (5)	29.4% (5)	46.9% (15)
Race				
<i>White/Caucasian</i>	62.5% (5)	85.7% (6)	76.5% (13)	75.0% (24)
<i>Black/African American</i>	25.0% (2)	0.0% (0)	11.8% (2)	12.5% (4)
<i>American Indian/Alaskan Native</i>	0.0% (0)	0.0% (0)	0.0% (0)	0.0% (0)
<i>Asian</i>	0.0% (0)	14.3% (1)	0.0% (0)	3.1% (1)
<i>Hispanic</i>	0.0% (0)	0.0% (0)	0.0% (0)	0.0% (0)
<i>Biracial</i>	12.5% (1)	0.0% (0)	11.8% (2)	9.4% (3)
* Numbers may not add to 100 due to rounding				

The concentrations of metals found in fingernails and toenails can be found in Table 60. Iron, zinc, and copper were found in the nail samples of all participants. Few participants had nail samples containing manganese (N=6), arsenic (N=1), strontium (N=2), or zirconium (N=5). Table 61 provides the ranges of levels of metals that have been found in nail samples. The values found in the literature have also been converted to ppm for comparison to the levels found in this study.

Table 60. Concentrations of Metals Found in Nails by Sex

Metals (ppm)	Male N=17	Female N=15	Total N=32	Metals (ppm)	Male N=17	Female N=15	Total N=32
<u>Aluminum</u>				<u>Nickel</u>			
Min	0	0	0	Min	0	0	0
Q1	93	80	92.5	Q1	0	0	0
Median	110	120	115	Median	1.2	1.1	1.2
Q3	150	180	175	Q3	1.6	3.1	2.0
Max	230	280	280	Max	6.6	7.8	7.8
Mean	128.6	127.3	128	Mean	1.6	1.7	1.6
SD	54.5	77.5	65.2	SD	2.0	2.2	2.1
Mode	110	0, 80, 110, 120, 180	110	Mode	0	0	0
Range	230	280	280	Range	6.6	7.8	7.8
IQR	57	100	82.5	IQR	1.6	3.1	2.0
<u>Titanium</u>				<u>Arsenic</u>			
Min	0	0	0	Min	0	0	0
Q1	0	0	0	Q1	0	0	0
Median	0	0	0	Median	0	0	0
Q3	0	24	16.5	Q3	0	0	0
Max	23	34	34	Max	0	1.6	1.6
Mean	4.6	10.3	7.3	Mean	0	0.1	0.1
SD	8.7	14.1	11.7	SD	0	0.4	0.3
Mode	0	0	0	Mode	0	0	0
Range	23	34	34	Range	0	1.6	1.6
IQR	0	24	16.5	IQR	0	0	0
<u>Chromium</u>				<u>Strontium</u>			
Min	0	0	0	Min	0	0	0
Q1	5.3	0	4.7	Q1	0	0	0
Median	7.1	7.1	7.1	Median	0	0	0
Q3	10	11	10.5	Q3	0	0	0
Max	13	23	23	Max	5.2	4.2	5.2
Mean	7.5	7.2	7.4	Mean	0.3	0.3	0.3
SD	3.3	6.3	4.9	SD	1.3	1.1	1.2
Mode	5.3, 10	0	0, 11	Mode	0	0	0
Range	13	23	23	Range	5.2	4.2	5.2
IQR	4.7	11	5.9	IQR	0	0	0
<u>Manganese</u>				<u>Zirconium</u>			
Min	0	0	0	Min	0	0	0
Q1	0	0	0	Q1	0	0	0
Median	0	0	0	Median	0	0	0
Q3	0	3.5	0	Q3	0	0	0
Max	4.3	4	4.3	Max	9.3	19	19
Mean	0.5	1	0.7	Mean	1.4	1.8	1.6
SD	1.3	1.7	1.5	SD	3.2	5.2	4.2
Mode	0	0	0	Mode	0	0	0
Range	4.3	4	4.3	Range	9.3	19	19
IQR	0	3.5	0	IQR	0	0	0

Table 60. Concentrations of Metals Found in Nails by Sex
(continued from previous page)

Metals (ppm)	Male N=17	Female N=15	Total N=32
<u>Iron</u>			
<i>Min</i>	42	44	42
<i>Q1</i>	62	56	59
<i>Median</i>	73	72	72.5
<i>Q3</i>	102	107	103.5
<i>Max</i>	145	430	430
<i>Mean</i>	82.8	101.9	91.8
<i>SD</i>	31.3	95.0	68.4
<i>Mode</i>	62	.	62, 66, 71
<i>Range</i>	103	386	388
<i>IQR</i>	40	51	44.5
<u>Zinc</u>			
<i>Min</i>	56	70	56
<i>Q1</i>	68	82	72.5
<i>Median</i>	76	94	83.5
<i>Q3</i>	87	106	98.0
<i>Max</i>	107	129	129.0
<i>Mean</i>	78.8	94.1	85.9
<i>SD</i>	14.3	16.3	16.9
<i>Mode</i>	76	82	76, 82, 90, 107
<i>Range</i>	51	59	73
<i>IQR</i>	19	24	25.5
<u>Copper</u>			
<i>Min</i>	1.6	2.6	1.6
<i>Q1</i>	2.9	3.8	3.5
<i>Median</i>	3.8	4.3	4.1
<i>Q3</i>	4.3	6.2	5.4
<i>Max</i>	6.2	8.7	8.7
<i>Mean</i>	3.8	4.9	4.3
<i>SD</i>	1.3	1.7	1.6
<i>Mode</i>	4.1	3.8	3.8
<i>Range</i>	4.6	6.1	7.1
<i>IQR</i>	1.4	2.4	1.9

Table 61. Ranges of Nail Biomarker Levels for Metals Studied in this Thesis

Metal	Metal Levels Found in Nails as Found in the Literature	Metal Levels Found in the Literature Converted to ppm
Aluminum	12 – 137 ug/g ^a 37.17 mg/kg (mean) ^b	12 – 137 ppm 37.17 ppm
Titanium	0.16 – 16.1 ug/g ^a 9.43 mg/kg (mean) ^b	0.16 – 16.1 ppm 9.43 ppm
Chromium	0.224 – 6.7 ug/g ^a 0.35 – 4.82 mg/kg ^c	0.224 – 6.7 ppm 0.35 – 4.82 ppm
Manganese	0.19 – 3.3 ug/g ^a 0.14 – 2.25 mg/kg (children) ^d	0.19 – 3.3 ppm 0.14 – 2.25 ppm
Nickel	0.14 – 6.95 ug/g ^a	0.14 – 6.95 ppm
Arsenic	0.016 – 1.816 ug/g ^e 0.009 – 2.57 ug/g ^a	0.016 – 1.816 ppm 0.009 – 2.57 ppm
Strontium	0.16 – 3.3 ug/g ^a 1.43 mg/kg ^f	0.16 – 3.3 ppm 1.43 ppm
Zirconium	0.054 – 7.89 ug/g ^a	0.054 – 7.89 ppm
Iron	12 – 1730 ug/g ^a 7.67 – 97.8 mg/kg ^c	12 – 1730 ppm 7.67 – 97.8 ppm
Zinc	73 – 3080 ug/g ^a 80 – 150 mg/kg ^c	73 – 3080 ppm 80-150 ppm
Copper	4.2 – 81ug/g ^a 3.72 – 8.27 mg/kg (in children) ^d	4.2 – 81 ppm 3.72 – 8.27 ppm
^a Rodushkin & Axelsson (2000) ^b Bozkus et al. (2011) ^c Favaro (2013)		^d Reis et al. (2015) ^e Gruber et al. (2012) ^f Blaurock-Busch et al. (2015)

Test Performance Results by Presence of Metals in Nails

Tables 62 through 69 report dichotomized test scores by the presence or absence of metals found in the nails of this population. The VMI, Purdue Pegboard, and Object Memory scores were dichotomized based on each test's standardized normal and abnormal values. The BARS tests were dichotomized using their mean or median, depending on the normality of the distribution. The mean scores for the BARS Tapping preferred, right, and left hand tests were 129.6, 136.4, and 82.8, respectively. The median score for the BARS Tapping non-preferred hand was 81.0 and the median scores for the BARS Simple Digit Span forward and reverse tests were 5 and 3, respectively.

a. Dichotomized Metal Variables

Dichotomized variables were created for metals in Tables 62 through 69 based on their presence or absence in participants' nail samples. Fisher's Exact and Chi-square p-values were calculated for dichotomized test scores and dichotomized metals.

No significant associations at $\alpha=0.05$ or patterns were observed between aluminum, chromium, and arsenic presence or absence and dichotomized test performance (Tables 62, 64, and 67).

A significant association between titanium and VMI scores was observed ($p=0.0367$; Table 63). A total of 95.2% ($N=20$) of those without titanium in their nail samples had normal VMI scores, while 36.4% ($N=4$) participants with titanium present had abnormal VMI scores. In an opposite manner, 76.2% of those ($N=16$) without titanium in nails had abnormal non-dominant hand Purdue Pegboard scores while 60.0% (6) of those with titanium in their nails had normal scores, though this relationship was not significant ($p=0.1055$). There were no other patterns or significant associations observed for titanium.

Manganese was significantly related to both VMI and dominant Purdue Pegboard scores (Table 65). Of those without manganese in their nail samples, 96.2% ($N=25$) had normal VMI scores while 66.7% ($N=4$) of those with manganese in their nail samples had abnormal VMI score ($p=0.0020$). The opposite relationship was observed between manganese and dominant Purdue Pegboard scores, with the majority (61.5%) of those with no manganese in their nails scoring normally on the test and 100.0% of with manganese present in their

nail samples scoring abnormally ($p=0.0177$).

