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Laura Schuch, Andrew Curtis & Joel Davidson

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Reducing Lead Exposure Risk to Vulnerable Populations: A Proactive Geographic Solution

Laura Schuch,* Andrew Curtis,* and Joel Davidson†

*Department of Geography, Kent State University
†Department of Pediatrics, Akron Children's Hospital

Recent headlines highlight disparities in childhood lead poisoning in urban areas yet discourse does not address the lack of primary prevention options. Previous geographic information systems (GIS) approaches, concentrated on census tracts or ZIP codes, miss contextual understanding of lead exposure and make intervention impractical. Through the combination of electronic medical record (EMR) data from an urban children's hospital and spatial video geonarrative (SVG), we show how blood lead level researchers, clinicians, and public health planners can become more proactive in prediction and intervention strategies through the development of an environmental lead index (ELI). Kernel density estimation (KDE) clusters of geocoded locations of children with elevated blood lead (EBL), from 2012 to 2014, were identified using GIS. Analyses identify an increased relative risk for African American and Asian patients compared to white patients and Nepali and non-English-speaking patients compared to English-speaking patients. Fine-scale analyses of EBL clusters reveal nuances of exposure and environmental characteristics that are not identifiable at an aggregate level. Initial testing of the ELI was conducted using identified locations of EBL and non-EBL test results. The mean ELI score was higher among EBL parcels, and comparison proportions of ELI variables between EBL and non-EBL parcels found a statistically significant increase in four variables. Preliminary results support the use of the ELI as a predictive tool; further validation is needed. The technology and the method are translatable to other environments and health conditions. *Key Words: childhood lead exposure, electronic health data, geospatial analysis, GIS, SVG.*

晚近的新闻头条，强调城市地区儿童铅中毒的不均分佈，但该论述却未着手处理关键防治选项的缺乏。过往的地理信息系统（GIS）方法聚焦人口普查区或邮政编号，因而错失了对于铅暴露率的脉络化理解，并使得介入变得不实际。我们透过结合一座城市儿童医院的电子医疗记录（EMR）以及空间录像地理叙事（SVG），展现如何能够透过建立环境铅指标（ELI），让血液铅含量的研究者，临床医生与公共健康规划师， 在预测与介入策略上能够更为主动。本研究运用地理信息系统，指认 2012 年至 2014 年间，血铅（EBL）上升的孩童的地理编码区位的核密度评估（KDE）集群。这些分析指认出，相较于白人病患，非裔美国与亚裔病患的相对风险有所增加；而与说英语的病患相较之下，尼泊尔和不说英语的病患的风险亦有所增加。 EBL 集群的微尺度分析，揭露了在总层级上无法指认的细微暴露与环境特徵。本研究并运用 EBL 与EBL检测结果之指认区位，进行初期的ELI检验。在 EBL 的区块中， ELI 的平均数较高，且 EBL 与非 EBL 区块之间的 ELI 变数的比较比例，在四个变项中皆有统计上的显着成长。初步的结果，支持运用 ELI 作为预测的工具，但需要进一步的确认。该技术与方法可转移至其他的环境与健康条件。*关键词： 儿童铅暴露率，电子健康数据，地理空间分析，地理信息系统，空间录像地理叙事。*

Titulares recientes destacan las disparidades en envenenamiento de la niñez con plomo en áreas urbanas, aunque el discurso no aboca la falta de opciones primarias de prevención. Enfoques anteriores con sistemas de información geográfica (SIG), concentrados en distritos censales o en códigos ZIP, fallan en la comprensión contextualizada de la exposición al plomo y hacen impráctica la intervención. Mediante la combinación de datos del registro médico electrónico (EMR) de un hospital infantil urbano y la geonarrativa del video espacial (SVG), mostramos la manera como quienes investigan el nivel de plomo en la sangre, los médicos clínicos y los planificadores de salud pública pueden llegar a ser más proactivos en estrategias de predicción e intervención a través del desarrollo de un índice de plomo ambiental (ELI). Con el uso de SIG se identificaron agrupamientos del kernel de estimación de densidad (KDE) de locaciones geocodificadas de niños que registran presencia elevada de plomo en la sangre (EBL), del 2012 al 2014. Los análisis detectan un riesgo relativo en aumento en pacientes afroamericanos y asiáticos en comparación con pacientes blancos, y de pacientes nepalíes y no hablantes de inglés comparados con pacientes hablantes del inglés. Los análisis de escala fina de agrupamientos con EBL revelan matices de exposición y características ambientales que no son identificables en un nivel agregado. La prueba inicial del ELI se realizó usando localizaciones identificadas con resultados de pruebas para EBL y para no–EBL. El marcador medio de ELI fue más alto entre las parcelas con EBL, y las proporciones de comparación de las variables de ELI entre las parcelas EBL y no–EBL hallaron un aumento estadísticamente significativo en cuatro variables. Los resultados preliminares apoyan el uso del

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ELI como una herramienta de predicción; se requiere validación adicional. La tecnología y el método son susceptibles de traslado a otros entornos y condiciones sanitarias. *Palabras clave: exposición de la niñez al plomo, datos electrónicos de salud, análisis geoespacial, SIG, SVG.*

Urban lead exposure in the United States continues to be a health issue for the socially vulnerable. As with the example of social injustice occurring in Flint, Michigan, during 2016 (Hanna-Attisha et al. 2016), many of the children enduring chronic exposure live in economically disadvantaged neighborhoods that lack affordable, safe housing (Leech et al. 2016). Indeed, in 2014 an estimated 4 million children within the United States lived in homes that put them at risk for cognitive and behavioral impairments due to exposure to environmental lead (Centers for Disease Control and Prevention [CDC] 2014). As many of the pathways leading to exposure are geographic in nature and have been well described and even mapped (Mielke 1994; Laidlaw and Filippelli 2008), the clinical health strategy addressing this problem remains largely reactive and nonspatially specific as clinicians have to wait for a child's blood test to have an elevated blood lead (EBL; American Academy of Pediatrics [AAP] 2016). Furthermore, commonly used interventions such as household education and dust-control measures are not considered effective, especially when not applied in conjunction with other practices that address other sources of lead (Yeoh et al. 2014; Kennedy et al. 2016). The CDC American Committee on Childhood Lead Poisoning Prevention (ACCLPP) recognized the deficiency in this reactive approach and promoted a shift to primary prevention of childhood lead poisoning (ACCLPP 2012; CDC 2012). In this article we consider this shift in lead exposure thinking by presenting a proactive geographic framework for reducing health effects resulting from lead exposure in older urban settings.

Recent changes in fine-scale geospatial technologies offer the opportunity to potentially move beyond more classic mapping of lead risk (Krieger et al. 2003; Oyana and Margai 2010) to be better able to spatially target intervention. Traditional coarse (neighborhood)-scale spatial analysis of lead exposure is limited, as it misses the actual source of a child's exposure. More granular analysis is possible as the electronic medical records (EMRs) contain address-level exposure data. This article advances the geographic lead exposure literature by focusing on a more granular analysis, enriched by other novel fine-scale spatial data, including a house-scale environmental lead index (ELI) for assessing environmental sources of exposure. Here we will use both granular EBL data and the ELI to spatially identify lead exposure risk in a typical at-risk northeastern neighborhood of Akron, Ohio. Unlike with more traditional approaches, here we attempt to shift the discourse to what is needed to identify lead-risk properties before a child has an EBL (AAP 2016).

