Environmental Research 202 (2021) 111642

Contents lists available at ScienceDirect

Environmental Research

journal homepage: www.elsevier.com/locate/envres

Firearm licenses associated with elevated pediatric blood lead levels in Massachusetts

Christian Hoover[a,*], Gabrielle Groth Hoover[b], Aaron J. Specht[c]

[a] Department of Health Policy, Harvard T.H. Chan School of Public Health, Boston, MA, USA
[b] Department of Psychiatry, Massachusetts General Hospital, Boston, MA, USA
[c] Department of Environmental Health, Harvard T.H. Chan School of Public Health, Boston, MA, USA

ARTICLE INFO

Keywords:
Lead
Pediatrics
Firearms
Environmental health
Public health

ABSTRACT

Objective: To determine the association between firearm-related lead exposure and pediatric blood lead levels.
Methods: Using data available through the Massachusetts Departments of Public Health and Criminal Justice Information Services, we examined the association between active class A firearm licenses in a community with the prevalence of elevated blood lead levels in children aged 0–4. Correlational and hierarchical multiple regression analyses were conducted with potential confounders and other exposures such as lead paint, lead in water, presence of firing ranges, and social, economic, and occupational variables.
Results: Data from 351 Massachusetts sub-counties were examined. Sub-counties with higher rates of firearm licensure also report higher rates of lead exposure among children. Children in the highest quartile communities were 2.16 times more likely to have elevated BLLs when compared to their peers in the lower quartiles. A one standard deviation change in firearm licensure percentage was found to reflect a 0.96% increase in elevated pediatric blood lead levels. Regression analyses demonstrated that the inclusion of firearm licensure significantly improved the prediction of pediatric BLL. Models were adjusted for percent of a population employed in construction, agriculture, forestry, fishing, hunting, and mining, income distribution, and potential lead paint exposure, which were found to be the primary predictors of elevated pediatric blood lead levels.
Discussion: Firearm use and ownership remains one of the least researched areas in the public health sphere. While the risks of childhood lead exposure are widely understood, including the mechanisms of firearm-related lead exposure and tracking, to date no research has extensively examined it in children and on the community level. Our findings indicate a dire need for continued research on the risks associated with firearm use, ownership, and lead exposure.

1. Introduction

Lead is a well-known environmental toxicant that has been linked to negative health outcomes such as cardiovascular disease (Navas-Acien et al., 2007), all-cause mortality (Lanphear et al., 2018; Weisskopf et al., 2009) and cognitive deficits across the lifespan (Braun et al., 2018; Farooqui et al., 2017; Power et al., 2014). Exposure sources differ based on age, with children principally exposed through ingestion via hand-to-mouth behavior and adults principally exposed through inhalation (Braun et al., 2018; Landrigan and Todd, 1994; Levin et al., 2008; O'Flaherty, 1999). Children are considered the highest risk population due to lead's increased deleterious effects during development alongside increased exposure through ingestion (Council on Environmental Health, 2016; Wu et al., 2018; Liu et al., 2014). Even at extremely low exposures, lead has been linked to steep declines in Intelligence Quotient scores and serious psychosocial impairments ranging from poor academic outcomes to antisocial behavior (for a review see (Caito and Aschner, 2017; Evens et al., 2015; Lanphear, 2017)).

Previous research focused on five major factors that have been significantly related to elevated pediatric Blood Lead Levels (BLL): paint (Lanphear et al., 2005), water (Brown and Margolis, 2012), soil (Datko-Williams et al., 2014), air (Brink et al., 2013), and tracking from occupational or environmental sources (Dignam et al., 2019). Lead paint was banned in 1978 but remains a significant source of poisoning, impacting low-income communities through older housing stock (Levin et al., 2008). Water, while tightly regulated by the EPA, is nevertheless a

* Corresponding author. Harvard T.H. Chan School of Public Health, 677 Huntington Avenue, Boston, MA, 02215, USA.
E-mail address: CHoover@hpsh.harvard.edu (C. Hoover).