Strontium presence was significantly related to abnormal delayed Object Memory scores ($p=0.0423$), though only two participants had strontium in their nail samples (Table 68). Nickel presence in nails was greater among those with below average BARS Tapping preferred hand results and normal Purdue Pegboard dominant and both hand tests, but these relationships were not significant at $\alpha=0.05$ (Table 66). Zirconium presence tended to be associated with above mean/median scores on BARS tests (Table 69). This relationship was not significant, however, and was likely confounded by sex and age.

Table 62. Neurobehavioral Tests Scores by Presence of Aluminum in Nails*

	Absent N=3	Present N=29	Total N=32	Fisher's Exact p-value
VMI				1.0000
<i>Normal Score</i>	100.0% (3)	82.8% (24)	84.4% (27)	
<i>Abnormal Score</i>	0.0% (0)	17.2% (5)	15.6% (5)	
Purdue Pegboard Dominant Hand				1.0000
<i>Normal Score</i>	33.3% (1)	51.7% (15)	50.0% (16)	
<i>Abnormal Score</i>	66.7% (2)	48.3% (14)	50.0% (16)	
Purdue Pegboard Non-Dominant Hand (missing=1)				1.0000
<i>Normal Score</i>	33.3% (1)	35.7% (10)	35.5% (11)	
<i>Abnormal Score</i>	66.7% (2)	64.3% (18)	64.5% (20)	
Purdue Pegboard Both Hands (missing=1)				0.2452
<i>Normal Score</i>	0.0% (0)	46.4% (13)	41.9% (13)	
<i>Abnormal Score</i>	100.0% (3)	53.6% (15)	58.1% (18)	
Object Memory - Immediate				1.0000
<i>Normal Score</i>	100.0% (3)	79.3% (23)	81.3% (26)	
<i>Abnormal Score</i>	0.0% (0)	20.7% (6)	18.8% (6)	
Object Memory - Delayed				1.0000
<i>Normal Score</i>	100.0% (3)	75.9% (22)	78.1% (25)	
<i>Abnormal Score</i>	0.0% (0)	24.1% (7)	21.9% (7)	
BARS Tapping – Preferred				1.0000
<i>Above Average Scores</i>	33.3% (1)	51.7% (15)	50.0% (16)	
<i>Below Average Scores</i>	66.7% (2)	48.3% (14)	50.0% (16)	
BARS Tapping – Non-Preferred				1.0000
<i>Above Median Scores</i>	33.3% (1)	51.7% (15)	50.0% (16)	
<i>Below Median Scores</i>	66.7% (2)	48.3% (14)	50.0% (16)	
BARS Tapping – Right Hand				1.0000
<i>Above Average Scores</i>	33.3% (1)	48.3% (14)	46.9% (15)	
<i>Below Average Scores</i>	66.7% (2)	51.7% (15)	53.1% (17)	
BARS Tapping – Left Hand				1.0000
<i>Above Average Scores</i>	33.3% (1)	44.8% (13)	43.8% (14)	
<i>Below Average Scores</i>	66.7% (2)	55.2% (16)	56.3% (18)	
BARS Simple Digit Span –Forward				1.0000
<i>Above Median Scores</i>	66.7% (2)	72.4% (21)	71.9% (23)	
<i>Below Median Scores</i>	33.3% (1)	27.6% (8)	28.1% (9)	
BARS Simple Digit Span – Reverse				1.0000
<i>Above Median Scores</i>	100.0% (3)	86.2% (25)	87.5% (28)	
<i>Below Median Scores</i>	0.0% (0)	13.8% (4)	12.5% (4)	
* Numbers may not add to 100 due to rounding.				

Table 63. Neurobehavioral Tests Scores by Presence of Titanium in Nails*

	Absent N=21	Present N=11	Total N=32	Fisher's Exact p-value
VMI				0.0367
<i>Normal Score</i>	95.2% (20)	63.6% (7)	84.4% (27)	
<i>Abnormal Score</i>	4.8% (1)	36.4% (4)	15.6% (5)	
Purdue Pegboard Dominant Hand				0.7097 ^a
<i>Normal Score</i>	47.6% (10)	54.6% (6)	50.0% (16)	
<i>Abnormal Score</i>	52.4% (11)	45.5% (5)	50.0% (16)	
Purdue Pegboard Non-Dominant Hand (missing=1)				0.1055
<i>Normal Score</i>	23.8% (5)	60.0% (6)	35.5% (11)	
<i>Abnormal Score</i>	76.2% (16)	40.0% (4)	64.5% (20)	
Purdue Pegboard Both Hands (missing=1)				0.2569
<i>Normal Score</i>	33.3% (7)	60.0% (6)	41.9% (13)	
<i>Abnormal Score</i>	66.7% (14)	40.0% (4)	58.1% (18)	
Object Memory - Immediate				0.6367
<i>Normal Score</i>	78.2% (16)	90.9% (10)	81.3% (26)	
<i>Abnormal Score</i>	23.8% (5)	9.1% (1)	18.8% (6)	
Object Memory - Delayed				1.0000
<i>Normal Score</i>	76.2% (16)	81.8% (9)	78.1% (25)	
<i>Abnormal Score</i>	23.8% (5)	18.2% (2)	21.9% (7)	
BARS Tapping – Preferred				0.7097 ^a
<i>Above Average Scores</i>	52.4% (11)	45.5% (5)	50.0% (16)	
<i>Below Average Scores</i>	47.6% (10)	54.6% (6)	50.0% (16)	
BARS Tapping – Non-Preferred				0.2642 ^a
<i>Above Median Scores</i>	57.1% (12)	36.4% (4)	50.0% (16)	
<i>Below Median Scores</i>	42.9% (9)	63.6% (7)	50.0% (16)	
BARS Tapping – Right Hand				0.3885 ^a
<i>Above Average Scores</i>	52.4% (11)	36.4% (4)	46.9% (15)	
<i>Below Average Scores</i>	47.6% (10)	63.6% (7)	53.1% (17)	
BARS Tapping – Left Hand				0.2656
<i>Above Average Scores</i>	52.4% (11)	27.3% (3)	43.8% (14)	
<i>Below Average Scores</i>	47.6% (10)	72.7% (8)	56.3% (18)	
BARS Simple Digit Span –Forward				0.2134
<i>Above Median Scores</i>	81.0% (17)	54.6% (6)	71.9% (23)	
<i>Below Median Scores</i>	19.1% (4)	45.5% (5)	28.1% (9)	
BARS Simple Digit Span – Reverse				1.0000
<i>Above Median Scores</i>	85.7% (18)	90.9% (10)	87.5% (28)	
<i>Below Median Scores</i>	14.3% (3)	9.1% (1)	12.5% (4)	
* Numbers may not add to 100 due to rounding.				
^a Chi-Square p-value				

Table 64. Neurobehavioral Tests Scores by Presence of Chromium in Nails*

	Absent N=5	Present N=27	Total N=32	Fisher's Exact p-value
VMI				1.0000
<i>Normal Score</i>	80.0% (4)	85.2% (23)	84.4% (27)	
<i>Abnormal Score</i>	20.0% (1)	14.8% (4)	15.6% (5)	
Purdue Pegboard Dominant Hand				1.0000
<i>Normal Score</i>	40.0% (2)	51.9% (14)	50.0% (16)	
<i>Abnormal Score</i>	60.0% (3)	48.2% (13)	50.0% (16)	
Purdue Pegboard Non-Dominant Hand (missing=1)				0.6310
<i>Normal Score</i>	20.0% (1)	38.5% (10)	35.5% (11)	
<i>Abnormal Score</i>	80.0% (4)	61.5% (16)	64.5% (20)	
Purdue Pegboard Both Hands (missing=1)				1.0000
<i>Normal Score</i>	40.0% (2)	42.3% (11)	41.9% (13)	
<i>Abnormal Score</i>	60.0% (3)	57.7% (15)	58.1% (18)	
Object Memory - Immediate				0.2279
<i>Normal Score</i>	60.0% (3)	85.2% (23)	81.3% (26)	
<i>Abnormal Score</i>	40.0% (2)	14.8% (4)	18.8% (6)	
Object Memory - Delayed				0.2964
<i>Normal Score</i>	60.0% (3)	81.5% (22)	78.1% (25)	
<i>Abnormal Score</i>	40.0% (2)	18.5% (5)	21.9% (7)	
BARS Tapping – Preferred				1.0000
<i>Above Average Scores</i>	60.0% (3)	48.2% (13)	50.0% (16)	
<i>Below Average Scores</i>	40.0% (2)	51.9% (14)	50.0% (16)	
BARS Tapping – Non-Preferred				1.0000
<i>Above Median Scores</i>	60.0% (3)	48.2% (13)	50.0% (16)	
<i>Below Median Scores</i>	40.0% (2)	51.9% (14)	50.0% (16)	
BARS Tapping – Right Hand				0.6454
<i>Above Average Scores</i>	60.0% (3)	44.4% (12)	46.9% (15)	
<i>Below Average Scores</i>	40.0% (2)	55.6% (15)	53.1% (17)	
BARS Tapping – Left Hand				0.6313
<i>Above Average Scores</i>	60.0% (3)	40.7% (11)	43.8% (14)	
<i>Below Average Scores</i>	40.0% (2)	59.3% (16)	56.3% (18)	
BARS Simple Digit Span –Forward				0.6042
<i>Above Median Scores</i>	60.0% (3)	74.1% (20)	71.9% (23)	
<i>Below Median Scores</i>	40.0% (2)	25.9% (7)	28.1% (9)	
BARS Simple Digit Span – Reverse				0.5120
<i>Above Median Scores</i>	80.0% (4)	88.9% (24)	87.5% (28)	
<i>Below Median Scores</i>	20.0% (1)	11.1% (3)	12.5% (4)	
* Numbers may not add to 100 due to rounding.				