Background

Health Impacts of Lead Poisoning

Children under six years old are at a greater risk of lead exposure due to physiological characteristics and behavioral risks (Needleman 2004; AAP Committee on Environmental Health 2005). Once ingested or inhaled, various systems within the body are affected by lead, including the central nervous, cardiovascular, immunological, endocrine (ACCLPP 2012), renal, and hepatic systems (AAP Committee on Environmental Health 2005). Whereas acute exposure can lead to coma or death, chronic exposure at low levels often results in irreversible lifelong effects such as hearing impairment; attention deficit disorder (AAP Committee on Environmental Health 2005; Braun et al. 2006); and a decline in IQ (Canfield et al. 2003; Lanphear, Hornung, and Ho 2005), vocabulary, reaction time, hand–eye coordination (AAP Committee on Environmental Health 2005), and impulse control (Byers and Lord 1943; Bellinger 2008). Outcomes of deleterious effects of lead exposure include poorer academic performance (Needleman et al. 1990; Miranda and Edwards 2011), higher absenteeism in school, lower class rank, delinquent behavior (Needleman et al. 1990; Needleman et al. 2002), lower lifetime achievement and earning potential (White et al. 1993; Grandjean and Landrigan 2006), and adult criminal behavior (Nevin 2007; Wright et al. 2008). In many ways lead exposure produces the classic poverty trap: There is a greater likelihood of exposure in troubled neighborhoods, and life course implications produce barriers for upward mobility (Leech et al. 2016).

Societal Impacts of Childhood Lead Poisoning

After a positive result of an EBL, environmental intervention steps include a risk assessment and removal of the lead source, possibly through abatement of the residence or relocation to a lead-safe home. Abatement can be costly; Schwartz (1994) estimated that in 1993 it would have cost billions of dollars to abate every home with lead-based paint. However, for an individual building, Brown (2002) estimated a net gain from abatement of $43,360 after the costs of treating an additional child is factored in. At the national scale, a comprehensive cost–benefit analysis by Schwartz (1994) estimated a yearly savings of $17.2 billion from lowering individual blood lead levels 1 μg/dL. For the U.S. cohort of children age five at the time of writing, Landrigan et al. (2002) estimated a loss of $43.4 billion due to loss of lifetime earnings from a decrease in IQ. More recently, analysis by Gould (2009) estimates a savings of $181 billion to $269 billion for investment in lead paint hazard controls.

Sources of Environmental Lead

Lead-based paint, old water pipes (Hanna-Attisha et al. 2016), lead-contaminated dust, and lead in soil are considered the sources with the highest potential for exposure (Mielke and Reagan 1998; CDC 2005). Houses built before 1978, when the United States banned lead-based paint for residential applications, is often considered the most pertinent environmental risk factor. Exposure to lead from household paint comes through aerosolized particles during renovation, paint chips on high-friction surfaces (window and door frames), and peeling paint flaking off into the soil. Despite the ban, leaded paint is still found in imported items such as toys, jewelry, dishware, and cosmetics (Levin et al. 2008; CDC 2014). Similarly, exposure from lead in dust can be the result of residual sources within the home, external sources tracked into the home (Hunt, Johnson, and Griffith 2006), exhaust fallout of leaded gasoline, fallout of industrial emissions (Landrigan et al. 1975), or from playing outside in lead-contaminated soil and dirt (Lanphear et al. 1998; Lucas et al. 2014).

Lead in soil is increasingly considered a significant source of exposure, especially for children engaging in hand-to-mouth, crawling, and pica behavior (an eating disorder resulting in eating nonnutritive substances; Mielke and Reagan 1998; U.S. Environmental Protection Agency [EPA] 2016). The positive relationship between soil lead values and EBL has been identified by several researchers (Mielke et al. 1999; Johnson and Bretsch 2002), with some studies demonstrating that blood lead levels in children might be more related to this source than age of housing (Lanphear et al. 1998; Mielke and Reagan 1998). Mielke et al. (1999; Mielke et al. 2013) found that at the census tract level, soil lead is significantly associated with blood lead in New Orleans, Louisiana. Spatial analysis of property-level soil lead tests has led to understanding of where lead exposure is greatest: nearer the foundation of the home (termed the *dripline*) and the region closest to the street (Mielke 1994; Schwarz et al. 2013).

Geographers and geographic methods have contributed many notable works to the urban lead exposure–social justice debate (Leech et al. 2016). The spatial distribution of soil lead concentrations has been mapped for several cities including Baltimore, Maryland (Mielke et al. 1983; Schwarz et al. 2013); New Orleans, Louisiana (Laidlaw et al. 2005; Mielke et al. 2013); Syracuse, New York (Griffith et al. 1998; Johnson and Bretsch 2002); Indianapolis, Indiana (Laidlaw and Filippelli 2008; Morrison et al. 2013); and Toledo, Ohio (Stewart et al. 2014). Results of these studies demonstrate that soil lead concentrates in the center of cities (Mielke et al. 1983) and in older neighborhoods (Griffith et al. 1998; Levin et al. 2008; Mielke, Gonzales, and Mielke 2011). For example, a profile of soil lead in New Orleans demonstrated not only the variability in soil lead from an urban center to the suburbs but also how the pattern of soil lead varied on individual properties along that continuum (Mielke 1994). In the city center, the highest values were found near building foundations, as compared to the street. The values were almost equivalent in the midcity and reversed in the suburbs (Mielke 1994). Also in New Orleans, Zahran et al. (2013) found that soil samples taken within one meter of residential and busy streets can be used to proximate exposure to environmental lead in the same way that age of housing is used as a proxy.

Social Risk Factors

Children most at risk for lead poisoning are younger than six (especially under three years old), from a racial-ethnic minority group (Lanphear, Weitzman, and Eberly 1996; Oyana and Margai 2010), in a recent immigrant or refugee family (Caron and Tshabangu-Soko 2012; CDC 2015), from a limited-income home (Kaplowitz, Perlstadt, and Post 2010; Ziven and Neidell 2013), have a sibling with a previous EBL (CDC 2015), are living in a rental property (Miranda, Dolinoy, and Overstreet

2002; Lanphear, Hornung, and Ho 2005), and have a parent's occupation linked to lead exposure (CDC 2015). Other aggregate risk factors are poverty level (Miranda, Dolinoy, and Overstreet 2002; Vivier et al. 2011), income (Kim et al. 2008; Zivin and Neidell 2013), and educational attainment (CDC 2014).

Spatially dependent environmental risk factors for lead poisoning include residence or substantial time spent in a home or location built before 1978 (Reissman et al. 2001; Kim et al. 2008), residence in a poorly maintained property (Lanphear, Hornung, and Ho 2005), residence in a home or location with pipes with lead (Hanna-Attisha et al. 2016), living near an active or former lead industry (Taylor et al. 2013), living near heavily trafficked roadways (Schwarz et al. 2012), living in an inner-city area (Mielke et al. 1983; Levin et al. 2008), residential density of the city, and ambient air lead (Johnson and Bretsch 2002; Laidlaw et al. 2012). In a review of twenty-three research articles using geographic information systems (GIS) to model childhood lead poisoning from 1991 to 2012, however, the most commonly cited risk factor was age of housing (Akkus and Ozdenerol 2014).

GIS in Research and Public Health Practice

Due to the ability to map many of the previously identified social risk factors, public health practitioners often use GIS to inform lead testing programs and prioritize blood screening (Schwarz et al. 2013; Ohio Department of Health [ODH] 2014). Many predictive models used to inform these choices, however, are predicated on age of housing as the only environmental risk factor based on the knowledge that residences built before 1978 and, more specifically, 1950 pose an increased risk due to the deterioration of lead-based paint (Reissman et al. 2001; Oyana and Margai 2010; ODH 2014). Given the ubiquitous number of homes built before 1978 in many older urban areas, housing age alone does not identify populations currently at risk. An age-based predictive approach also fails to take into account lead in soil as a pathway of exposure, which poses an equal, if not greater, risk through contribution to lead dust (Mielke et al. 1997; Laidlaw et al. 2014).