https://doi.org/10.1016/j.envres.2021.111642
Received 1 March 2021; Received in revised form 15 June 2021; Accepted 1 July 2021
Available online 9 July 2021
0013-9351/

well-documented exposure concern (Chowdhury et al., 2018). Contaminated air is primarily the result of emissions from commercial sites (e.g., battery manufacturers, airports) but can also result from disturbing contaminated soil or dust (Brunekreef, 1984). Finally, secondary and tertiary exposures (e.g., lead dust adheres to a caregiver's clothing which a child then touches) are one of the largest contributing factors to pediatric lead poisoning and have been linked to certain occupations (Laidlaw et al., 2017; Centers for Disease Contr, 2012; Indoor Firing Ranges and, 2014a; Gottesfeld and Pokhrel, 2011; Newman et al., 2015; Rinsky et al., 2018). In 2018, an investigation by the CDC found significant tracking of lead from occupational workers at a lead-oxide facility, resulting in increased BLLs in their children (Rinsky et al., 2018). Other research has found similar elevated BLL in children related to lead-tracking from various occupational or community-level exposure sources (Centers for Disease Contr, 2012; Gottesfeld and Pokhrel, 2011). Lead-tracking occurs when lead dust particles adhere to the ground, skin and clothing and are then transported beyond the location where the dust originated; discharge of lead ammunition is a common source of lead dust (Laidlaw et al., 2017). Most occupational risks are well known, do not overlap with recreational activities, and their sources are subject to regulation; yet implementation and adherence remain inconsistent (Koh et al., 2015; Ettinger et al., 2019; Alarcon, 2016).

The CDC compiles national data through their occupational lead monitoring program, but stresses its limitations (Alarcon, 2016). Particularly, there exist large gaps of knowledge, regulation, and efficacy among states (Alarcon, 2016). Given these gaps, it is concerning that one of the greatest sources of lead tracking—the ownership and use of firearms—exists in both occupational and recreational settings, has been well-documented for nearly two decades, and has no federal or state level regulations to reduce or prevent lead-tracking (Laidlaw et al., 2017). Lack of federal funding for firearm-related research further stifles knowledge in this critical area (Rajan et al., 2018).

Lead bullets and primers are used in the United States with no restrictions; the only exception is a complete ban on lead bullets and primers in the state of California, which was implemented in 2013 (Laidlaw et al., 2017; California Becomes First, 2019). When lead ammunition is discharged, dust is inhaled by persons in the vicinity and contributes to primary toxicity (Laidlaw et al., 2017). Secondary and tertiary exposures occur through particles adhering to the ground, skin and clothing (i.e., tracking) (Laidlaw et al., 2017). Firearm-related tracking has been linked to certain types of occupations, such as police officers, hunters, and factory workers (Laidlaw et al., 2017; Indoor Firing Ranges and, 2014a). A 2014 CDC report documented the cases of Firearm-related Lead Poisoning (FLP) between 2002 and 2013. The report cited an alarming number of FLP cases with BLL $\geq$10 μg/dL[25]. There were 2056 physician-mandated reports of occupational FLP in 41 states, with an additional 2673 cases from recreational attendance at firing ranges (Indoor Firing Ranges and, 2014a). In these recreational cases, 48% had BLL $\geq$25 μg/dL[25]. Additional government reports echo the dangers of FLP, especially concerning women due to the capacity for lead to store in bones and subsequently impact fetal development during the increased bone turnover of pregnancy and breastfeeding (Laidlaw et al., 2017; Gulson et al., 1998; Manton et al., 2003; Latorre et al., 2002; Low Level Lead Exposure H, 2012; Nie et al., 2009; Riedt et al., 2009). Unfortunately, most studies focus on firing range attendees despite the risks to pediatric populations through tracking (Indoor Firing Ranges and, 2014a). No research exists that directly examines pediatric FLP on a community level.

The closest literature has come to this is through studies on hunting (Thiboldeaux, 2008). Hunting poses exposure risks via soil, water, and consumption of game (Fustinoni et al., 2017; Mateo et al., 2007, 2011; Tsuji et al., 2008). However, these studies examine only the impact on hunters, not the larger community. One potential reason for this is the impact of politics on firearm research, which for decades received no CDC funding due to the annual inclusion of the Dickey Amendment in relevant legislation, a provision promoted by the National Rifle Association and pro-firearm politicians (He and Sakran, 2019; Galea and Vaughan, 2018; Rostron, 2018). The Dickey Amendment was included in the 1996 U.S. spending bill that prevented any federal funding from being made available to advocate for or promote gun control, which in practice led to a near-complete stifling of firearm-related research (Rostron, 2018).

Data that accurately and objectively measures firearm ownership is sorely missing from current knowledge. Research has been limited in its ability to examine the link between firearms in a community and BLL. The current study aims to fill this knowledge gap by utilizing a unique dataset of firearm licensure in Massachusetts and its relationship with pediatric blood lead when compared to major sources of exposure in the same community.