Table 65. Neurobehavioral Tests Scores by Presence of Manganese in Nails*

	Absent N=26	Present N=6	Total N=32	Fisher's Exact p-value
VMI				0.0020
<i>Normal Score</i>	96.2% (25)	33.3% (2)	84.4% (27)	
<i>Abnormal Score</i>	3.9% (1)	66.7% (4)	15.6% (5)	
Purdue Pegboard Dominant Hand				0.0177
<i>Normal Score</i>	38.5% (10)	100.0% (6)	50.0% (16)	
<i>Abnormal Score</i>	61.5% (16)	0.0% (0)	50.0% (16)	
Purdue Pegboard Non-Dominant Hand (missing=1)				1.0000
<i>Normal Score</i>	36.0% (9)	33.3% (2)	35.5% (11)	
<i>Abnormal Score</i>	64.0% (16)	66.7% (4)	64.5% (20)	
Purdue Pegboard Both Hands (missing=1)				0.2076
<i>Normal Score</i>	36.0% (9)	66.7% (4)	41.9% (13)	
<i>Abnormal Score</i>	64.0% (16)	33.3% (2)	58.1% (18)	
Object Memory - Immediate				1.0000
<i>Normal Score</i>	80.8% (21)	83.3% (5)	81.3% (26)	
<i>Abnormal Score</i>	19.2% (5)	16.7% (1)	18.8% (6)	
Object Memory - Delayed				1.0000
<i>Normal Score</i>	76.9% (20)	83.3% (5)	78.1% (25)	
<i>Abnormal Score</i>	23.1% (6)	16.7% (1)	21.9% (7)	
BARS Tapping – Preferred				1.0000
<i>Above Average Scores</i>	50.0% (13)	50.0% (3)	50.0% (16)	
<i>Below Average Scores</i>	50.0% (13)	50.0% (3)	50.0% (16)	
BARS Tapping – Non-Preferred				0.6539
<i>Above Median Scores</i>	53.9% (14)	33.3% (2)	50.0% (16)	
<i>Below Median Scores</i>	46.2% (12)	66.7% (4)	50.0% (16)	
BARS Tapping – Right Hand				1.0000
<i>Above Average Scores</i>	46.2% (12)	50.0% (3)	46.9% (15)	
<i>Below Average Score</i>	53.9% (14)	50.0% (3)	53.1% (17)	
BARS Tapping – Left Hand				0.6722
<i>Above Average Scores</i>	46.2% (12)	33.3% (2)	43.8% (14)	
<i>Below Average Scores</i>	53.9% (14)	66.7% (4)	56.3% (18)	
BARS Simple Digit Span –Forward				0.3140
<i>Above Median Scores</i>	76.9% (20)	50.0% (3)	71.9% (23)	
<i>Below Median Scores</i>	23.1% (6)	50.0% (3)	28.1% (9)	
BARS Simple Digit Span – Reverse				0.1504
<i>Above Median Scores</i>	92.3% (24)	66.7% (4)	87.5% (28)	
<i>Below Median Scores</i>	7.7% (2)	33.3% (2)	12.5% (4)	
* Numbers may not add to 100 due to rounding.				

Table 66. Neurobehavioral Tests Scores by Presence of Nickel in Nails*

	Absent N=12	Present N=20	Total N=32	Fisher's Exact p-value
VMI				0.6264
<i>Normal Score</i>	91.7% (11)	80.0% (16)	84.4% (27)	
<i>Abnormal Score</i>	8.3% (1)	20.0% (4)	15.6% (5)	
Purdue Pegboard Dominant Hand				0.1441 ^a
<i>Normal Score</i>	33.3% (4)	60.0% (12)	50.0% (16)	
<i>Abnormal Score</i>	66.7% (8)	40.0% (8)	50.0% (16)	
Purdue Pegboard Non-Dominant Hand (missing=1)				1.0000
<i>Normal Score</i>	33.3% (4)	36.8% (7)	35.5% (11)	
<i>Abnormal Score</i>	66.7% (8)	63.2% (12)	64.5% (20)	
Purdue Pegboard Both Hands (missing=1)				0.1289*
<i>Normal Score</i>	25.0% (3)	52.6% (10)	41.9% (13)	
<i>Abnormal Score</i>	75.0% (9)	47.4% (9)	58.1% (18)	
Object Memory - Immediate				0.3704
<i>Normal Score</i>	91.7% (11)	75.0% (15)	81.3% (26)	
<i>Abnormal Score</i>	8.3% (1)	25.0% (5)	18.8% (6)	
Object Memory - Delayed				0.6833
<i>Normal Score</i>	83.3% (10)	75.0% (15)	78.1% (25)	
<i>Abnormal Score</i>	16.7% (2)	25.0% (5)	21.9% (7)	
BARS Tapping – Preferred				0.1441 ^a
<i>Above Average Scores</i>	66.7% (8)	40.0% (8)	50.0% (16)	
<i>Below Average Scores</i>	33.3% (4)	60.0% (12)	50.0% (16)	
BARS Tapping – Non-Preferred				0.4652 ^a
<i>Above Median Scores</i>	41.7% (5)	55.0% (11)	50.0% (16)	
<i>Below Median Scores</i>	58.3% (7)	45.0% (9)	50.0% (16)	
BARS Tapping – Right Hand				0.6474 ^a
<i>Above Average Scores</i>	41.7% (5)	50.0% (10)	46.9% (15)	
<i>Below Average Scores</i>	58.3% (7)	50.0% (10)	53.1% (17)	
BARS Tapping – Left Hand				0.8540 ^a
<i>Above Average Scores</i>	41.7% (5)	45.0% (9)	43.8% (14)	
<i>Below Average Scores</i>	58.3% (7)	55.0% (11)	56.3% (18)	
BARS Simple Digit Span –Forward				0.4224
<i>Above Median Scores</i>	83.3% (10)	65.0% (13)	71.9% (23)	
<i>Below Median Scores</i>	16.7% (2)	35.0% (7)	28.1% (9)	
BARS Simple Digit Span – Reverse				1.0000
<i>Above Median Scores</i>	91.7% (11)	85.0% (17)	87.5% (28)	
<i>Below Median Scores</i>	8.3% (1)	15.0% (3)	12.5% (4)	
* Numbers may not add to 100 due to rounding.				
^a Chi-Square p-value				

Table 67. Neurobehavioral Tests Scores by Presence of Arsenic in Nails*

	Absent N=31	Present N=1	Total N=32	Fisher's Exact p-value
VMI				1.0000
<i>Normal Score</i>	83.9% (26)	100.0% (1)	84.4% (27)	
<i>Abnormal Score</i>	16.1% (5)	0.0% (0)	15.6% (5)	
Purdue Pegboard Dominant Hand				1.0000
<i>Normal Score</i>	48.4% (15)	100.0% (1)	50.0% (16)	
<i>Abnormal Score</i>	51.6% (16)	0.0% (0)	50.0% (16)	
Purdue Pegboard Non-Dominant Hand (missing=1)				1.0000
<i>Normal Score</i>	36.7% (11)	0.0% (0)	35.5% (11)	
<i>Abnormal Score</i>	63.3% (19)	100.0% (1)	64.5% (20)	
Purdue Pegboard Both Hands (missing=1)				0.4194
<i>Normal Score</i>	40.0% (12)	100.0% (1)	41.9% (13)	
<i>Abnormal Score</i>	60.0% (18)	0.0% (0)	58.1% (18)	
Object Memory – Immediate				1.0000
<i>Normal Score</i>	80.7% (25)	100.0% (1)	81.3% (26)	
<i>Abnormal Score</i>	19.4% (6)	0.0% (0)	18.8% (6)	
Object Memory – Delayed				1.0000
<i>Normal Score</i>	77.4% (24)	100.0% (1)	78.1% (25)	
<i>Abnormal Score</i>	22.6% (7)	0.0% (0)	21.9% (7)	
BARS Tapping – Preferred				1.0000
<i>Above Average Scores</i>	51.6% (16)	0.0% (0)	50.0% (16)	
<i>Below Average Scores</i>	48.4% (15)	100.0% (1)	50.0% (16)	
BARS Tapping – Non-Preferred				1.0000
<i>Above Median Scores</i>	51.6% (16)	0.0% (0)	50.0% (16)	
<i>Below Median Scores</i>	48.4% (15)	100.0% (1)	50.0% (16)	
BARS Tapping – Right Hand				1.0000
<i>Above Average Scores</i>	48.4% (15)	0.0% (0)	46.9% (15)	
<i>Below Average Scores</i>	51.6% (16)	100.0% (1)	53.1% (17)	
BARS Tapping – Left Hand				1.0000
<i>Above Average Scores</i>	45.2% (14)	0.0% (0)	43.8% (14)	
<i>Below Average Scores</i>	54.8% (17)	100.0% (1)	56.3% (18)	
BARS Simple Digit Span –Forward				1.0000
<i>Above Median Scores</i>	71.0% (22)	100.0% (1)	71.9% (23)	
<i>Below Median Scores</i>	29.0% (9)	0.0% (0)	28.1% (9)	
BARS Simple Digit Span – Reverse				1.0000
<i>Above Median Scores</i>	87.1% (27)	100.0% (1)	87.5% (28)	
<i>Below Median Scores</i>	12.9% (4)	0.0% (0)	12.5% (4)	
* Numbers may not add to 100 due to rounding.				