Although some models use point-level geocodes of residences where a child has had an EBL (Griffith et al. 1998; Oyana and Margai 2010), many models assess risk using aggregate geographies, such as by census tract or ZIP codes (Krieger et al. 2003; Kim et al. 2008; Kaplowitz, Perlstadt, and Post 2010). These aggregate-level analyses are beneficial in that they are cost effective and overcome challenges associated with the collection of fine-scale environmental data, although this scale of analysis also has several limitations (Kaplowitz, Perlstadt, and Post 2010: Oyana and Margai 2010), not least of which is the ability to effectively target intervention.[1]

Contextual Understanding through Geospatial Technologies

New field-based geospatial approaches can be used to help further inform the complex risk pathways leading to exposure. Here we use building-scale visuals as a proxy for risk and institutional knowledge to contextualize these data using spatial video and spatial video geonarrative (SVG). Spatial video has previously been used to conduct street-scale audits of the built environment, often for multiple time periods, providing previously unavailable data and temporal changes in those (Mills et al. 2010; Curtis and Mills 2012). In addition, SVG adds to the body of work that employs the tools of narrative analysis (Kwan and Ding 2008; Hawthorne and Kwan 2013) to visualize institutional knowledge of experts to help provide historical and practical context to exposure landscapes (Curtis et al. 2015; Curtis et al. 2016). Case studies of previous uses of SVG to add insight include the psychopathology of microspaces in postdisaster environments, multiple perspectives on neighborhood factors affecting health in contested spaces, the mapping of institutional knowledge of health professionals, and sensitive and high-risk populations that are challenging to study, such as the homeless and sex workers (Curtis et al. 2015). More recently, spatial video and SVG were incorporated in an exploratory analysis to elucidate contextual factors and multiple perspectives influencing the crime–health nexus of nested geographies: a microscale hot spot and its surrounding neighborhood. Analysis revealed the necessity to investigate the microscale and multiple on-the-ground perspectives, including neighborhood institutional knowledge, when conducting research and developing interventions (Curtis et al. 2016).

In a precursor project to this article, our team attempted to spatially prioritize lead exposure risk within a neighborhood in Cleveland where soil lead levels had previously been found to be five times above the acceptable levels for play (Cleveland Department of Public

Figure 1. Example of visual characteristics: deteriorated (peeling) paint, evidence of renovation, exposed soil, and neglect (boarded windows). (Color figure available online.)

Health 2012; "Ghost Factories" 2012), by developing an ELI using visual characteristics of properties such as peeling paint, exposed soil, evidence of renovation, and signs of neglect (boarded windows), as shown in Figure 1. Consultation with an environmental health professional with extensive experience in lead risk assessment helped determine the categories as input for the ELI. This exercise was purely exploratory, as a lack of EBL address-scale data meant no ability to validate the results.

The value of developing such a fine-scale tool is that the typical health approach to reducing lead exposure is reactive. For children of at-risk families moving into an older neighborhood, especially into a rental property, there is little guidance for finding locations that are lead safe. The first and only indicator is when an EBL is recorded during screening. If the child is not screened, there is little to no intervention that can occur. Screening is provided by the health care provider at the point of care. Although children on Medicaid are scheduled to undergo blood lead testing at twelve and twenty-four months, responses to screening questions determine whether a health provider tests non-Medicaid children and all children older than twenty-four months. Under the current protocol, blood lead levels above 5 μg/dL initiate a public health response, which includes a risk assessment to determine the source of exposure. Intervention methods include one or more of the following: education in lead reduction practices, abatement of home,[2] and medical treatment if necessary.

Most worryingly, in the study setting presented here, even if a child is found to have an EBL and then the family moves, there is no mechanism to identify the property as being at risk for subsequent renters. The rationale for developing the ELI was to redress this social injustice by helping inform those most at risk and the professionals providing assistance.

Here we further the evolution of this approach for another typical older northeastern neighborhood by this time including address-level blood level data. The study area is a neighborhood in Akron, Ohio, a metropolitan area with a population of approximately 200,000 (U.S. Census Bureau 2010). As with many older U.S. cities, Akron also suffers from an unevenness in diagnosis; lead blood tests were completed for only 5,800 of the 38,000 (15 percent) children estimated to be at risk in 2010 (ODH 2014). The neighborhood of study, however, has a disproportionate number of lead tests, as approximately 500 refugees have been resettled here each year since 2008 (International Institute of Akron [IIA] 2014). The majority of the refugees are from countries in eastern Asia, including Bhutan, Nepal, and Burma; a minority are from Iraq and Afghanistan (IIA 2014). Even after initial placement, resettled families tend to stay proximate to the study neighborhood. Therefore, our study neighborhood contains multiple risk factors, including age of housing, renters, a refugee population, and families living with limited means, although arguably, children in the neighborhood are oversampled because of their refugee status, giving us more points of comparison.

Data and Methods

Electronic Health Data

Individual patient blood test results were extracted from the Akron Children's Hospital EMR system from June 2012 through December 2014.[3] Lab results are entered into the EMR by personnel at the hospital's lab as soon as they are available. The lab performs the analysis of blood lead samples for the hospital, all of the associated health centers, and other local health providers; the authors are not aware of other labs within the study area that are using this analysis method. A confirmed EBL in this study is a test result above 5 μg/dL. Results above 10 μg/dL are analyzed twice for confirmation.

For each patient, extracted records include a medical record number, current patient address, sex, date of birth, date of lead test, lead test result, address at the time of lead test, race, and language spoken. The initial query yielded 15,024 records. Multiple lead test results were provided for each patient in addition to addresses at the time of the lead test. To count each patient once in the analysis and to ensure the respective address was selected for geocoding, the number of lead tests was tallied for each patient. Of the 12,233 unique patients, 81 percent had one lead test, and 17 percent had exactly two. The remaining 2 percent had between three and eight test results. For patients with more than one test, only the highest blood lead value was included. In the case of two or more equivalent lead test results, the earliest test date and the relevant address at the time of the lead test was used for analysis. The majority of these duplicate test results are confirmations of the first test, conducted within a week of each other. In the case of identical EBL test results, we selected the result with the earliest date to capture the address associated with the initial test of an EBL. The patients with three or more test results are most likely due to the periodic testing after the initial EBL, above 10 μg/dL, to evaluate whether or not the measures taken to reduce blood lead were effective.

Patient addresses were geocoded using street reference files through an Address Locator in ArcGIS Software, Version 10.2 (ArcGIS 2013) with a match rate of 91.2 percent. Efforts to correct for errors in the addresses and hand-matching yielded an additional sixty-five geocoded addresses. Descriptive statistics, measures of disease burden, and a measure of association were calculated with SAS software, Version 9.3 (2013). Prevalence was calculated for the sample population as well as the following strata: age, sex, race, language spoken, and residential mobility. For race, language spoken, and residential mobility categories, relative risk (RR) values were calculated by comparing within strata prevalence ratios to the reference value.