2. Methods

Firearm Licensure Percentage. Data were collected through requests under 2017 Massachusetts Public Records Law (M.G.L. Chapter 66, Section 10), made to the Massachusetts Department of Criminal Justice Information Services. Reports contained the number of Class A & B License to Carry for all 351 Massachusetts sub-counties. There was a reported total of 394,462 active Class A licenses in 2017 (Fig. 1), which allows the license holder to purchase, possesses, and carry a firearm. Class B is uncommon, used for purchase and carry of small-capacity firearms, and was discontinued after 2015. When Class B data were included in the analyses results remained unchanged; therefore, they were removed to maintain a consistent variable. Federal Identification cards are used for certain small capacity firearms and for 15-18-year-olds who own self-defense ("Pepper") spray. These were excluded as they include non-firearms. The license and 2017 census data on population of Massachusetts sub-counties were used to calculate a primary variable of interest: firearm licensure percentage. Firearm licensure percentage is the percentage of 18+ citizens in a community who possessed a Class A license in 2017. This variable does not provide information on number of firearms owned – only that a citizen of a community possesses an active license.

Firing Ranges. To control for all sources of FLP, data regarding firing ranges were collected via publicly available information on the Mass.gov Shooting Ranges with Public Access page and the "Where To Shoot" MA Registry and Database (Find, 2019; Commonwealth of Massachusetts, 2019). Of the 351 sub-counties in MA, 108 had 1 firing range, 16 had 2 and 1 had 3 ranges (Fig. 2). Due to the low count of multiple-range communities (n = 17) a dichotomous variable was created: communities with a firing range or ranges and communities without a firing range.

Child Lead Levels. Pediatric BLL data were obtained from the Bureau of Environmental Health (Bureau of BEH, 2018) which, in accordance with Massachusetts lead regulation, tests the capillary BLL of a representative sample of children annually from 9-12 months–47 months, for a total of three testing periods (approximately 1 year, 2 years, and 3 years of age). For children who test above the threshold discussed below or live in high risk communities, an additional follow-up test is completed at age four. High risk sub-counties are those that have a 5-year incidence rate of BLL $\geq$10 μg/dL greater than the state's average after adjusting for low to moderate income and prevalence of lead paint (Childhood Lead Poisoning, 2018). The potential for multiple elevated tests in high risk areas is considered in the data, as an incident case is only counted once over a child's 5-year tested period. This means that the rates calculated for 2017 include only those who tested positive for the first time.

These results are used to calculate estimated cases of confirmed BLL $\geq$5 μg/dL and $\geq$10 μg/dL utilizing the UMass Donahue Institute's modified Hamilton-Perry method. The Hamilton-Perry Methodology uses prior US Census data to create a ratio between a demographic or geographic cohort population, for age in a year, to its corresponding group 10 years earlier/later (Massachusetts Department of Public Health

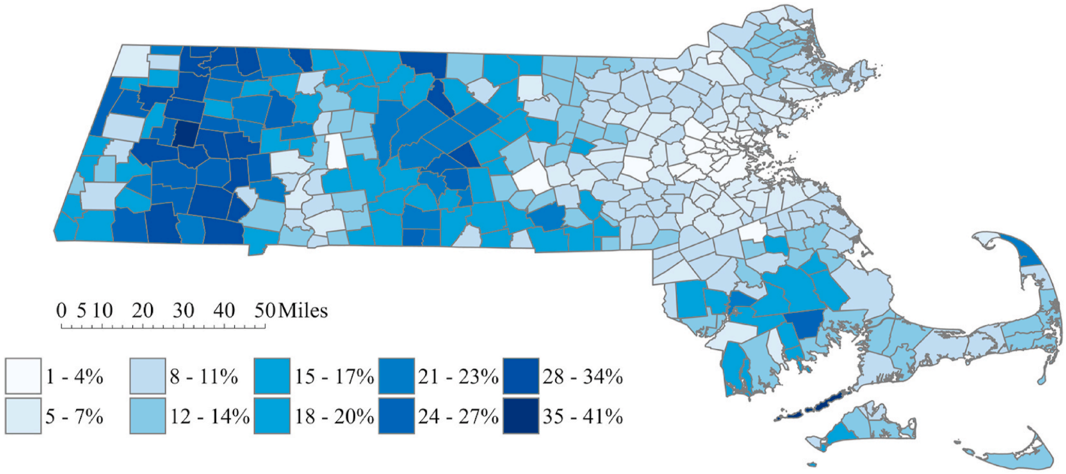

Fig. 1. Firearm licensure percentage in Massachusetts sub-counties (2017).