Table 68. Neurobehavioral Tests Scores by Presence of Strontium in Nails*

	Absent N=30	Present N=2	Total N=32	Fisher's Exact p-value
VMI				0.2923
<i>Normal Score</i>	86.7% (26)	50.0% (1)	84.4% (27)	
<i>Abnormal Score</i>	13.3% (4)	50.0% (1)	15.6% (5)	
Purdue Pegboard Dominant Hand				0.4839
<i>Normal Score</i>	46.7% (14)	100.0% (2)	50.0% (16)	
<i>Abnormal Score</i>	53.3% (16)	0.0% (0)	50.0% (16)	
Purdue Pegboard Non-Dominant Hand (missing=1)				0.5269
<i>Normal Score</i>	37.9% (11)	0.0% (0)	35.5% (11)	
<i>Abnormal Score</i>	62.1% (18)	100.0% (2)	64.5% (20)	
Purdue Pegboard Both Hands (missing=1)				1.0000
<i>Normal Score</i>	41.4% (12)	50.0% (1)	41.9% (13)	
<i>Abnormal Score</i>	58.6% (17)	50.0% (1)	58.1% (18)	
Object Memory - Immediate				0.3448
<i>Normal Score</i>	83.3% (25)	50.0% (1)	81.3% (26)	
<i>Abnormal Score</i>	16.7% (5)	50.0% (1)	18.8% (6)	
Object Memory - Delayed				0.0423
<i>Normal Score</i>	83.3% (25)	0.0% (0)	78.1% (25)	
<i>Abnormal Score</i>	16.7% (5)	100.0% (2)	21.9% (7)	
BARS Tapping – Preferred				0.4839
<i>Above Average Scores</i>	46.7% (14)	100.0% (2)	50.0% (16)	
<i>Below Average Scores</i>	53.3% (16)	0.0% (0)	50.0% (16)	
BARS Tapping – Non-Preferred				0.4839
<i>Above Median Scores</i>	46.7% (14)	100.0% (2)	50.0% (16)	
<i>Below Median Scores</i>	53.3% (16)	0.0% (0)	50.0% (16)	
BARS Tapping – Right Hand				0.2117
<i>Above Average Scores</i>	43.3% (13)	100.0% (2)	46.9% (15)	
<i>Below Average Scores</i>	56.7% (17)	0.0% (0)	53.1% (17)	
BARS Tapping – Left Hand				1.0000
<i>Above Average Scores</i>	43.3% (13)	50.0% (1)	43.8% (14)	
<i>Below Average Scores</i>	56.7% (17)	50.0% (1)	56.3% (18)	
BARS Simple Digit Span –Forward				0.4899
<i>Above Median Scores</i>	73.3% (22)	50.0% (1)	71.9% (23)	
<i>Below Median Scores</i>	26.7% (8)	50.0% (1)	28.1% (9)	
BARS Simple Digit Span – Reverse				1.0000
<i>Above Median Scores</i>	86.7% (26)	100.0% (2)	87.5% (28)	
<i>Below Median Scores</i>	13.3% (4)	0.0% (0)	12.5% (4)	
* Numbers may not add to 100 due to rounding.				

Table 69. Neurobehavioral Tests Scores by Presence of Zirconium in Nails*

	Absent N=27	Present N=5	Total N=32	Fisher's Exact p-value
VMI				1.0000
<i>Normal Score</i>	85.2% (23)	80.0% (4)	84.4% (27)	
<i>Abnormal Score</i>	14.8% (4)	20.0% (1)	15.6% (5)	
Purdue Pegboard Dominant Hand				0.3326
<i>Normal Score</i>	55.6% (15)	20.0% (1)	50.0% (16)	
<i>Abnormal Score</i>	44.4% (12)	80.0% (4)	50.0% (16)	
Purdue Pegboard Non-Dominant Hand (missing=1)				1.0000
<i>Normal Score</i>	34.6% (9)	40.0% (2)	35.5% (11)	
<i>Abnormal Score</i>	65.4% (17)	60.0% (3)	64.5% (20)	
Purdue Pegboard Both Hands (missing=1)				0.3679
<i>Normal Score</i>	46.2% (12)	20.0% (1)	41.9% (13)	
<i>Abnormal Score</i>	53.9% (14)	80.0% (4)	58.1% (18)	
Object Memory - Immediate				1.0000
<i>Normal Score</i>	81.5% (22)	80.0% (4)	81.3% (26)	
<i>Abnormal Score</i>	18.5% (5)	20.0% (1)	18.8% (6)	
Object Memory - Delayed				1.0000
<i>Normal Score</i>	77.8% (21)	80.0% (4)	78.1% (25)	
<i>Abnormal Score</i>	22.2% (6)	20.0% (1)	21.9% (7)	
BARS Tapping – Preferred				1.0000
<i>Above Average Scores</i>	48.2% (13)	60.0% (3)	50.0% (16)	
<i>Below Average Scores</i>	51.9% (14)	40.0% (2)	50.0% (16)	
BARS Tapping – Non-Preferred				0.3326
<i>Above Median Scores</i>	44.4% (12)	80.0% (4)	50.0% (16)	
<i>Below Median Scores</i>	55.6% (15)	20.0% (1)	50.0% (16)	
BARS Tapping – Right Hand				0.1609
<i>Above Average Scores</i>	40.7% (11)	80.0% (4)	46.9% (15)	
<i>Below Average Scores</i>	59.3% (16)	20.0% (1)	53.1% (17)	
BARS Tapping – Left Hand				0.1420
<i>Above Average Scores</i>	37.0% (10)	80.0% (4)	43.8% (14)	
<i>Below Average Scores</i>	63.0% (17)	20.0% (1)	56.3% (18)	
BARS Simple Digit Span –Forward				1.0000
<i>Above Median Scores</i>	70.4% (19)	80.0% (4)	71.9% (23)	
<i>Below Median Scores</i>	29.6% (8)	20.0% (1)	28.1% (9)	
BARS Simple Digit Span – Reverse				0.5120
<i>Above Median Scores</i>	88.9% (24)	80.0% (4)	87.5% (28)	
<i>Below Median Scores</i>	11.1% (3)	20.0% (1)	12.5% (4)	
* Numbers may not add to 100 due to rounding.				

b. Continuous Metal Variables

Iron, copper, and zinc were present in the nails of all participants. Copper and zinc were normally distributed, while iron was not. Wilcoxon Rank-Sum tests were used to compare iron levels between dichotomized test score groups, and two-sample unpaired t-tests were used to compare copper and zinc levels between dichotomized test score groups.

Higher iron levels were significantly associated with lower right hand BARS Tapping scores ($p=0.0234$), normal dominant hand Purdue Pegboard scores ($p=0.0074$), and normal immediate Object Memory scores ($p=0.0450$; Table 70). Relationships with non-preferred and left BARS Tapping scores were also observed, though not significant ($p>0.05$).

Higher zinc levels were significantly associated with abnormal VMI scores ($p=0.0348$) and below median non-preferred (0.0402) and left hand BARS Tapping scores ($p=0.0199$; Table 71). Copper was only significantly associated with one dichotomized test (Table 72). Higher mean copper levels were significantly associated with abnormal VMI scores ($p=0.0271$).

Table 70. Neurobehavioral Tests Scores by Iron Concentration in Nails*

	N	Sum of Scores	Wilcoxon Rank-Sum P-value
VMI			0.2756
<i>Normal Score</i>	27	424.0	
<i>Abnormal Score</i>	5	104.0	
Purdue Pegboard Dominant Hand			0.0074
<i>Normal Score</i>	16	335.5	
<i>Abnormal Score</i>	16	192.5	
Purdue Pegboard Non-Dominant Hand (missing=1)			0.4449
<i>Normal Score</i>	11	195.0	
<i>Abnormal Score</i>	20	301.0	
Purdue Pegboard Both Hands (missing=1)			0.2622
<i>Normal Score</i>	13	236.5	
<i>Abnormal Score</i>	18	259.5	
Object Memory - Immediate			0.0450
<i>Normal Score</i>	26	471.0	
<i>Abnormal Score</i>	6	57.0	
Object Memory - Delayed			0.9636
<i>Normal Score</i>	25	411.0	
<i>Abnormal Score</i>	7	117.0	
BARS Tapping – Preferred			0.5590
<i>Above Average Scores</i>	16	248.0	
<i>Below Average Scores</i>	16	280.0	
BARS Tapping – Non-Preferred			0.1091
<i>Above Median Scores</i>	16	221.0	
<i>Below Median Scores</i>	16	307.0	
BARS Tapping – Right Hand			0.0234
<i>Above Average Scores</i>	15	187.0	
<i>Below Average Scores</i>	17	341.0	
BARS Tapping – Left Hand			0.0741
<i>Above Average Scores</i>	14	183.5	
<i>Below Average Scores</i>	18	344.5	
BARS Simple Digit Span –Forward			0.8668
<i>Above Median Scores</i>	23	375.0	
<i>Below Median Scores</i>	9	153.0	
BARS Simple Digit Span – Reverse			0.7976
<i>Above Median Scores</i>	28	457.0	
<i>Below Median Scores</i>	4	71.0	

Table 71. Neurobehavioral Tests Scores by Zinc Concentration in Nails*

	Mean Zinc (ppm)	SD	N	Two-sample Unpaired T-test P-value
VMI				0.0348
<i>Normal Score</i>	83.3	16.0	27	
<i>Abnormal Score</i>	100.4	15.4	5	
Purdue Pegboard Dominant Hand				0.6676
<i>Normal Score</i>	87.3	16.0	16	
<i>Abnormal Score</i>	84.6	18.2	16	
Purdue Pegboard Non-Dominant Hand (missing=1)				0.8911
<i>Normal Score</i>	87.2	13.9	11	
<i>Abnormal Score</i>	86.3	18.4	20	
Purdue Pegboard Both Hands (missing=1)				0.5226
<i>Normal Score</i>	88.9	18.0	13	
<i>Abnormal Score</i>	84.9	16.0	18	
Object Memory - Immediate				0.3478
<i>Normal Score</i>	87.3	14.9	26	
<i>Abnormal Score</i>	80.0	24.7	6	
Object Memory - Delayed				0.2886
<i>Normal Score</i>	87.6	16.1	25	
<i>Abnormal Score</i>	79.9	19.4	7	
BARS Tapping – Preferred				0.7748
<i>Above Average Scores</i>	86.8	20.2	16	
<i>Below Average Scores</i>	85.1	13.4	16	
BARS Tapping – Non-Preferred				0.0402
<i>Above Median Scores</i>	79.9	16.7	16	
<i>Below Median Scores</i>	92.0	15.2	16	
BARS Tapping – Right Hand				0.1024
<i>Above Average Scores</i>	80.7	4.7	15	
<i>Below Average Scores</i>	90.5	3.6	17	
BARS Tapping – Left Hand				0.0199
<i>Above Average Scores</i>	78.2	17.3	14	
<i>Below Average Scores</i>	91.9	14.3	18	
BARS Simple Digit Span –Forward				0.5004
<i>Above Median Scores</i>	84.7	17.8	23	
<i>Below Median Scores</i>	89.2	14.8	9	
BARS Simple Digit Span – Reverse				0.3003
<i>Above Median Scores</i>	84.8	17.1	28	
<i>Below Median Scores</i>	94.3	14.2	4	