Cluster analysis of geocoded EBL tests was completed using the ArcGIS Kernel Density Estimation (KDE) tool. Spatial analysis methods in previous studies using geocoded addresses of lead test results incorporate interpolation (Oyana and Margai 2010), Moran's *I*, or local indicators of spatial autocorrelation (LISA; Hanchette 2008; Oyana and Margai 2010). These studies aggregate the point-level data to a polygon unit, such as blocks (Oyana and Margai 2010), block groups (Oyana and Margai 2010; Vivier et al. 2011), census tracts (Oyana and Margai 2010), and counties (Hanchette 2008), before analysis. In this article, we retain the granular data to conduct analysis at the house level and link EBL status with housing characteristics. Therefore, the scale of data analysis necessitates the retention of point-level data and the use of KDE. No weighting was used in KDE, and a consistent classification scheme, quantiles, was applied to each KDE raster, which engenders comparison among the maps. The geocoded addresses were also analyzed for repeat offenders, meaning addresses associated with more than one patient EBL. For each address set, dates of the lead tests were compared to determine whether the lead tests occurred within a three-month time frame that might indicate a sibling exposure.

Spatial Video Geonarrative

The process of collecting spatial video and the potential applications have been presented elsewhere (Curtis et al. 2015). Here four Contour 2+ high-definition cameras, two mounted on each side of a motor vehicle, were used to survey the study neighborhood. In addition to a 270° angle of the view, the cameras have an internal Global Positioning System (GPS) that attaches a coordinate to every second of the video. Given the location recorded by GPS, environmental attributes are coded into a GIS for map analysis and visualization. In effect this allows for new perspectives of the built environment, especially within EBL hot spots. For this study, SVGs were also completed with two professionals with experience in lead assessment and abatement in May and June 2015 (Curtis et al. 2015). SVG involves the concurrent recording of (1) an interview conducted while the participant directs the travel route through the study area and (2) the environment through spatial video. Given the intended usage of the SVG to inform the ELI as a proof-of-concept, the coded content was reviewed for descriptions of properties that indicated a potential for lead poisoning. The video from these locations was analyzed for evidence of ELI variables.

Environmental Lead Index

Spatial video used for coding the study neighborhood was collected in February 2013. Each property in the video, corresponding to 1,639 parcels, was assessed for eight ELI variables and coded 0 (*not present*) or 1 (*present*) in a GIS. Parcels excluded from coding include commercial properties and apartment complexes. The ELI was summed for the number of variables on each parcel, and at this point each variable is given equal weight. Given the possibility that a property might have been abated for lead, only EBL results after the video collection date were used for comparison with the ELI variables. Two additional analyses, using SAS, compared (1) the difference in mean ELI value (*t* statistic) for parcels with an EBL and those

Table 1. Descriptive statistics and prevalence of elevated blood lead

Variable	*N*	% Total	EBL	Prevalence (%)
Sample	12,233		439	
Age				
12 months and under	1,375	11.2	16	1.2
12–23 months	6,279	51.3	157	2.5
24–35 months	2,193	17.9	133	6.1
36–47 months	855	7.0	58	6.8
48–59 months	903	7.4	42	4.7
60–71 months	335	2.7	18	5.4
6 years and over	293	2.4	15	5.1
Sex				
Male	6,386	52.2	254	4.0
Female	5,847	47.8	185	3.2
Race				
African American/black	3,677	30.1	149	4.1
American Indian/Alaskan Native	11	0.1	0	0.0
Asian	698	5.7	65	9.3
Hawaiian and Pacific Islander	5	0.0	0	0.0
Hispanic	193	1.6	7	3.6
Middle Eastern Indian	159	1.3	12	7.5
Other	263	2.1	15	5.7
Unknown	367	3.0	7	1.9
White or Caucasian	6,860	56.1	184	2.7
Language spoken				
Arabic	68	0.6	4	5.9
Burmese	69	0.6	4	5.8
English	11,201	91.6	345	3.1
Karen	113	0.9	12	10.6
Nepali	361	3.0	53	14.7
Spanish	142	1.2	4	2.8
Address change				
	8,637	70.0	351	4.1

Note: Languages listed are those with more than 10 patients. EBL = elevated blood lead.

with a lead test result under 5 μg/dL (non-EBL) and (2) the difference in proportion (z statistic) for each ELI variable between EBL and non-EBL parcels.

Results

Epidemiological Analysis

Table 1 provides descriptive statistics and stratified prevalence for the study population. The results show categories of age, sex, race, language spoken, and residential mobility, defined by an address change. The columns show the number of patients within each subgroup, the number of patients with an EBL, and the prevalence of an EBL. Of the 12,333 patients with a lead test result, 439, or 3.6 percent, had an EBL. Study population blood lead values ranged from 1 to 45 μg/dL, with an overall mean of 8.3 μg/dL and a standard deviation of 5.6 μg/dL.

The age ranges with the highest prevalence of EBL were thirty-six to forty-seven months with 6.8 percent and twenty-four to thirty-five months with 6.1 percent. The next highest were (by percentage) sixty to seventy-one months (5.4), six years and over (5.1), forty-eight to fifty-nine months (4.7), and twelve to twenty-three months (2.5). Prevalence in boys was higher than in girls, with 4.0 percent and 3.2 percent, respectively. Fifty-six percent of the study population were white or Caucasian, but the prevalence among whites, 2.7 percent, was under the average for the population. Among the nine races or ethnicities present in the data, Asians had the highest prevalence of EBL, 9.3 percent, even though they only comprised 5.7 percent of the study population. Prevalence among African Americans was also higher than the study average, with 4.1 percent. Prevalence among the other identified races of children with EBL, Hispanic (3.6 percent) and Middle Eastern Indian (5.7 percent), were present in small numbers.

Thirty-one languages were identified among the patients; the six shown in Table 1 were spoken by ten or more patients. The language spoken variable serves as a proxy for resettled refugees given the absence of such designation within the medical record. English speakers accounted for 91.5 percent of the study population and 78.6 percent of children with EBL. Speakers of Nepali and Karen had the highest prevalence, at

Table 2. Relative risk for selected race, language, and residential mobility

Variable	*N*	EBL	RR	95% CI
Race				
White or Caucasian	6,860	184	[a]	
African American/Black	3,677	149	1.51	[1.22, 1.87]
Asian	698	65	3.47	[2.65, 4.56]
Language spoken				
English	11,201	345	[a]	
Nepali	361	53	4.77	[3.64, 6.24]
Non-English	1,032	94	2.96	[2.38, 3.68]
Address change				
No	3,596	88	[a]	
Yes	8,637	351	1.66	[1.31, 2.10]

Note: EBL = elevated blood lead; RR = relative risk; CI = confidence interval.
[a]Reference value.