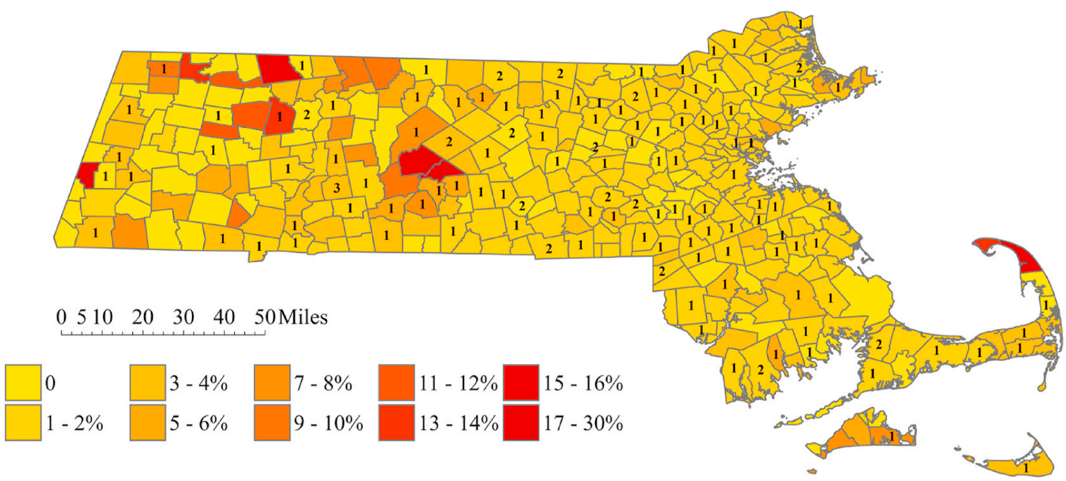

Fig. 2. Prevalence of elevated BLL by sub-county and number of Firing Ranges (2017).

and Bureau of Environmental Health, 2019). This value controls for mortality and migration effects and can be used to calculate cohort-change ratios. It has been modified to estimate young age groups, which use women aged 20–44 (instead of 15–44) and 30–49 (instead of 20–49) to estimate population of 0–9-year-olds. These data can be used in the absence of yearly census data to predict overall populations; for more information on this process please see the referenced publication (Massachusetts Department of Public Health and Bureau of Environmental Health, 2019).

Of the 351 total sub-counties included in 2017, 4 did not have a large enough sample of children and thus were not included in our analyses. A further 17 sub-counties were considered high risk. While capillary tests are vital for use as a preliminary screen, a single test cannot provide accurate and detailed results. When studied, only 1/3 of positive results (5–9 μg/dL range) are confirmed positive when retested (Bureau of BEH, 2018). MA calculates an estimate of the true number of children with BLL $\geq$5 μg/dL as the sum of confirmed (the highest recorded value regardless of follow up tests) with a proportion of unconfirmed $\geq$5 μg/dL (Bureau of BEH, 2018). A confirmed blood lead case is a single venous blood lead specimen, or two capillary blood lead specimens greater than $\geq$5 μg/dL and taken within 12 weeks of each other. An unconfirmed case is a single capillary blood lead specimen of any value (Bureau of BEH, 2018). The proportion of unconfirmed cases estimated to be valid is based on the annual Massachusetts proportion of retested and confirmed positive (i.e., positive predictive value) (Bureau of BEH, 2018) For 2017, this represented 1.6% of all testing cases (Bureau of BEH, 2018).

In sum, the child lead level data reported by the Massachusetts Childhood Lead Poisoning Prevention Program reflects the estimated number of children aged 0–4 in each sub-county with BLL $\geq$5 μg/dL. For the current study, these numbers for each sub-county were divided by the number of children aged 0–4 reported in the 2017 census data for each sub-county to create a variable that reflects the percentage of children aged 0–4 estimated to have elevated BLL in each sub-county (Fig. 2). The variable was examined for outliers; two sub-counties' values for this variable (i.e., Truro and West Stockbridge) were excluded from analyses as they represented extreme outliers. With these outliers removed, the skewness and kurtosis of the variable were within normal limits (Tabachnick and Fidell, 2013). A Moran's I was run to examine the potential for spatial clustering and was found to be non-significant ($I = 0.054$, $p = .793$).