Table 72. Neurobehavioral Tests Scores by Copper Concentration in Nails*

	Mean Copper (ppm)	SD	N	Two-sample Unpaired T-test P-value
VMI				0.0271
<i>Normal Score</i>	4.1	1.4	27	
<i>Abnormal Score</i>	5.7	2.2	5	
Purdue Pegboard Dominant Hand				0.5281
<i>Normal Score</i>	4.5	1.8	16	
<i>Abnormal Score</i>	4.1	1.3	16	
Purdue Pegboard Non-Dominant Hand (missing=1)				0.9402
<i>Normal Score</i>	4.4	1.4	11	
<i>Abnormal Score</i>	4.4	1.7	20	
Purdue Pegboard Both Hands (missing=1)				0.8585
<i>Normal Score</i>	4.3	2.1	13	
<i>Abnormal Score</i>	4.4	1.2	18	
Object Memory - Immediate				0.7784
<i>Normal Score</i>	4.4	1.4	26	
<i>Abnormal Score</i>	4.2	2.4	6	
Object Memory - Delayed				0.7690 ^a
<i>Normal Score</i>	4.4	1.3	25	
<i>Abnormal Score</i>	4.1	2.5	7	
BARS Tapping – Preferred				0.6020
<i>Above Average Scores</i>	4.5	1.8	16	
<i>Below Average Scores</i>	4.2	1.4	16	
BARS Tapping – Non-Preferred				0.1868
<i>Above Median Scores</i>	3.9	1.6	16	
<i>Below Median Scores</i>	4.7	1.6	16	
BARS Tapping – Right Hand				0.4473
<i>Above Average Scores</i>	4.1	1.7	15	
<i>Below Average Scores</i>	4.5	1.5	17	
BARS Tapping – Left Hand				0.1320
<i>Above Average Scores</i>	3.8	1.6	14	
<i>Below Average Scores</i>	4.7	1.5	18	
BARS Simple Digit Span –Forward				0.1254
<i>Above Median Scores</i>	4.0	1.4	23	
<i>Below Median Scores</i>	5.0	1.9	9	
BARS Simple Digit Span – Reverse				0.6876
<i>Above Median Scores</i>	4.3	1.6	28	
<i>Below Median Scores</i>	4.6	1.5	4	
^a Satterthwaite test due to unequal variances.				

Aim 3 Results

The demographics of the population can be found in Tables 73 and 74. Fly ash data were available for 49 participants. The population was 49.0% female and had a median age of 11 years (IQR=4). Females in this population were younger than males. Overall, the participants were 76.1% white, 10.9% African-American, 2.2% Asian, and 10.9% biracial. Figure 2 shows a map of the locations of participants' homes in proximity to the ash landfills and indicates whether fly ash was present in the home.

Table 73. Demographics of Population Used for Aim 3 by Sex

	Male N=25	Female N=24	Total N=49
Age (in years)			
<i>Min</i>	7	6	6
<i>Q1</i>	10	7.5	9
<i>Median</i>	12	10	11
<i>Q3</i>	13	12	13
<i>Max</i>	14	14	14
<i>Mean</i>	11.4	9.8	10.6
<i>SD</i>	2.3	2.5	2.5
<i>Mode</i>	12, 14	10	12
<i>Range</i>	7	8	8
<i>IQR</i>	3	4.5	4
Age (in months)			
<i>Min</i>	89	74	74
<i>Q1</i>	130	95	109
<i>Median</i>	149	122.5	140
<i>Q3</i>	167	145	161
<i>Max</i>	178	178	178
<i>Mean</i>	143.8	122.2	133.2
<i>SD</i>	28.1	30.4	30.9
<i>Mode</i>	130, 165, 178	86, 124, 161	178
<i>Range</i>	89	104	104
<i>IQR</i>	37	50	52
Grade*			
<i>Kindergarten</i>	0.0% (0)	4.2% (1)	2.0% (1)
<i>1st grade</i>	0.0% (0)	12.5% (3)	6.1% (2)
<i>2nd grade</i>	12.0% (3)	12.5% (3)	12.2% (6)
<i>3rd grade</i>	4.0% (1)	12.5% (3)	8.2% (4)
<i>4th grade</i>	8.0% (2)	16.7% (4)	12.2% (6)
<i>5th grade</i>	12.0% (3)	4.2% (1)	8.2% (4)
<i>6th grade</i>	16.0% (4)	20.8% (5)	18.4% (9)
<i>7th grade</i>	20.0% (5)	4.2% (1)	12.2% (6)
<i>8th grade</i>	12.0% (3)	8.3% (2)	10.2% (5)
<i>9th grade</i>	16.0% (4)	4.2% (1)	10.2% (5)
Race* (missing = 3)			
<i>White/Caucasian</i>	72.0% (18)	81.0% (17)	76.1% (35)
<i>Black/African American</i>	16.0% (4)	4.8% (1)	10.9% (5)
<i>American Indian/Alaskan Native</i>	0.0% (0)	0.0% (0)	0.0% (0)
<i>Asian</i>	0.0% (0)	4.8% (1)	2.2% (1)
<i>Hispanic</i>	0.0% (0)	0.0% (0)	0.0% (0)
<i>Biracial</i>	12.0% (3)	9.5% (2)	10.9% (5)
* Numbers may not add to 100 due to rounding.			

Table 74. Demographics of Population Used for Aim 3 by Age Group

	Ages 6-8 N=12	Ages 9-11 N=15	Ages 12-14 N=22	Total N=49
Sex*				
<i>Male</i>	25.0% (3)	46.7% (7)	68.2% (15)	51.0% (25)
<i>Female</i>	75.0% (9)	53.3% (8)	31.9% (7)	49.0% (24)
Race* (missing = 3)				
<i>White/Caucasian</i>	63.6% (7)	78.6% (11)	81.0% (17)	76.1% (35)
<i>Black/African American</i>	18.2% (2)	7.1% (1)	9.5% (2)	10.9% (5)
<i>American Indian/Alaskan Native</i>	0.0% (0)	0.0% (0)	0.0% (0)	0.0% (0)
<i>Asian</i>	0.0% (0)	7.1% (1)	0.0% (0)	2.2% (1)
<i>Hispanic</i>	0.0% (0)	0.0% (0)	0.0% (0)	0.0% (0)
<i>Biracial</i>	18.2% (2)	7.1% (1)	9.5% (2)	10.9% (5)

* Numbers may not add to 100 due to rounding.

Figure 2.

Test Performance and Fly Ash Presence

Table 75 displays fly ash presence/absence by dichotomized test scores. The VMI, Purdue Pegboard, and Object Memory scores were dichotomized based on each test's standardized normal and abnormal values. The BARS tests were dichotomized using their mean or median, depending on the normality of the distribution. The mean scores for the BARS Tapping preferred, right, and left hand tests were 130.4, 134.9, and 80.6, respectively. The median score for the BARS Tapping non-preferred hand was 80 and the median scores for the BARS Simple Digit Span forward and reverse tests were 5 and 3, respectively. Fisher's Exact and Chi-square tests were used to compare fly ash presence or absence to dichotomized test scores. Fisher's Exact was used if a comparison had an expected cell count of less than 5. Chi-square tests were used for larger cell counts.

Fly ash presence was confirmed in 42.9% (21 out of 49) of participants' homes. There were no significant associations between dichotomized testing performance and fly ash presence at $\alpha=0.05$ (Table 75). Additionally, there were no notable patterns between testing performance and fly ash presence.

Table 75. Fly Ash from Filters and Lift Tapes

	Absent N=28	Present N=21	Total N=49	Chi-Square p-value
VMI				0.2630 ^a
<i>Normal Score</i>	89.3% (25)	76.2% (16)	83.7% (41)	
<i>Abnormal Score</i>	10.7% (3)	23.8% (5)	16.3% (8)	
Purdue Pegboard Dominant Hand				0.5086
<i>Normal Score</i>	57.1% (16)	47.6% (10)	53.1% (26)	
<i>Abnormal Score</i>	42.9% (12)	52.4% (11)	46.9% (23)	
Purdue Pegboard Non-Dominant Hand (missing=1)				0.7624
<i>Normal Score</i>	39.3% (11)	35.0% (7)	37.5% (18)	
<i>Abnormal Score</i>	60.7% (17)	65.0% (13)	62.5% (30)	
Purdue Pegboard Both Hands (missing=1)				0.9602
<i>Normal Score</i>	39.3% (11)	40.0% (8)	39.6% (19)	
<i>Abnormal Score</i>	60.7% (17)	60.0% (12)	60.4% (29)	
Object Memory - Immediate				1.0000 ^a
<i>Normal Score</i>	89.3% (25)	85.7% (18)	87.8% (43)	
<i>Abnormal Score</i>	10.7% (3)	14.3% (3)	12.2% (6)	
Object Memory - Delayed				0.4698 ^a
<i>Normal Score</i>	85.7% (24)	78.2% (16)	81.6% (40)	
<i>Abnormal Score</i>	14.3% (4)	23.8% (5)	18.4% (9)	
BARS Tapping – Preferred Hand				0.6200
<i>Above Average Score</i>	50.0% (14)	57.1% (12)	53.1% (26)	
<i>Below Average Score</i>	50.0% (14)	42.9% (9)	46.9% (23)	
BARS Tapping – Non-Preferred Hand				0.8690
<i>Above Median Score</i>	50.0% (14)	52.4% (11)	51.0% (25)	
<i>Below Median Score</i>	50.0% (14)	47.6% (10)	49.0% (24)	
BARS Tapping – Right Hand				0.6200
<i>Above Average Score</i>	50.0% (14)	42.9% (9)	46.9% (23)	
<i>Below Average Score</i>	50.0% (14)	57.1% (12)	53.1% (26)	
BARS Tapping – Left Hand				0.6200
<i>Above Average Score</i>	50.0% (14)	42.9% (9)	46.9% (23)	
<i>Below Average Score</i>	50.0% (14)	57.1% (12)	53.1% (26)	
BARS Simple Digit Span – Forward				0.8624
<i>Above Median Score</i>	64.3% (18)	66.7% (14)	65.3% (32)	
<i>Below Median Score</i>	35.7% (10)	33.3% (7)	34.7% (17)	
BARS Simple Digit Span – Reverse				0.6830 ^a
<i>Above Median Score</i>	82.1% (23)	90.5% (19)	85.7% (42)	
<i>Below Median Score</i>	17.9% (5)	9.5% (2)	14.3% (7)	
* Numbers may not add to 100 due to rounding.				
^a Fisher's Exact p-value				

