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Impact of air manganese on child neurodevelopment in East Liverpool, Ohio

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ABSTRACT

Background: East Liverpool, Ohio, the site of a hazardous waste incinerator and a manganese (Mn) processor, has had air Mn concentrations exceeding United States Environmental Protection Agency reference levels for over a decade. Save Our County, Inc., a community organization, was formed to address community environmental health concerns related to local industry. Researchers from the University of Cincinnati partnered with Save Our County to determine if air Mn had an impact on the neurocognitive function of children in the community.

Methods: Children 7–9 years of age from East Liverpool and its surrounding communities, were enrolled (N = 106) in the Communities Actively Researching Exposure Study from between March 2013–June 2014. Blood and hair were analyzed for Mn and lead, and serum was analyzed for cotinine. We used linear regression to assess associations between biological measures and IQ subscale scores.

Results: Geometric mean blood lead (n = 67), blood Mn (n = 66), hair Mn (n = 98), and serum cotinine (n = 69) concentrations were $1.13 \pm 1.96 \mu\text{g/dL}$, $10.06 \pm 1.30 \mu\text{g/L}$, and $360.22 \pm 2.17 \text{ ng/g}$, $0.76 \pm 6.12 \mu\text{g/L}$ respectively. After adjusting for potential confounders, hair Mn was negatively associated with Full Scale IQ.

Conclusions: Hair Mn was negatively associated with child IQ scores. Community partners were instrumental in the conception and implementation of this study.

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Abbreviations: BSMSS, Barratt Simplified Measure of Social Status; CARES, Communities Actively Researching Exposure Study; Cd, cadmium; GSD, geometric standard deviation; Hg, mercury; HI, hazard index; ICP-MS, Inductively Coupled Plasma Mass Spectrometry; MDL, method detection limit; Mn, manganese; OhioEPA, Ohio Environmental Protection Agency; Pb, lead; PM₁₀, particle with aerodynamic diameter <10 μm; PM_{2.5}, particle with aerodynamic diameter <10 μm; PRQ, Parenting Relationship Questionnaire; RfC, reference concentration; TSP, Total Suspended Particulate; US EPA, United States Environmental Protection Agency; WASI, Wechsler Abbreviated Scale of Intelligence; WISC IV, Wechsler Intelligence Scale for Children-IV.

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1. Introduction

The City of East Liverpool sits on the Ohio River in northeastern Ohio. East Liverpool was once the center of the American pottery industry and was coined the “Pottery Capital of the Nation” ([East Liverpool Historical Society Webpage, 2016](#)). It reached its peak in 1970 with a population over 26,000 but rapidly declined along with the pottery industry; 2015 Census population estimate was just under 11,000 (92% Caucasian) ([US Census American Fact Finder, 2016](#)). Overall, 7.3% of residents have earned a bachelor's degree or higher compared to 29.3% in the nation; 30.6% of East Liverpool residents are below the federal poverty limit compared to 15.6% in the nation ([US Census American Fact Finder, 2016](#)). The

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East Liverpool School District reported that in 2010, they had a higher percentage of students in special education (19%) as compared to the state of Ohio (13%) (FY2010 District Profile Report, 2016). These socioeconomic issues are compounded by potentially significant environmental exposures. An environmental organization, Save Our County, Inc., was formed by East Liverpool residents in 1982 in response to the proposed construction of a hazardous waste incinerator in their community. In 2005, East Liverpool was deemed a potential environmental justice area by the United States Environmental Protection Agency (US EPA).

The Ohio Environmental Protection Agency (Ohio EPA) 2010 All Ohio Air Toxics Report reported that manganese (Mn) concentrations from an air sampling station in East Liverpool were 30 times higher than the US EPA reference concentration of 0.05 $\mu\text{g}/\text{m}^3$ (All Ohio Air Toxics Report, 2016). Based on the evaluation of ambient air Mn data, Ohio EPA indicated that S.H. Bell, a warehouse facility which handles and distributes metals, minerals, and semi-finished industrial materials was the primary source of the airborne Mn (Director's Final Findings and Orders, 2016). Their data indicate that Mn concentrations in East Liverpool are highest when the wind is blowing from the direction of S.H. Bell (Health Consultation-East Liverpool Air Quality, 2016). Primarily due to elevated Mn levels, Ohio EPA calculated the non-cancer hazard index (HI) in East Liverpool as 34.5; an HI below 1.0 is considered "safe" (All Ohio Air Toxics Report, 2016).