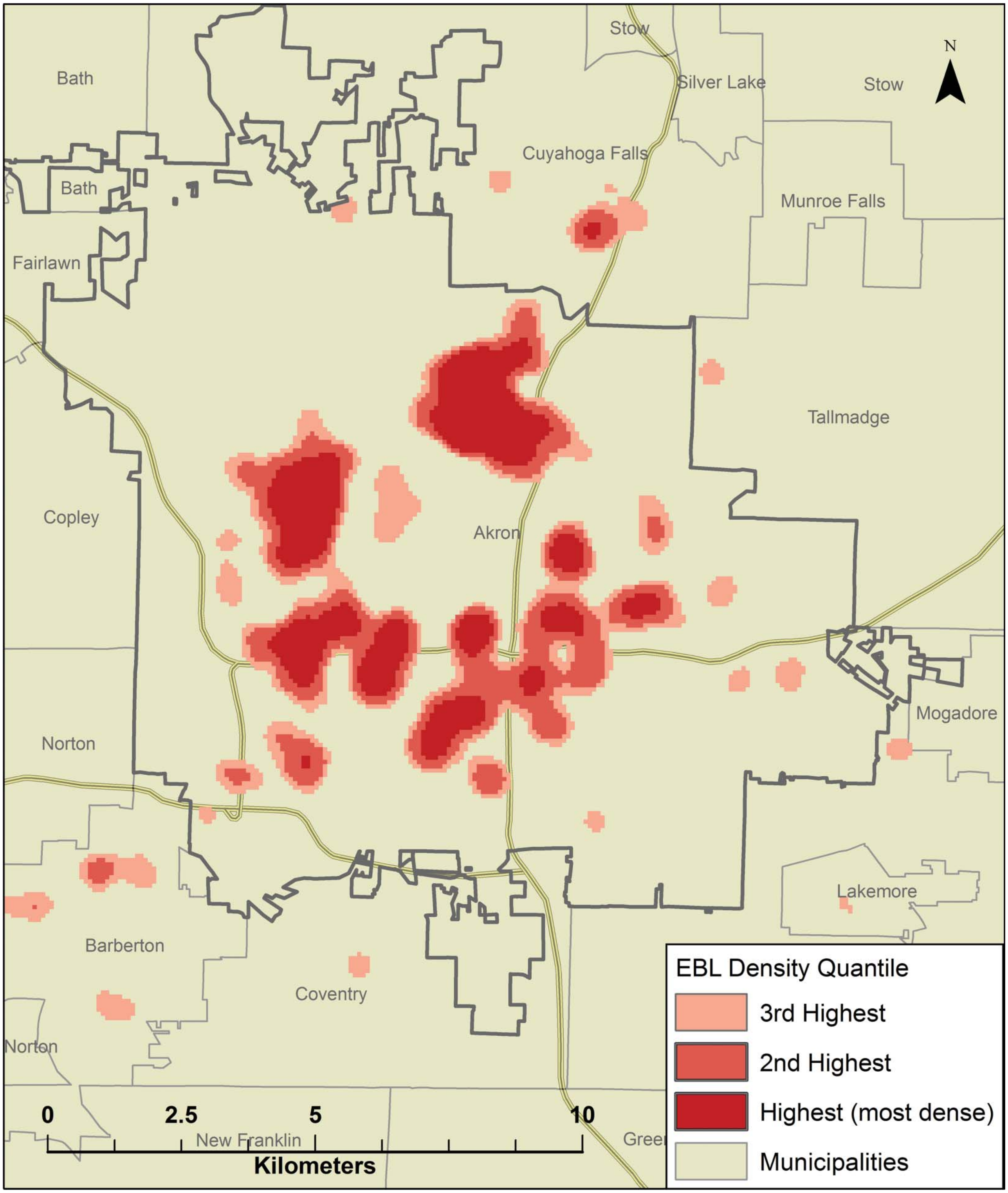

Figure 2. Kernel density estimation of elevated blood lead test results for 2012 to 2014. EBL = elevated blood lead. (Color figure available online.)

14.7 percent and 10.6 percent, respectively. The small sample of Karen speakers might have affected measures of association, however. Likewise, the speakers of Arabic, Burmese, and Spanish had very small numbers.

A change of address was documented for 70.6 percent of the study population. Of children with an EBL, 79.9 percent had more than one address, with a prevalence of 4.1 percent.

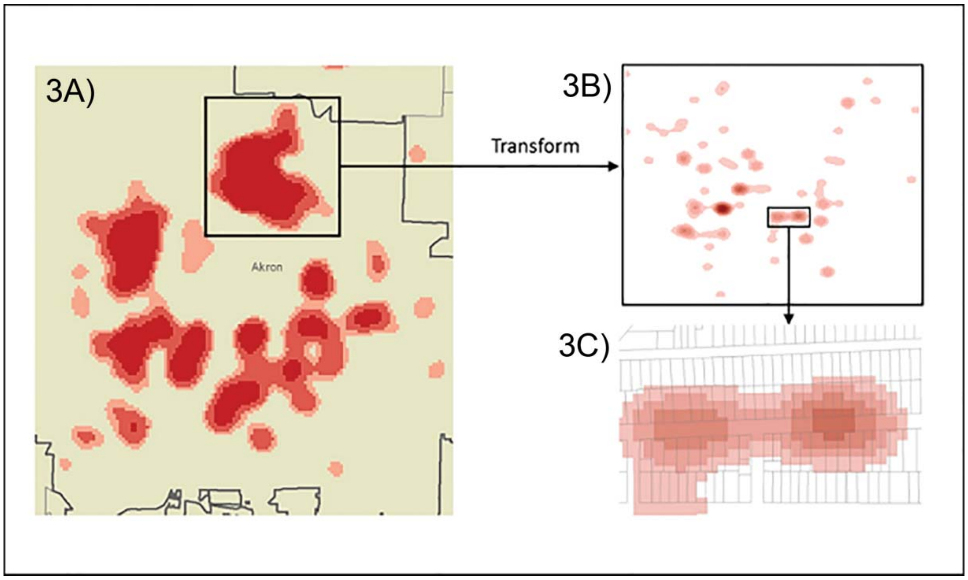

Figure 3. (A) Kernel density estimation of a cluster to identify smaller clusters. (B) Fine-scale clusters have been transformed to maintain confidentiality. (C) Street segment cluster is the result of seven elevated blood lead test results. (Color figure available online.)

Table 2 provides an RR measure of association for strata-specific prevalence ratios for the study population. As compared to whites, African Americans were 1.5 times more likely to have an EBL, and Asians were 3.4 times more likely. Nepali speakers were 4.8 times more likely to have an EBL as compared to English speakers. Collectively non-English speakers were nearly three times more likely to have an EBL. Children with a change of address were 1.6 times more likely to have EBL levels.

Spatial Patterns of EBL

KDEs of the geocoded addresses of patients with an EBL are shown in Figure 2. Despite two small clusters southwest and northeast of Akron, the majority of clusters are within the city of Akron, forming a ring around the city center. The large cluster in the northeast section of Akron is concentrated over our study neighborhood in the northern section of the city, whereas the clusters along the southeast are smaller and more dispersed. Likewise, the western clusters span several neighborhoods. At a neighborhood level, the KDE clusters provide insight into the overall EBL burden. To understand the construction of those hot spot areas and guide intervention, however, more granular analyses are required, as seen in Figure 3.

Figure 3 shows the results of KDE using the extent of the northern cluster (Figure 3A) after a transformation process (Figure 3B) to ensure patient confidentiality.[4] The fine-scale KDE reveals clusters that correspond with street segments and blocks. The street cluster in Figure 3C is the result of seven EBL results at six addresses with EBL test results; one address is geocoded for two EBL over a year apart. Analysis of the geocoded addresses identified twenty-six properties that are listed for more than one patient. Twenty-four of these correspond to two patients, but one apartment building provided housing for five children at the time of each of the lead tests. The dates of the lead tests were reviewed to determine whether multiple patients at one address were tested within three months of each other. These properties were excluded because they likely indicate a sibling who was tested, which just confirmed the exposure of a brother or sister. Six of the properties had lead tests completed over a year apart, implying a potential change of residents. Nevertheless, an interval of a year would allow for a clearing of the home as lead-safe following the abatement process.

To ascertain whether age of housing constitutes an appropriate proxy for risk of an EBL, a contour of the KDE clusters is layered over Akron parcels coded by housing age in Figure 4. As mentioned previously, approximately 85 percent of housing stock in Akron was built before 1980 (U.S. Census Bureau 2010). Figure 4 shows EBL clusters surrounding the city center and possible cold spots around the fringe despite similar age of housing. This pattern might indicate a bias of oversampling for certain populations, such as resettled refugees.