Tables 76 through 99 report the results of logistic regression modeling with dichotomized test scores, dichotomized fly ash presence/absence, and variable potentially associated with test scores. Possible covariates were included in the modeling step if their univariate Wald Chi-square p-values were less than 0.05.

None of the logistic regression models involving the fly ash presence/absence variable reached statistical significance at $\alpha=0.05$. However, the odds of abnormal VMI performance (AOR = 2.134), abnormal Purdue Pegboard dominant (AOR = 1.150) and non-dominant (AOR = 1.210) hand scores, and abnormal immediate (AOR = 1.374) and delayed (OR = 1.875) Object Memory scores were higher among those with fly ash in their homes than among those without fly ash in their homes. Among the BARS tests, the odds of below average left hand (AOR = 1.769) and right hand (AOR = 1.639) Tapping scores were higher among those with fly ash in their homes than among those without fly ash in their homes, even after adjustment for sex and age and sex, respectively.

Table 76. Variables Potentially Associated with VMI Scores

Variable	Chi-square p-value
Age (in months)	0.7141
Sex	0.9497
Median Income	0.0238
Pre-1978 Home	0.9476
Environmental Tobacco Smoke Exposure	0.6278
Family History of Learning Disability	0.9197

Table 77. Logistic Regression for VMI

Model Variables*	OR	95% CI
Fly ash	2.604	(0.546, 12.428)
Median income	1.000	(1.000, 1.000)
Fly ash + Median income	2.134	(0.390, 11.682)
<i>* No adjustments for age, sex, home age, tobacco smoke, or family history of learning disability since these variables were not significant in univariate analyses.</i>		

Table 78. Variables Potentially Associated with Purdue Pegboard Dominant Hand Scores

Variable	Chi-square p-value
Age (in months)	0.0909
Sex	0.4695
Median Income	0.6731
Pre-1978 Home	0.0170
Environmental Tobacco Smoke Exposure	0.8194
Family History of Learning Disability	0.5480

Table 79. Logistic Regression for Purdue Pegboard Dominant Hand Scores

Model Variables*	OR	95% CI
Fly ash	1.467	(0.470, 4.574)
Pre-1978 Home	0.187	(0.047, 0.741)
Fly ash + Pre-1978 Home	1.150	(0.297, 4.456)
<i>* No adjustments for sex, median income, tobacco smoke, or family history of learning disability since these variables were not significant in univariate analyses.</i>		

Table 80. Variables Potentially Associated with Purdue Pegboard Non-Dominant Hand Scores

Variable	Chi-square p-value
Age (in months)	0.0310
Sex	0.0781
Median Income	0.7258
Pre-1978 Home	0.4418
Environmental Tobacco Smoke Exposure	0.0743
Family History of Learning Disability	0.9638

Table 81. Logistic Regression for Purdue Pegboard Non-Dominant Hand Scores

Model Variables*	OR	95% CI
Fly ash	1.202	(0.365, 3.956)
Age (in months)	1.024	(1.002, 1.045)
Fly ash + Age (in months)	1.210	(0.344, 4.250)
<i>* No adjustments for sex, median income, tobacco smoke, or family history of learning disability since these variables were not significant in univariate analyses.</i>		

Table 82. Variables Potentially Associated with Purdue Pegboard Both Hands Scores

Variable	Chi-square p-value
Age (in months)	0.1463
Sex	0.1438
Median Income	0.2778
Pre-1978 Home	0.1245
Environmental Tobacco Smoke Exposure	0.9248
Family History of Learning Disability	0.9638

Table 83. Logistic Regression for Purdue Pegboard Both Hands Scores

Model Variables*	OR	95% CI
Fly ash	0.971	(0.300, 3.136)
<i>* No adjustments for age, sex, median income, tobacco smoke, or family history of learning disability since these variables were not significant in univariate analyses.</i>		

Table 84. Variables Potentially Associated with Immediate Object Memory Scores

Variable	Chi-square p-value
Age (in months)	0.0358
Sex	0.9574
Median Income	0.3955
Pre-1978 Home	0.6689
Environmental Tobacco Smoke Exposure	0.4468
Family History of Learning Disability	0.7718

Table 85. Logistic Regression for Immediate Object Memory Scores

Model Variables*	OR	95% CI
Fly ash	1.389	(0.251, 7.688)
Age (in months)	1.055	(1.004, 1.110)
Fly ash + Age (in months)	1.374	(0.231, 8.864)
<i>* No adjustments for sex, median income, tobacco smoke, or family history of learning disability since these variables were not significant in univariate analyses.</i>		

Table 86. Variables Potentially Associated with Delayed Object Memory Scores

Variable	Chi-square p-value
Age (in months)	0.7197
Sex	0.0920
Median Income	0.9289
Pre-1978 Home	0.8652
Environmental Tobacco Smoke Exposure	0.5132
Family History of Learning Disability	0.7933

Table 87. Logistic Regression for Delayed Object Memory Scores

Model Variables*	OR	95% CI
Fly ash	1.875	(0.436, 8.066)
<i>* No adjustments for age, sex, median income, tobacco smoke, or family history of learning disability since these variables were not significant in univariate analyses.</i>		

Table 88. Variables Potentially Associated with BARS Tapping Preferred Hand Scores

Variable	Chi-square p-value
Age (in months)	0.0004
Sex	0.3222
Median Income	0.9724
Pre-1978 Home	1.0000
Environmental Tobacco Smoke Exposure	0.8194
Family History of Learning Disability	0.0926

Table 89. Logistic Regression for BARS Tapping Preferred Hand Scores

Model Variables*	OR	95% CI
Fly ash	0.750	(0.240, 2.341)
Age (in months)	0.951	(0.925, 0.978)
Fly ash + Age (in months)	0.708	(0.174, 2.885)
<i>* No adjustments for sex, median income, tobacco smoke, or family history of learning disability since these variables were not significant in univariate analyses.</i>		

Table 90. Variables Potentially Associated with BARS Tapping Non-Preferred Hand Scores

Variable	Chi-square p-value
Age (in months)	0.0002
Sex	0.0176
Median Income	0.1272
Pre-1978 Home	1.0000
Environmental Tobacco Smoke Exposure	0.4333
Family History of Learning Disability	0.2550

Table 91. Logistic Regression for BARS Tapping Non-Preferred Hand Scores

Model Variables*	OR	95% CI
Fly ash	0.909	(0.293, 2.821)
Age (in months)	0.939	(0.909, 0.971)
Sex	4.249	(1.287, 14.026)
Fly ash + Age (in months)	0.924	(0.206, 4.139)
Fly ash + Sex	0.816	(0.242, 2.746)
Fly ash + Age (in months) + Sex	0.829	(0.179, 3.845)
<i>* No adjustments for median income, tobacco smoke, or family history of learning disability since these variables were not significant in univariate analyses.</i>		

Table 92. Variables Potentially Associated with BARS Tapping Right Hand Scores

Variable	Chi-square p-value
Age (in months)	0.0003
Sex	0.0170
Median Income	0.5931
Pre-1978 Home	0.5195
Environmental Tobacco Smoke Exposure	0.6276
Family History of Learning Disability	0.6358

Table 93. Logistic Regression for BARS Tapping Right Hand Scores

Model Variables*	OR	95% CI
Fly ash	1.333	(0.427, 4.162)
Age (in months)	0.936	(0.903, 0.970)
Sex	4.317	(1.299, 14.344)
Fly ash + Age (in months)	1.819	(0.389, 8.510)
Fly ash + Sex	1.262	(0.375, 4.247)
Fly ash + Age (in months) + Sex	1.639	(0.341, 7.875)
<i>* No adjustments for median income, tobacco smoke, or family history of learning disability since these variables were not significant in univariate analyses.</i>		

Table 94. Variables Potentially Associated with BARS Tapping Left Hand Scores

Variable	Chi-square p-value
Age (in months)	0.0003
Sex	0.0649
Median Income	0.3404
Pre-1978 Home	0.8969
Environmental Tobacco Smoke Exposure	0.2385
Family History of Learning Disability	0.1695

Table 95. Logistic Regression for BARS Tapping Left Hand Scores

Model Variables*	OR	95% CI
Fly ash	1.333	(0.427, 4.162)
Age (in months)	0.941	(0.910, 0.972)
Fly ash + Age (in months)	1.769	(0.396, 7.909)
<i>* No adjustments for sex, median income, tobacco smoke, or family history of learning disability since these variables were not significant in univariate analyses.</i>		

Table 96. Variables Potentially Associated with BARS Forward Simple Digit Span Scores