Water. We utilized the 90th percentile lead sample results for 2017 taken from the Massachusetts Environmental Public Health Tracking database (Massachusetts Environment, 2021), which complies with the EPA guidelines for monitoring lead in water. Periodically throughout the year public water systems, up to 25 at-risk homes (e.g., older housing stock) and one childcare facility are tested using first-draw samples (i.e., no flushing, measurements are taken on water immediately released from the fixture). Contamination of drinking water is a concern as lead leeches into water left standing in pipes and fixtures, with older housing stock more likely to employ lead fixtures. While there is no maximum contaminant level, there is an action level of 0.015 mg/L. If triggered, public water systems must take immediate steps towards reduction. However, the action level is only triggered when the 90th percentile value, of all results collected during a monitoring period, exceeds 0.015 mg/L. While all sub-counties were required to report their water quality, data were available for only 223 of 351 sub-counties in 2017 (Bureau of BEH, 2018).

Paint and Housing Stock. Data on lead paint and age of housing stock were provided through the same dataset as BLL (Bureau of BEH, 2018). The lead paint variable was calculated as an estimate of the percentage of all housing units built prior to 1978 using data from the 2012–2016 American Community Survey (ACS). Lead-based paint was banned in 1977; housing units built prior to this date likely contain dangerous lead levels. Massachusetts, which has the 4th oldest housing stock in the country (Massachusetts Department, 2019), legally requires the removal or covering of lead in pre-1978 housing if a child under the age of six is an occupant. Such legislation is linked to a significant reduction in recurrent lead exposure; however, significance was unsubstantiated once other confounding variables were included in the analyses (Kennedy et al., 2016). Therefore, data on lead paint were included to control for this known source of exposure in children.

Demographics. Demographic information for sub-counties was obtained from the 2017 American Community Survey (ACS) 1-Year estimates and U.S. Census Bureau 2010 TIGER database. We obtained data on Sex, Age, Race/Ethnicity, Occupation/Industry (focused on occupations with increased risk of lead exposure), and Education. We also included a measure of income distribution, the MIT Livable Wage Calculator (Glasmeier et al., 2014). This is a calculated value, akin to comparing median income to the federal poverty threshold, that considers living costs beyond basic food budget. A value of 1 is considered 100% of the livable wage required of a community.

Covariates. To account for the variability in size and population of sub-counties in Massachusetts, the population density of each was calculated using the U.S. Census Bureau's population density formula (Population/Land Mass) and 2010 Census TIGER data.

Ethical Statement. The IRB at Harvard T.H. Chan School of Public Health reviewed the study and declared it to be non-human subjects research; as such the study did not undergo full review with the IRB. Data collected as part of the study were all publicly available and revealed no personal identifying information on individuals in the areas described. Approval was obtained in August of 2019.

Statistical Analyses. Following the guidance of Tabachnick and Fidell, correlational (i.e., Pearson correlation coefficient) and 'hierarchical multivariable regression (i.e., OLS) was used to analyze the data (Tabachnick and Fidell, 2013). Multivariable regression was chosen as the analytical approach because the goal was to account for the association of particular variables (e.g., livable wage) with the dependent variable (i.e., BLL) while examining the relationship between firearm licensure and BLL. Hierarchical multivariable regression, specifically, was used to compare two models of the data, one of which examined the predictive power of variables with an established relationship to pediatric BLL and the second which included the novel variable of firearm licensure. Hierarchical multivariable regression allowed for the examination of the relationship between firearm licensure and pediatric BLL, while adjusting statistically for the effects of the other independent variables (Tabachnick and Fidell, 2013). A priori levels of significance were set at 0.05 for two-sided tests. Data were analyzed using IBM's SPSS 21.0.0.0 software.

3. Results

Descriptive Statistics. Descriptive statistics were conducted to describe the sample. Overall in 2017, Massachusetts sub-counties were majority white (i.e., on average 89.95%) and non-Hispanic/Latino (i.e., on average 95.18%), most adult citizens did not have a college degree (i.e., on average 41.43% had attained a college degree or above), and the average unemployment rate was 3.39%. When examining variables related to lead exposure, the maximum lead level water reading was 0.03 mg/L on average, the average percentage of houses built prior to lead regulations was 63.42%, and on average 2.26% of children aged 0–4 years in Massachusetts sub-counties were found to have elevated BLLs. The average rate of firearm licensure was 13.27% in Massachusetts sub-counties. Further details on the sample are found in Table 1.