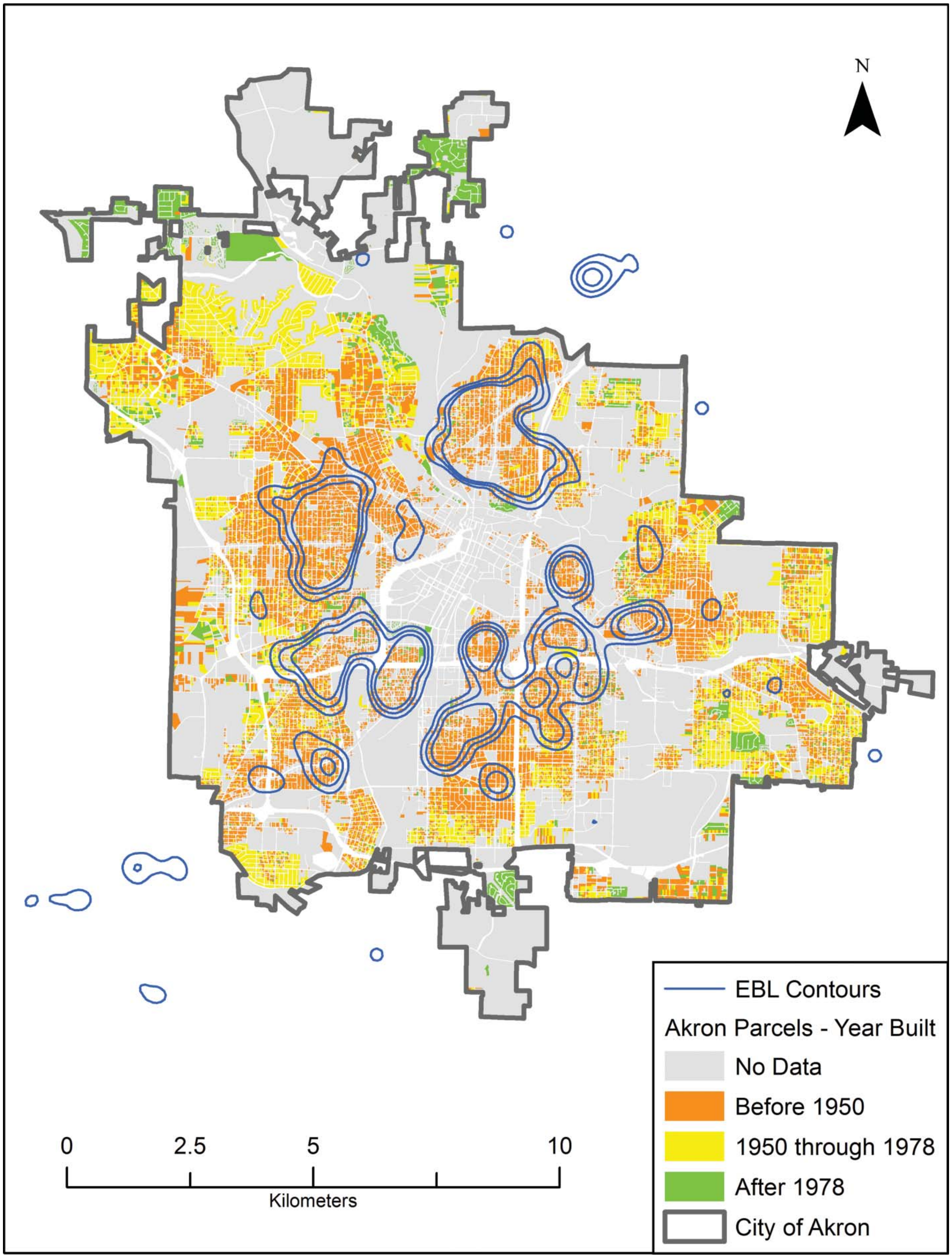

Figure 4. Contour of kernel density estimation clusters and housing age. EBL = elevated blood lead. *Source*: Parcel data from the City of Akron Property Tax Assessor, 2015. (Color figure available online.)

SVG

Transcriptions of the two SVG drives with environmental health professionals were analyzed for spatial references and content related to environmental lead. The participants provided professional insight into visual features that signify the potential for lead exposure. Content analysis of descriptions for sixteen properties identified five features that were mentioned repeatedly: peeling paint, original features, exposed

Table 3. Spatial video geonarrative characteristics of properties indicative of environmental lead

Characteristic	Properties
Peeling paint	16
Original features	15
Exposed soil	12
Water damage	11
Gravel driveway	6
Dripline exposed	5
Play space	5
Gardening activity	3

soil, water damage, and gardening activities (food source).[5]

Informed by the institutional knowledge of the participants, the spatial video of the sixteen properties was reviewed for these characteristics as well as three others: presence of a gravel driveway, exposed dripline next to the house, and evidence of children at play. Table 3 provides a count of the number of the described properties with each of the characteristics viewed during the SVG rides.

Environmental Lead Index

Seven of the eight variables identified through the SVG constitute the ELI variables used to code spatial video collected within the northern EBL cluster. The dripline variable was removed from coding, as it is not usually visible for most houses due to the height and angle of the camera during video capture. As shown in Table 4, of the 1,639 coded parcels, 164 have at least one geocoded blood lead test result, and 33 (or over 15 percent) of these are an EBL.[6] The ELI range is greater for the non-EBL parcels, but there are no EBL parcels with a zero ELI value. The ELI mean for the coded parcels, non-EBL and EBL, are 2.08 and 3.09, respectively. The results of a t test for independent sample means demonstrate that this difference is statistically significant (p value = 0.05).

As shown in Table 4, the proportion of each ELI variable varies between non-EBL and EBL parcels. Yet, the ordering of the ELI variables by proportion is identical and closely resembles the SVG analysis, with the exception of water damage. This might be due to the fact that visual indications of water damage are often along the rooftop and gutter, which might not be easily detected depending on camera angle, height, and distance from the house. Six variables coded for EBL parcels are present at a greater percentage as compared to non-EBL parcels, with the exception of no instances of garden among EBL parcels. The results of tests for difference between sample proportions are statistically significant (p value = 0.05) for four variables: peeling paint, original features, exposed soil, and gravel driveway.

Discussion

The best scenario for primary prevention is the provision of a lead-safe environment through housing and properties devoid of sources of environmental lead (AAP 2016). Achieving this would require testing for lead among the majority of the housing stock in an older urban area and abating properties with lead in paint, dust, and soil. This task would require signifi-

Table 4. ELI components for parcels with a lead test

ELI variables	Non-EBL	%	EBL	%	z score[a]	p value*
No. of parcels	131	79.9	33	20.1		
ELI range	0–7		1–6			
ELI M (SD)	2.08 (1.3)		3.09 (1.2)		3.85	*
Peeling paint	72	55.0	26	78.8	2.49	0.013
Original features	63	48.1	24	72.7	2.53	0.011
Exposed soil	60	45.8	23	69.7	2.45	0.014
Gravel driveway	40	30.5	17	51.5	2.26	0.024
Water damage	17	13.0	8	24.2	1.61	0.107
Play space	11	8.4	3	9.1	0.13	0.897
Garden	1	0.8	0	0.0	Not calculated	Not calculated

Note: ELI = environmental lead index; EBL = elevated blood lead.
[a] t test was used for difference between means; F test was used for the difference between.
*p significant at 0.05.

cant resources in the form of time, personnel, and especially finances. In the absence of funding and political will to make this possible, many communities have relied on the practice of using elevated blood levels in children to identify homes to "treat" by means of abatement and remediation (AAP 2016). Although this process ensures a safe environment moving into the future, albeit one house at a time, it does nothing to prevent exposure for families living in other homes. Furthermore, given the high proportion of renters in the study population, there is the potential for reexposure when a family chooses to relocate.

This study presents a fine-scale investigation of childhood lead poisoning using a mixed-methods approach that enhances analysis of EBL data from an EMR system through the addition of environmental assessment, incorporating both statistical and spatial analyses. More important, through the inclusion of SVG and spatial video, we have developed a tool that identifies properties that pose a risk of lead, before exposure occurs, which provides a means of primary prevention.