Variable	Chi-square p-value
Age (in months)	0.0012
Sex	0.6862
Median Income	0.7161
Pre-1978 Home	0.5822
Environmental Tobacco Smoke Exposure	0.7614
Family History of Learning Disability	0.7716

Table 97. Logistic Regression for BARS Forward Simple Digit Span Scores

Model Variables*	OR	95% CI
Fly ash	0.900	(0.273, 2.964)
Age (in months)	0.958	(0.934, 0.983)
Fly ash + Age (in months)	0.970	(0.241, 3.908)
<i>* No adjustments for sex, median income, tobacco smoke, or family history of learning disability since these variables were not significant in univariate analyses.</i>		

Table 98. Variables Potentially Associated with BARS Reverse Simple Digit Span Scores

Variable	Chi-square p-value
Age (in months)	0.1330
Sex	0.6420
Median Income	0.2978
Pre-1978 Home	0.6689
Environmental Tobacco Smoke Exposure	0.6278
Family History of Learning Disability	0.2162

Table 99. Logistic Regression for BARS Reverse Simple Digit Span Scores

Model Variables*	OR	95% CI
Fly ash	0.484	(0.084, 2.783)
<i>* No adjustments for age, sex, median income, tobacco smoke, or family history of learning disability since these variables were not significant in univariate analyses.</i>		

V. DISCUSSION

The larger study from which data for this thesis were obtained is ongoing, and it should be noted that the findings of this thesis are therefore preliminary. Though the findings in this thesis were affected by its small sample size, several patterns between neurobehavioral test performance and 1) proximity of residence to coal ash storage sites, 2) heavy metal concentrations found in nails, and 3) presence of fly ash in the home were noted.

Overall Neurobehavioral Test Performance

The prevalence of abnormal standardized performance on neurobehavioral tests used in this thesis was 16.4% for the Beery VMI, 49.1% for the dominant Purdue Pegboard, 61.1% for the non-dominant Purdue Pegboard, 57.4% for the both hand Purdue Pegboard, 10.9% for the immediate Object Memory, and 16.4% for the delayed Object Memory test for the total population (N=55). The prevalence of these abnormal scores was within expected range for the Beery VMI (15.9%) and Object Memory tests (15.9%), but was greater than expected for the Purdue Pegboard tests (15.9%). Occasionally, sex and age were related to standardized test performance, even if the standardized test score was already adjusted for these variables.

The prevalence of the BARS scores that were below the mean or median for Finger Tapping were 47.3% for the preferred hand, 49.1% for the non-preferred hand, 52.7% for the left hand, and 54.5% for the right hand. The

prevalence of BARS scores that were below the median for Simple Digit Span were 32.7% for forward tests and 12.7% for reverse tests. There were no standards to compare the BARS tests to, however, sex and age were related to the BARS test performance.

BARS Test Performance in Previous Literature

Although there are not standards with which to compare the BARS test results, previous studies using these tests in populations of children can be useful when reviewing these data. For example, Rohlman et al. (2000b) reported a mean forward Simple Digit Span score of 5.1 (SD 1.2) and a mean reverse Simple Digit Span score of 3.5 (SD 0.8) among a group of American school children ages 4-5 years (mean age: 60.7 months). These findings are similar to those reported in this thesis, which were a median forward Simple Digit Span score of 5 (IQR=2) and median reverse Simple Digit Span score of 3 (IQR=1), although this population was younger than the one used in this thesis. Another study involving a population of occupationally exposed and unexposed 9-15 year-olds in Egypt reported mean forward Simple Digit Span scores of 5.4 (SE 0.2) and 6.1 (SE 0.2), respectively, and reverse scores of 4.7 (SE 0.2) and 5.5 (SE 0.2), respectively (Abdel Rasoul et al., 2008). These mean scores are higher than the median scores found in this study, but this study's population is older than the one used in this thesis.

Since the parameters of the BARS tests can be changed within the BARS system, it is important to ensure that comparisons are only made between studies with similar testing parameters, such as the length of time that is allotted

for a given section or the number of attempts given for each span length during the Simple Digit Span test. Previous studies have either not reported test intervals or used a shorter interval (20 seconds) than the one (30 seconds) used in this study. However, the data from these studies are still informative. Non-exposed children aged 48-71 months (approximately 4-6 years) in two different regions in one exposure study had mean right hand Tapping scores of 53.4 (SD 3.1) and 47.3 (SD 2.1) and mean left hand Tapping scores of 42.2 (SD 2.7) and 39.0 (SD 1.8) for tests given over a 20 second duration (Rohlman et al., 2005). Another study reported a mean of 62.4 (SD 15.1) taps with the right hand and 57.8 (SD 16.8) taps with the left hand over the course of an unreported length of time for a population of children aged 4-5 years (Rohlman et al., 2000b).

Relationship with Distance to Ash Landfill

While none of the logistic regression models involving nearest landfill distance and test performance outcomes reached statistical significance, the odds of abnormal or below mean/median performance were higher in those living closer to the ash landfills than those living further from the ash landfills, after adjustment for covariates, for six of the twelve tests (50%). Median income, environmental exposure to tobacco smoke, and a family history of learning disability, variables potentially associated with neurobehavioral test performance, were not found to be significantly associated with test performance in the full sample (N=55). Age of home, another potential covariate, was only found to be significantly associated with dominant Purdue Pegboard performance in which

the odds of abnormal test performance were lower among those living in older houses than those living in newer houses.

Relationship with Heavy Metal Body Burden

Metals such as cadmium, lead, mercury, chromium, manganese, and arsenic have been associated with impaired neurobehavioral performance in past studies (Chia et al., 1997; Ciesielski et al., 2013; Grashow et al., 2013; Gunther et al., 1996; Needleman et al., 1990; Rodriguez-Barranco et al., 2014; Schwartz et al., 2005; Wright et al., 2006). However, none of the study participants had nail levels of cadmium, lead, or mercury that exceeded the PIXE's level of detection. Only one participant had arsenic in their nails, making comparisons between test performance groups difficult.

Metal level ranges for seven metals considered in this thesis exceeded the ranges of metal levels found in nails as reported in the literature. These seven metals included aluminum, titanium, chromium, manganese, nickel, strontium, and zirconium. Of the 32 participants for which nail data were available, 13 of the 29 with aluminum in their nails had concentrations exceeding the ranges reported in the literature. The same was found for 6 of the 11 titanium concentrations, 18 of the 27 chromium concentrations, 3 of the 6 manganese concentrations, 1 of the 20 nickel concentrations, 2 of the 2 strontium concentrations, and 4 of the 5 zirconium concentrations.

Presence of titanium and manganese were each significantly related to abnormal VMI test performance ($p = 0.0367$ and $p = 0.0020$, respectively). Chromium was found in the nails of most participants (27 of 32), but was not

significantly related to any of the neurobehavioral tests ($p > 0.05$). The absence of manganese was significantly related to abnormal dominant hand Purdue Pegboard scores ($p = 0.0177$). Strontium presence was significantly related to abnormal delayed Object Memory scores ($p = 0.0423$); however strontium concentrations in nails only exceeded the PIXE's limit of detection in two participants. Higher levels of iron were significantly related to normal performance on the dominant hand Purdue Pegboard test ($p = 0.0074$) and the immediate Object Memory test (0.0450), while higher levels of iron were also significantly related to below average right hand BARS Tapping performance ($p=0.0234$). Higher levels of zinc were significantly related to abnormal VMI scores ($p = 0.0348$), below median non-preferred BARS Tapping scores ($p = 0.0402$), and below average left hand BARS Tapping scores ($p = 0.0199$). Finally, higher levels of copper were significantly related to abnormal VMI performance ($p = 0.0271$).

Relationship with Fly Ash Presence

Fly ash was confirmed in samples from 21 of the 49 homes (42.9%) for which results were available. Preliminary results suggest that as many as 38 of the 49 homes, or 77.6%, may have fly ash present, but these additional 17 results could not be confirmed by SEM/EDX for use in this thesis. The presence of fly ash was not significantly associated with performance on neurobehavioral tests. However, the odds of abnormal or below average test performance were higher in those with fly ash in their homes than those without fly ash in their homes, even after adjustment for covariates, for 7 of the 12 (58.3%) tests.

Strengths and Limitations

There were several limitations of this study including the limited sample size. The overarching community-based study has only been recruiting participants for ten months, which has led to a small sample size for this thesis. As the study continues and gains additional participants, there will be more power to detect possible differences in neurobehavioral performance between those living closer to and further from coal ash storage sites, those with higher and lower concentrations of heavy metals in their nail samples, and those with or without fly ash in their homes.

In conjunction with the study's small sample size, the issue of missing data also led to difficulty in determining significant relationships. Potential covariates for use in modeling that were impacted by missing data included the age of the participant's home, exposure to environmental tobacco smoke, and having a family history of a learning disability. Although a surrogate for socioeconomic status based on block group median household income (U.S. Census Data / American Community Survey, 2014) was incorporated into this analysis, a more sensitive marker of socioeconomic status such as family income may be helpful in future analyses; however, tests of fine motor skills are not often significantly related to socioeconomic status (Beery et al., 2010).

Another limitation of this study is that the limit of detection for cadmium in the PIXE analysis of nail samples was approximately 35 ppm, which is substantially higher than the mean (0.457 ppm) or range (0.0 – 0.00196 ppm) of cadmium levels found in pediatric nails in previous studies (Sherief et al., 2015;

Wilhelm, Hafner, Lombeck, & Ohnesorge, 1991). Cadmium was a metal of interest in this thesis as it was related to decreased neurobehavioral performance in past studies (Ciesielski et al., 2013; Ciesielski et al., 2012; Rodriguez-Barranco et al., 2014). Of the studies reviewed, only one reported cadmium levels in nails that may reach PIXE's limit of detection, and those were at the upper bound of the concentration range found among adults occupationally exposed to cadmium (range: 0.214 – 35.714 ppm; Mehra & Juneja, 2004). It is possible that levels of cadmium unable to be measured by PIXE may have been related to neurobehavioral performance in this study. The same may be true of other metal concentrations in nails that failed to reach PIXE's limit of detection.