Table 2 compares elevated pediatric blood lead levels between sub-counties in the highest ($n = 87$, 23%) and lowest ($n = 87$, 5%) quartiles of firearm licensure, including variables previously considered to be the greatest predictors of elevated lead levels. While children in the highest quartile communities were less likely to have older housing stock, higher lead water deposits, and to come from wealthier communities, they were 2.16 times more likely to have elevated BLLs when compared to their peers in the lower quartiles. When examined via *t*-test, the 87 sub-counties with the highest firearm licensure ($m = 23.67$, $SD = 4.89$) compared to the 87 with the lowest firearm licensure ($m = 5.32$, $SD = 1.79$) demonstrated significantly higher BLL ($t\,(174) = -3.08$, $p < .01$) and lower livable wage ($t\,(174) = 2.24$, $p < .05$) (Gonzalez-Chica et al., 2015). This contrasted with comparable tests on percentage of houses with lead ($t\,(174) = 8.39$, $p = 1.65$) and water ($t\,(110) = 0.54$, $p = .59$), which were not significant.

To determine if there were differences on pediatric BLL between sub-counties with a firing range(s) and those without a firing range, we conducted a *t*-test; results demonstrated that the relationship was not significant ($t\,(343) = 1.02$, $p = .31$). Based on these results, we conclude that the presence of a firing range is not a confounding variable and therefore did not control for it in the regression analyses.

Bivariate Correlational Results. Correlational analyses using the Pearson correlation coefficient were used to examine the relationship between BLL among young children and all variables with research support as possible predictors of elevated pediatric BLL. Table 3 below summarizes the results of the bivariate correlation analyses. Of note, demographic variables were not included (e.g., race) beyond the descriptive statistics as previous research does not support demographic characteristics—with the exception of income inequality and wealth (i.e., livable wage)—as predictors of pediatric BLL. Firearm licensure is significantly positively correlated with rates of BLL among children in a sub-county, indicating that sub-counties with higher rates of firearm licensure also report higher rates of lead exposure among children. Lead exposure is also significantly positively correlated with the citizens in a sub-county employed in construction, agriculture, forestry, fishing, hunting, and mining, indicating that sub-counties with higher proportions of elevated BLL among children aged 0–4 years also report higher numbers of citizens employed in the abovementioned industries. The percentage of houses built prior to lead paint regulations is also positively and significantly correlated with rate of elevated BLL among children. Livable wage was significantly negatively correlated with nearly all included variables, suggesting that communities with higher proportions of the population earning a livable wage also demonstrate lower levels of many of the variables (e.g., firearm licensure, lead exposure). No other variables measuring sources of lead (e.g., water) were significantly related to childhood lead exposure.

Hierarchical Multivariable Regression Results. Informed by the results of the correlational analyses, the hierarchical multivariable regression analysis (see Table 4) first examined a model predicting lead exposure utilizing variables shown to be related to BLL. The model indicated R (Lanphear et al., 2018) = 0.15, Adjusted R (Lanphear et al., 2018) = 0.14, F (4,340) = 15.46, $p < .001$. When examining standardized coefficients and confidence intervals of each variable, rate of citizens employed in agriculture, forestry, fishing, hunting, and mining, livable wage, as well as rate of homes built prior to lead regulations were all significant. The second model in the hierarchical multiple regression analyses included the variable of rate of firearm licensure; the second model indicated R (Lanphear et al., 2018) = 0.16, Adjusted R (Lanphear

Table 1
Descriptive statistics.

Variable		N	Min	Max	Median	Mean	Standard deviation
Density (population per square mile)		351	.55	19362.38	457.66	1175.80	2269.05
Livable wage		351	0.64	3.48	1.48	1.57	0.41
Children with elevated BLL (%)		345	0.00	15.56	1.29	2.11	2.69
Firearm licensure (%)		351	1.00	41.20	11.90	13.27	7.35
Water lead level (mg/L)		223	.00	.39	.00	.96	.03
Housing built prior to lead regulations (%)		351	27.00	92.00	64.00	63.42	12.50
Unemployment rate (%)		351	1.90	12.21	3.22	3.39	0.92
College degree or above (%)		351	11.00	85.00	39.00	41.43	16.17
Sex	% Male	351	38.40	64.80	48.30	48.52	3.04
	% Female	351	35.20	61.60	51.70	51.48	3.04
Race	% White	351	39.80	100.00	93.20	89.95	9.99
	% Black or African American	351	0.00	41.00	1.40	2.62	4.28
	% American Indian and Alaska Native	351	0.00	42.30	0.00	0.27	2.29
	% Asian	351	0.00	29.00	1.60	3.36	4.66
	% Native Hawaiian and other pacific islander	351	0.00	2.90	0.00	.04	0.19
	% Biracial	351	0.00	30.80	1.80	2.19	2.19
Ethnicity	% hispanic or latino	351	0.00	79.10	2.70	4.82	7.92
	% Not hispanic or latino	351	20.90	100.00	97.30	95.18	7.92
Employment	% Working in agriculture, forestry, fishing, hunting, mining	351	0.00	7.14	4.67	1.00	1.42
	% Working in construction	351	.67	27.77	6.78	6.96	3.19
	% Working in manufacturing	351	0.00	22.64	9.44	9.72	4.16