The results of the statistical analysis of EMR data corroborate the findings of previous research but also elucidate the importance of understanding the nuances of the underlying sample population. The prevalence among the study population, 3.6 percent, is consistent with the 2013 national average of 3.7 percent (CDC 2014) and is the same as the reported rate for Summit County, but it is less than the overall rate for Ohio of 5.4 percent (ODH 2014). Results of the stratified analysis of prevalence by age, sex, and race, and increased likelihood of an EBL among racial minorities and refugees are congruent with commonly cited risk factors of an EBL. Few studies have considered residential mobility as a risk factor; further research regarding both the contribution of residential mobility to EBL and a change in residence resulting from a discovery of lead exposure is needed considering increased mobility of families might signify financial stress or other crises (Van Vliet 1986; Hagan, MacMillan and Wheaton 1996), which would enhance understanding of context of individual lead poisoning events.

Despite a comprehensive sample of the patients with a blood lead screening in Summit County, there are some data limitations. Foremost, the data source is a medical record system designed for the purposes of medical assessment and treatment, not research. The race and ethnicity categories within the database are limited and might not accurately reflect the patient population. As such, 630 patients (5.1 percent) did not have a race or ethnicity documented in the medical record. This inconsistency might bias the results of the measures of association. Even so, the increased prevalence among minorities needs further investigation within this population as an issue of environmental justice in that a disproportionate burden of disease is repeatedly found among those of minority race or ethnicity (Leech et al. 2016). The increased prevalence for African American patients in this study supports this. Yet, considering that this subpopulation resides mostly in neighborhoods found in the potential cold spots of older housing, there is the potential for underreporting. The CDC states that the underlying reason for the racial disparities is related to "differences in housing quality, environmental conditions, nutrition and other factors" (ACCLPP 2012, x). The application of the ELI with the locations of EBL will provide a means to confirm the role of housing quality and environmental conditions.

Similarly, the use of language spoken as a proxy for refugee status also might not fully represent the population. The field is reliable, however, given that it is used to inform health providers of the need to provide interpretive services. In consideration of the desire for primary prevention of lead poisoning, this amount of language and cultural diversity speaks to the importance of culturally relevant health communication among a diverse patient population. Provision of health education to speakers of thirty-one different languages is a challenge to the health care and public health system in Summit County, especially considering that several languages had low numbers.

In addition, the increased prevalence among Nepali and Karen speakers and higher RR among Asians and Nepali speakers, as compared to whites, could be indicative of an oversampling of the refugee population. As part of the resettlement process, each refugee gets a health exam, which for children includes a blood lead level test. Despite the inclusion of refugee status as a risk factor (CDC 2005), in this study the screening rate among this population might be higher than the screening rate for nonrefugee children, which will overestimate the prevalence ratios. The ODH (2014) estimated that in 2012, only 15.2 percent of children considered at risk for lead poisoning were screened. Even among Ohio Medicaid children eligible for blood lead screening through the Early Periodic Screening, Diagnostic and Treatment (EPSDT) program, the testing rate for children twenty-four months and under in 2014 was 41.0 percent (Medicaid 2015).

Despite this, the periodic testing required by Medicaid might result in increased capture of EBL among this population as compared to non-Medicaid patients. This low screening rate could partially explain the possible cold spots of EBL in areas of older housing seen in Figure 4. As mentioned previously, other sources of exposure could contribute to clusters such as occupational exposure (Levin et al. 2008; CDC 2014), cultural practices (CDC 2005; Levin et al. 2008), and daily activities away from the home.

One of the challenges to connecting environmental exposures to health outcomes is temporality, or changes in residential location over time. Although this study benefits from previous known addresses within the EMR data, such as the address at the time of the lead test result, there are limitations in the ability to infer causality. First, each address for a patient has an associated date range. A change in patient address is initiated and completed during registration for a visit within the hospital network. Similarly, each lead test has an associated date. In this study, one assumption is that exposure to lead occurred at the address associated with the highest lead test date, which is consistent with other research (Kim et al. 2008; Kaplowitz, Perlstadt, and Post 2010). Given the understanding that lead circulates in blood for approximately three months, this reasoning might be faulty. Furthermore, the child or family might have relocated one or more times before the lead test but did not have an encounter with the health system that would have prompted a change of address within the EMR. Having multiple addresses with dates of residency, however, does provide a means to identify potential sources of exposure from previous addresses. The analysis in this study was limited to looking at the addresses at the time of the highest lead test result, but a future direction is to look at repeat addresses among multiple children, regardless of magnitude of the lead test result, to determine contribution to an EBL in one or more children.

In the identification of properties that contribute to lead exposure in children of multiple families, analysis used a greater than three-month cutoff between lead tests to eliminate the inclusion of sibling exposures. Despite the potential of multifamily living situations, our assumptions are that (1) only one family is living on the property at a time and (2) a nuclear family is going to relocate together. These assumptions lower our estimations, especially when the three-month time frame includes one family moving in and another moving out. Further efforts will investigate the role of houses contributing to multiple exposures due to residential mobility.

Spatial Analysis

In this study, geocoded addresses associated with an EBL were mapped and analyzed for clusters. Given the use of the highest lead test value, the mapped locations and clusters represent the locations that are most likely to have contributed to an EBL in the study population. The assumption is that the EBL was a result of an environmental source of lead; however, exposure to alternative lead sources such as parental occupational exposure to lead (CDC 2005; Levin et al. 2008); cultural practices that include substances containing lead such as jewelry, cosmetics, or dishware (CDC 2005; Levin et al. 2008); or exposure from a location or source apart from the residential address could be possible. Interestingly, the mapped EBL clusters for Summit County are consistent with the results of mapping the levels of lead in soil found in other urban areas; the clusters of EBL are found closer to the city center and decrease toward the fringe (Mielke et al. 1983; Levin et al. 2008; Stewart et al. 2014). Other researchers have pointed to the increased number of roadways and potential for exposure from the fallout of leaded gasoline (Levin et al. 2008; Schwarz et al. 2012), which can contribute to the locations of the EBL clusters as compared to housing age in Figure 4. Further exploration of the role of roadways needs to be explored.

Density analysis at a finer scale (Figure 3) reveals that there are pockets of EBL. Consequently, the geocoding of test results in the northern cluster for spatial video coding reveals an increased prevalence of EBL, 15.7 percent, as compared to the Summit County prevalence of 3.6 percent. This could be associated with aspects of housing and environmental conditions, or considering the increased prevalence among the resettled refugee population this effect might be the result of behaviors, such as a preference to live near other refugees. Further analysis of spatial distribution of lead exposure and residential segregation incorporating spatial statistics is needed to further delineate the underlying reasons for the spatial patterns.

Similarly, mean EBL (and standard deviation) among the ELI coded parcels was lower than the study population, 6.94 μg/dL (SD = 2.58) and 8.3 μg/dL (SD = 5.6), respectively. This difference might reflect the selection of only one lead test result for each coded parcel regardless of the number of patients with a result associated with the address. Cluster analysis completed for the whole study area selected one test value for each patient but includes results for multiple patients at each address. The result for the coded parcels reflects decreased variability, yet spatially specific data. Increased variability among the whole population indicates a need to understand the role of residences in multiple patient exposures, in addition to the role of residential mobility.