Metal concentrations were evaluated based on absence vs. presence for metals that were not found in the nails of all participants. Evaluating all metal concentrations on a continuous scale or dichotomizing based on within normal metal level range or out of normal metal level range may have provided different results than those reported in this thesis study. If more data were available and if more of the neurobehavioral test results were normally distributed in this dataset, these would have been interesting additional methods for analyzing these data. Additionally, analyses using the limit of detection as the minimum level might have shown different responses than the 0 ppm used in this study. Finally, the creation of a metal score should be considered in future studies, as the presence of an elevated concentration of a single metal may not be independently associated with test performance, but the presence of several elevated metals may.

An additional limitation of this study is that outside labs are contracted for the PIXE and SEM/EDX analyses. After collecting nail samples, lift tapes, and air filters, there is a period of several weeks to a few months before results of these analyses are returned. This aspect of the study's timeline impacted the number of lift tapes available for use in this thesis. SEM/EDX results on 49 lift tapes for 22 participants were not available at the time of this analysis. Five of these participants had fly ash confirmed by SEM/EDX on polycarbonate air filters; however 17 participants were given a status of "fly ash absence," even though preliminary results from OM indicated that fly ash may be present. Since the potential fly ash on the lift tapes from these 17 participants could not be confirmed by SEM/EDX, their fly ash presence was based on their SEM/EDX-confirmed filters alone. In past analyses of lift tape samples, 53.8% of those found positive with OM were also positive with SEM/EDX. Therefore, it is possible that approximately 26 of these samples (53.8%) were positive, but since we did not have the final results, they were not reported as having fly ash present on their samples. This likely resulted in an underestimation of the number of participants' homes with fly ash.

In regards to the neurobehavioral test performance data, few abnormal scores on some tests and unstandardized BARS scores may play a role in the lack of significant relationships observed in this study. There are currently few abnormal scores on the Beery VMI (N=9) and Object Memory (N=6 for immediate; N=9 for delayed) tests. Though this may be due to the small sample size of this thesis, the small number of abnormal scorers on these tests makes it

difficult to determine relationships between testing performance and other variables, such as ash landfill distance, heavy metal body burden, and fly ash presence. Additionally, no standardized norms for the BARS tests have been developed, even though these tests have been administered in populations of children in past studies including exposure studies (Dahl et al., 1996; Otto et al., 1996; Rohlman et al., 2000b). Evaluating the BARS test performances based on above or below mean/median performance is not as meaningful as the comparison of standardized test performance, as it does not provide information on how normally participants are performing on these tests relative to others in their same age and/or gender group.

One other limitation of this study is in working with children aged 6-14 years. The total mass of nails that needed to be collected was ~150 mg, which took some of the younger children months to collect. Children began to lose interest, and even with consistent reminders, it was often difficult to collect multiple clippings from participants. Furthermore, neurobehavioral testing was almost always conducted on schooldays after children returned home. Testing takes approximately 40 minutes, and the BARS section of testing takes the longest. Some children would begin to squirm or yell things like, “You’re killing me!” during the BARS tests due to the length of time it took to complete these tests. While the BARS test battery has been used with children, the studies are limited. Behaviors such as these may have affected their scores. Additionally, the air samplers were left in participants’ homes for a week. The instructions given to the participants were to not touch the equipment, but, in some situations, we had

equipment stop working and filters overload (possibly from smoke being blown into the impactor). Children may have touched the samplers, especially the youngest participants or younger siblings of older participants. Any of these disruptions may have impacted the sampler's ability to collect particles, particularly the fly ash particles that were of interest in this thesis.

It is also possible that recruiting efforts have impacted these results. Early recruitment by footwork and mailing efforts were conducted by zip code, which occasionally led to having multiple participants in one geographic area. Exposure to fly ash may be similar for individuals living in these clusters, and having multiple clusters instead of an even distribution of participants throughout the study area may have impacted the ability to detect patterns between fly ash presence and the location of the homes relative to the ash landfills. Moreover, few participants in the sample used for this thesis lived near the Mill Creek coal ash landfill, with no participants living within one mile of this landfill. Also, only four participants lived within one mile of the Cane Run coal ash landfill. While the results of this analysis are preliminary and based on a small sample size with several clusters, future recruiting efforts throughout the entire study area will help to provide a better understanding of fly ash distribution and exposure within the study area.

Seasonal weather changes and participant behaviors may play a role in the dispersion of fly ash. Seasonal weather changes may also affect how often people open windows and doors in their homes. Such behaviors may increase the ability of fly ash to enter the home and, therefore, be collected by the air

samplers and lift tapes. Data were only available for three seasons (fall, winter, and spring) at the time of this thesis, so these data do not represent fly ash presence in homes at all points in time during the year. Cleaning practices may also have impacted the measure of fly ash on both the filters and the lift tape samples, but these data were not used in this analysis.

A final limitation of this study is that there currently is not a good measure for predicting a participant's coal ash exposure based on their home's location. Though we have each home's distance to each ash landfill, the proximity of the home to a landfill is not equivalent to a particular risk level of exposure to coal ash. Wind patterns are especially important for consideration here, and while these data are beginning to be explored, they were not available for use in this thesis. Eventually these data might indicate that a person who lives three miles east of the Cane Run ash landfill is at greater risk for coal ash exposure than a person who lives one mile south of the same ash landfill. Furthermore, the issue of close proximity to more than one plant is not addressed in this analysis. Neurobehavioral test performance may differ between those who live close to two ash landfills and those who live close to one.

While there were several limitations, there are also many positive attributes associated with this study. First, the overarching study is the only attempt to study coal ash exposure within a community, utilizing a community-based model. Coal ash is an emerging environmental problem that affects people in almost every state in the U.S. This is just a first step to investigating health related to coal ash exposure in people who live near these storage sites. Second,

this study brings answers to many people in the community who are concerned about coal ash. Since the study results are made available to the participants, they can begin to understand their risk of exposure and learn about coal ash and air pollution. Third, the exposure assessment includes multiple methods to characterize coal ash exposure, including air monitors, lift samples, and toenails/fingernails as biomarkers. When the study is completed, it should provide a good picture of children's exposure to fly ash and metals. Fourth, we are using two measures of neurobehavioral performance: the Child Behavior Checklist, which is a well-known measure of children's behavioral, emotional, and social functioning, and neurobehavioral tests including three standardized tests and the BARS test battery, which has been used mainly in studies designed to assess neurotoxicity in workers and children. While the BARS does not have standardized scores, the Beery VMI, Purdue Pegboard, and Object Memory tests, do, thus allowing us to make comparisons to other populations.

Conclusion

This study represents the beginning of the research on coal ash. Although limited by sample size, some interesting preliminary findings have been discussed in this thesis. More research is needed to make conclusive comments about the relationship between coal ash and memory and fine motor skills in children living near coal ash storage sites, and these relationships should be further explored as the study's sample size increases.

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EDUCATION

SCHOOL OF PUBLIC HEALTH AND INFORMATION SCIENCES,
UNIVERSITY OF LOUISVILLE, LOUISVILLE, KY
Master of Science, Epidemiology
Graduation: August 2016

UNIVERSITY OF NORTH CAROLINA, CHAPEL HILL, NC
Bachelor of Science, Psychology
Graduation: May 2012

RESEARCH EXPERIENCE

UNIVERSITY OF LOUISVILLE, DEPARTMENT OF COMMUNICATION,
LOUISVILLE, KY
Graduate Research Assistant, March 2016 – Present
Responsibilities include data entry and analysis and questionnaire development for future studies evaluating the perceptions and communication surrounding tobacco use, particularly among youth.

UNIVERSITY OF LOUISVILLE, SCHOOL OF PUBLIC HEALTH AND
INFORMATION SCIENCES, DEPARTMENT OF EPIDEMIOLOGY AND
POPULATION HEALTH, LOUISVILLE, KY
Research Assistant, August 2015 – Present
Responsibilities include recruiting and consenting participants, collecting lift and air samples, collecting survey information and biological samples, preparing samples for analysis, and entering and analyzing data for a large community-based cross-sectional environmental epidemiology study.

EXXONMOBIL BIOMEDICAL SCIENCES, INC., CLINTON, NJ
Epidemiology Intern, May 2015 – August 2015
Responsibilities included data entry for and management of a large-scale meta-analysis project, literature reviews to aid in updates of occupational exposure limits, and literature reviews to aid in the development of future research projects.

CIRRUS PHARMACEUTICALS, MORRISVILLE, NC

Student Intern, August 2009 – May 2012

Responsibilities included aiding in the research and development of pharmaceutical products and laboratory management.

HEALTHCARE EXPERIENCE

KOSAIR CHILDREN'S MEDICAL CENTER, LOUISVILLE, KY

Emergency Room Technician, May 2012 – May 2015

CENTRAL REGIONAL HOSPITAL, BUTNER, NC

Group Therapy Volunteer, September 2011 – December 2011

UNIVERSITY OF NORTH CAROLINA HOSPITALS, ANESTHESIOLOGY
DEPARTMENT, CHAPEL HILL, NC

Student Aid, January 2009 – May 2009

AWARDS

2016 **University Fellowship**, University of Louisville

2016 **Commission on Diversity and Racial Equality Graduate Research Grant Recipient**, University of Louisville

2012 **Buckley Public Service Scholar**, University of North Carolina

SERVICE ACTIVITIES

May 2015 – March 2016

Treasurer, Kentucky Public Health Association, University of Louisville chapter

May 2011 – April 2012

President, Operation Building Courage, University of North Carolina

September 2009 – April 2011

Executive Board Member, Operation Building Courage, University of North Carolina