Table 2
Average Pediatric BLL, Water Lead level, and Livable Wage in Massachusetts sub-counties: The Highest vs. Lowest Quartile of Firearm Licensure (2017) (Quartile cut-offs in % Armed are 0.01, 0.08, 0.12, 0.18, and 0.41 respectively).

Average Pediatric Pb Level, Water Pb level, and Livable Wage in Massachusetts sub-counties: The Highest vs. Lowest Quartiles of Firearm Ownership (2017)				
	Reference quartile 1 (Low % licensure)	Prevalence ratio quartile 2:1 (95% CI)	Prevalence ratio quartile 3:1 (95% CI)	Prevalence ratio quartile 4:1 (High % licensure) (95% CI)
Housing built prior to lead regulations (%)	73.05%	**1.18** (1.12, 1.24)**	**0.81** (0.77, 0.86)**	**0.80**(0.76, 0.84)**
Children with elevated BLL (%)	1.70%	1.01 (0.71, 1.31)	1.14 (0.83, 1.45)	**2.16**(1.42, 2.90)**
Water lead level (ppb)	0.01	3.07 (0.33, 5.88)	0.55 (0.39, 1.48)	0.77 (0.26, 2.20)
Livable wage	1.63	1.04 (0.94, 1.14)	0.96 (0.88, 1.04)	**0.91*(0.83, 0.99)**

* = p < .05, ** = p < .01.

et al., 2018) = 0.15, F (5, 339) = 13.31, $p < .001$. The model indicates that one standard deviation change in firearm licensure percentage was found to reflect a 0.96% increase in elevated pediatric blood lead levels; this value was obtained by multiplying the standard deviation of firearm licensure by the regression coefficient.

Examining the standardized coefficients and confidence intervals of each variable in the second regression model, the rate of homes built prior to lead regulations, rate of citizens employed in the agriculture, forestry, fishing, hunting, and mining industries, and rate of firearm licensure were significant and positive, indicating each of the above-mentioned variables were significant positive predictors of elevated BLLs among children aged 0–4 years after controlling for the other variables in the model. The standardized coefficient for livable wage was significant and negative, indicating that the level of residents in a community earning a livable wage is a significant and negative predictor of elevated BLLs among children after controlling for the other variables in the model. The standardized coefficient for firearm licensure suggests that there is a 13% increase in elevated BLL in a sub-county for each unit change in the rate of firearm licensure, as compared to a 16% increase for lead paint in homes. Examining the change between the two models indicates that the inclusion of rate of firearm licensure adds significant explanatory power to the regression model $\Delta R^2 = 0.01$, $\Delta F\ (1, 339) = 4.15$ $p < .05$. Model fit was assessed by examining F-test results, which were significant for both models, as well as the R-squared and adjusted R-squared results, both of which are reported in the text above.

4. Discussion

Our current investigation is the first of its kind to study firearm licensing data on the sub-county level, related lead exposure, and its community-level impact (Brunekreef, 1984; Laidlaw et al., 2017; Koh et al., 2015). It is also the first to do so while accommodating variables previously determined to pose some of the greatest risk for lead exposure in a pediatric population: paint and water (Levin et al., 2008).

Review of findings. Research has established the risks of pediatric lead exposure and substantiated the mechanisms by which tracking can

Table 3
Pearson correlation coefficient matrix.