SVG

The geonarratives provided by the health professionals access both tacit and institutional knowledge. Many of the comments of the participants were triggered by the environmental conditions in view but reflect knowledge gained from working in the field for years. The narrative content provides greater insight into the actual conditions assessed by professionals during a visual property inspection. Comments regarding peeling paint occurred for all sixteen properties; considered for almost as many was the evidence of original features. Both of these characteristics might correlate with age of housing as a primary risk factor, but exposed soil and water damage do not necessarily correspond with age of housing. Although consideration of lead in soil as a pathway of exposure is one that is supported by other research (Laidlaw and Filippelli 2008; Lucas et al. 2014), the connection between water intrusion and paint flaking is not well documented in the literature. Gardening activities are commonly considered as a means to absorb lead in soil as a form of bio-remediation, but what has not been considered is knowledge among urban residents of soil as a risk factor for lead poisoning and the potential to increase lead intake through residential gardening. Even so, the SVG comment regarding container gardening on porches as a source of exposure signifies the need to think beyond the traditional garden.

ELI

One benefit of using spatial video to document visual environmental characteristics is the ability to perform a precursory desktop assessment of environmental factors. In this manner, the video and ELI are an efficient initial environmental risk assessment triage tool that could be implemented by health departments as a preliminary exposure assessment for an address or clusters associated with an EBL. Conversely, if the video images do not show peeling paint, original features, and exposed soil (and others), this might indicate another source of exposure, such as lead in water. The results of the ELI demonstrate a statistically significant difference between parcels associated with non-EBL and EBL test results for four variables. This implies that the ELI might indicate increased potential for exposure to environmental lead. Future efforts are needed to further validate the ELI through additional coding of parcels in other clusters within Summit County to increase sample size. Additional methods, such as regression, could be conducted to provide insight into how much each variable contributes to the ELI. Further refinement could determine that one or more variables need to be weighted more than others, and additional variables such as lead in water (pipes) could enhance the predictive power of the ELI.

Although the use of spatial video to code the ELI provides greater insight into potential environmental sources of lead, there are limitations associated with using the technology. The EMR data were from June 2012 to December 2014 and the earliest video was from February 2013. Therefore, any blood test results from before February 2013 were not included in the geocoding. In addition, the distance from the road to the housing structure affects the ability to see housing characteristics such as peeling paint. Weather also affects coding quality in that video collected in sunny or slightly overcast conditions is easier to code. The video was collected on a sunny February afternoon, which provided ample light but, given the season, might not provide data for two variables in particular: gardens and play spaces. The absence of leaves, however, increased ability to see water damage and peeling paint on roofs and second-story features. Other limitations of the ELI include alternative sources of lead exposure such as property characteristics not visible from the street and conditions inside the home such as paint chips, dust, and lead in pipes. Similarly, diet and nutrition, cleaning practices, duration of exposure to lead, and exposure from previous locations and time periods are also important considerations. Even with limitations, though, what is proposed here is still an advance on a purely reactive lead surveillance system.

Applications

The outcomes of this study have several practical applications that enhance current response practices and advance primary prevention practices. The use of individual-level EMR data as a basis for cluster detection increases accuracy of disparate levels of lead poisoning among racial groups and ethnicities, including refugee populations through the use of a data proxy. This knowledge can be used to design interventions relevant to these subpopulations. For example, interventions at the neighborhood (or subneighborhood) scale can reflect the nuances of the at-risk population, such as culturally relevant messaging. Partnering with neighborhood-level resources would enhance outreach and message delivery. Conversely, the absence of clusters in areas of older housing informs health professionals of the need to determine why this paradox exists. These areas might need increased outreach, screening, and education, or perhaps there is an effective strategy in place.

Efforts to provide safe housing can also benefit from the results of this study. Fine-scale clusters signify areas in which to focus abatement efforts. Whether due to location preference of the at-risk population or housing characteristics that increase exposure, the clusters represent concentrated areas that can be prioritized for abatement. Several of the observed clusters are the result of one property, such as a multifamily residence, which will ideally undergo abatement for the entire property. Where one residence is associated with multiple children with an EBL, reminding landlords of the requirement to inform residents of the presence of lead and the available resources related to lead abatement can reduce future lead exposure. In this regard, this geographic method should absolutely be considered a tool to address the issue of social injustice found in many older U.S. neighborhoods.

In this article we use knowledge of addresses associated with EBL to test the ELI, which identifies homes that pose a risk based on a comprehensive list of external property characteristics, one being peeling paint. The ELI serves as a screening mechanism to identify risky properties and, consequently, this knowledge can be used at various scales, when put into action. A registry of property ELI scores empowers residents looking to rent or purchase and community organizations active in housing placement. Similarly, agencies receiving federal funds for housing development and improvement can use the ELI to assist with prioritization of homes to test and abate to maximize the impact of tight resources, before a lead poisoning event occurs. Likewise, knowledge of risky properties can be used by stakeholders involved in housing remediation of other environmental hazards or removal of blighted homes in communities struggling with the negative impacts of abandoned and vacant properties. Finally, the ELI can be integrated with the EMR system to alert health practitioners of patients' residence in a home that might pose a risk. This alert can enhance the traditional screening practice and assist with the crucial transition to a preventive model.

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Notes

1. It should be noted that there are also problems associated with using the residential address for individual-level blood exposure data, such as the uncertain geographic context problem (UGCoP; Kwan 2012), which includes, for example, exposure through the activity space beyond the home residence. Residential mobility can also be a confounder as the exposure might have occurred at a previous residence.
2. Grant assistance through the local health department requires presence of a child under six years old. At-risk populations are identified through the blood lead screening and age of housing (ODH 2014). The health department advertises the available grant funds through various outreach activities.
3. Institutional review board approval was provided before data extraction was initiated.
4. The transformation is not reported so as to limit the possibility of reengineering (Curtis, Mills, and Leitner 2006).
5. Examples of comments related to each of these characteristics are as follows:

   Peeling paint
   Lead paint has a very distinct way of deteriorating. . . . Lead paint has a very blocky, it almost looks like alligator skin. If you look across the top of the ceiling where the house numbers are, see where it is really blocky.
   Like that one right there, you can tell. For sure. See the posts on the front? That is typical lead paint, very blocky.

Original features
I can tell by the old components that they have. . . . That lattice is original lattice.
Whatever was painted when they built the house in 1947 would be lead paint. They have newer aluminum windows, but they didn't change the trim.

Exposed soil
And the other issue for the home is the bare dirt, because over the years chips have fallen in the dirt. The dog walks through that, so the dog can bring that in to the living room.

Water damage
And that is water damage. Because the gutters are overflowing. You don't see any downspouts. So that is the beginning of paint issues, the water. . . . The leaks start the ceiling paint flaking, which is a hazard because when you walk across it, it pulverizes into dust which gets tracked into the house.

Gardening activities
I could easily see how someone could get poisoned there. Growing pots on porch, it is on a leaded porch, so it could easily get dust on it or in the soil.

6. The Summit County prevalence for 2014 is 3.6 percent.

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LAURA SCHUCH is a Doctoral Candidate in the Department of Geography at Kent State University, Kent, OH 44343. E-mail: lschuch@kent.edu. Her research interests include applying geospatial methods to contextualize health challenges, to reduce health disparities, and to develop relevant solutions.

ANDREW CURTIS is a Professor in the Department of Geography and Co-Director of the GIS Health and Hazards Lab at Kent State University, Kent, OH 44242. E-mail: acurti13@kent.edu. His research interests include the mapping and analysis of problems in challenging environments using novel granular "scale of intervention" geospatial solutions. His projects primarily fall in the area of health and hazards.

JOEL DAVIDSON is a General Pediatrician and Clinical Assistant Professor in the Department of Pediatrics at Akron Children's Hospital, Akron, OH 44308. E-mail: jdavidson@chmca.org. His research interests include lead exposure, refugee care, and health care of underserved and vulnerable populations.