Mn is an essential nutrient, but is neurotoxic in excess. Adverse neurological outcomes, such as declines in cognitive and motor function, are associated with occupational exposures as well as environmental exposures among highly exposed adults and children (Racette et al., 2012; Rugless et al., 2014; Lucchini et al., 1997, 2012; Bowler et al., 2006; Haynes et al., 2015a). In response to the 2010 reports regarding elevated airborne Mn levels, the East Liverpool Public Schools Superintendent requested that "hair metal level tests" and "follow-up neuropsychological tests" be conducted on school-aged children . . . by Dr. Erin Haynes" (McElwain, 2010). The first author (E.N.H.) and co-authors (E.N.H., P.K., N.N., K.D.) were already engaged in an ongoing community-based participatory research study, Communities Actively Researching Exposure Study (CARES) in Marietta, Ohio with residents concerned about airborne Mn (Haynes et al., 2011). Following meetings with East Liverpool residents and the East Liverpool Board of Health, a pilot study was conducted to examine hair Mn and blood Mn concentrations in children (Haynes et al., 2015b). Hair Mn concentrations in that pilot study were nearly double the levels found in children of similar age from the Marietta cohort (Haynes et al., 2015b). The purpose of this study was to respond to the request of the school district Superintendent and investigate the association between Mn exposure and child cognition.

2. Methods

2.1. Study participants

This current study represents an expansion of CARES (Haynes et al., 2015a) into East Liverpool, Ohio. Children aged 7, 8, or 9 were recruited to participate if they resided in East Liverpool or the surrounding area throughout their life with no plans to relocate in the coming year (Fig. 1). The biological mother must also have resided in the area during her pregnancy with the child. A volunteer sampling strategy was used for recruitment, which included postcards sent home from schools, advertisements aired on local radio and printed in local newspapers, and recruitment information placed in public locations such as libraries. Participant data collection took place March 2013–June 2014.

Children with a health condition that could impede their ability to participate in the behavioral assessment testing (i.e. a significant visual, auditory, or motor impairment) were excluded from participation. The University of Cincinnati Institutional Review Board approved this study. All parents signed an informed consent and children signed an informed assent.

High-volume sampling for Total Suspended Particulate (TSP) was conducted by Ohio EPA at three East Liverpool locations: Port Authority, Maryland Avenue and Water Plant (Fig. 2). Through a public records request, Ohio EPA provided monthly values since 2003 for each of these locations. The values are a composite result from analysis of five filters for each month.

2.2. Specimen collection and analysis

The methods for specimen collection and analysis have been described in detail elsewhere (Haynes et al., 2015a; Wright et al., 2006). Approximately 20 strands of hair were collected from the occipital region, cut with ceramic scissors as close to the scalp as possible. Long hair was trimmed to 6 cm and taped towards the non-scalp-side of the hair shaft onto an index card with an arrow pointing in the direction of the scalp end. The hair sample was placed into a pre-labeled envelope and stored at room temperature until shipped. The Channing Trace Metals Laboratory, Brigham and Women's Hospital, Harvard School of Public Health, which processed hair samples for the pilot study, relocated to the Molecular Environmental Health Laboratory at the Mount Sinai Hospital in the interim and was utilized for the current study. The samples were first washed in a 1% (v/v) Triton™ X-100 solution and then digested using concentrated HNO₃. Acid digestates were then analyzed by Inductively Coupled Plasma Mass Spectrometry (ICP-MS) using previously described methods. The method detection limit (MDL) for Mn in hair was 2 ng/g. In light of this change in location, five hair samples from the pilot study were re-tested, with the new lab providing slightly higher values, but within 10% of the original lab.

Venous whole blood specimens were collected and shipped to the Laboratory of Inorganic and Nuclear Chemistry at the New York State Department of Health's Wadsworth Center where they were analyzed for Mn via Graphite Furnace Atomic Absorption Spectrometry (GFAAS). The MDL for Mn in blood was 2.1 $\mu\text{g}/\text{L}$. Blood lead (Pb), cadmium (Cd), and mercury (Hg) was determined by ICP-MS. The MDL for blood Pb, Cd, and Hg were 0.069 $\mu\text{g}/\text{L}$, 0.042 $\mu\text{g}/\text{L}$, and 0.33 $\mu\text{g}/\text{L}$ respectively. Serum cotinine levels were also measured at the Wadsworth Center. The MDL was 0.05 $\mu\text{g}/\text{L}$ cotinine in serum. Child's serum ferritin was measured by the East Liverpool City Hospital.

2.3. Neurocognitive assessment

Neurocognitive assessments of the children were conducted by a registered nurse from East Liverpool after training by an experienced developmental neuropsychologist (K.N.D.). Quality control was maintained via periodic review of videotapes of the assessment sessions. The Wechsler Intelligence Scale for Children-IV (WISC-IV) (Wechsler, 2003) was administered at the time of biological sample collection.

The WISC-IV provides an overall score (Full Scale IQ) and four major areas of intellectual functioning including Perceptual Reasoning, Processing Speed, Working Memory, and Verbal Comprehension.

2.4. Other covariates

The IQ of the primary caregiver was assessed with the Wechsler Abbreviated Scale of Intelligence (WASI) (Wechsler, 1999). The

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