Variable	Firearm licensure	Elevated BLL	Lead paint	Construction	Agriculture	Livable wage
Percentage of children with elevated BLL	0.20**					
Houses built prior to lead paint regulations	-0.37**	0.11*				
Citizens employed in construction	0.46**	0.14**	-0.29**			
Citizens employed in agriculture, forestry, fishing, hunting, mining	0.41**	0.29**	-0.17**	0.38**		
Livable wage[a]	-0.13**	-0.22**	-0.13*	-0.25**	0.00	
Average lead levels in water	-0.01	-0.07	-0.10	-0.06	0.09	0.08

*Correlation is significant at the 0.05 level (2-tailed).
**Correlation is significant at the 0.01 level (2-tailed).
[a] The Livable Wage is a measure of income and wealth. See methods section for further details on the variable.

Table 4
Hierarchical multivariable regression analysis of predictors of elevated BLL among children.

Predictor variables	Standardized coefficient in regression 1	95% CI [UL, LL]	Standardized coefficient in regression 2	95% CI [UL, LL]
Percent of citizens employed in construction	-0.03	-0.15, 0.09	-0.05	-0.17, 0.07
Percent of citizens employed in agriculture, forestry, fishing, hunting, and mining	0.34**	0.23, 0.45	0.29**	0.18, 0.41
Livable wage	-0.21**	-0.32, − 0.11	-0.20**	-0.30, − 0.09
Homes built prior to lead regulations	0.13*	0.01, .05	0.16**	0.05, .28
Firearm licensure			0.13*	0.01, .26
	R-squared	**Adjusted R-squared**	**F**	
Regression 1	0.15	0.14	15.46**	
Regression 2	0.16	0.15	13.31**	

* = $p < .05$, ** = $p < .01$.

impact a family and community (Laidlaw et al., 2017; Indoor Firing Ranges and, 2014a). Results from our analyses confirm previous research findings, including the link between various predictors (e.g., housing stock, employment in particular industries, and livable wage) and pediatric BLL. However, the findings from this analysis are novel; firearm licensure was found to be a significant predictor of pediatric BLL for children aged 0–4 years, on par with housing stock. Additionally, the relationship between firearm licensure and pediatric BLL was demonstrated, even when controlling for known sources and associated demographic variables. These findings warrant further research.

The findings from the correlational matrix support our model of tracking being an important possible source of childhood lead poisoning. Occupational exposure through professions that do not require a uniform change were significantly related to BLL: construction and agriculture, hunting, and mining. Surprisingly, these variables were related more strongly with rate of firearm licensure than BLL. Given the lack of research on specific features of firearm owners in Massachusetts we hypothesize that these professions represent a demographic more likely to own firearms and therefore increase lead exposure via tracking. Further research is required to confirm.

Lead has disproportionately impacted low income communities (Leech et al., 2016). This connection has been explained through lower-income-stratified housing and lack of public resources, as compared to more economically advantaged communities (Leech et al., 2016). As such, there has been extensive attention paid to the presence of lead in water and older housing stock. Indeed, livable wage was a significant and negative predictor of lead exposure, suggesting that communities with higher levels of the population earning a livable wage also demonstrated lower BLL.

From our regression analysis, it is evident that many of the variables may share some contribution from our firearm licensure percentage variable. Specifically, we expected in the second regression model, including the firearm licensure percentage variable, that the coefficient associated with occupations in hunting would be reduced. Hunters have an obvious use of firearms and this occupational variable served as a check on the strength of our data in properly identifying this population and modifying this coefficient in the model. The further inclusion of this variable was based on the other activities in these occupations which would also increase lead outside of firearm ownership.

A surprising finding was that lead in water was not significantly correlated with BLL. We theorize the primary reason is that the variable is a well-established exposure vehicle, and that public awareness facilitates a reduction in risk. Another reason is the incomplete data (n = 223) in the current sample which may not accurately capture a relationship. Additionally, there were no differences between the average pediatric BLL in communities with one or more firing ranges and those without a firing range. This lack of difference may be due to travel from other communities to use the firing ranges as only about one third of sub-counties in Massachusetts have firing ranges. Further, Massachusetts allows target practice on an individual's property, which potentially impacts the population that utilizes firing ranges.

Similarly, the prevalence rate analysis of variables by quartile of firearm licensure found that traditional variables known to impact lead were all reversed from highest to lowest quartile, while increased BLL prevalence followed licensure closely (Table 2). Research in this area is narrow and this form of analysis has various limitations. However, what limited findings we have indicate the potential for a large impact from firearm licensure on pediatric BLL. The findings from the regression help underline the impact firearm licensure may have on a community. Firearms are unregulated sources of lead introduced into a community and are potentially responsible for a proportion of cases of elevated pediatric BLL, which should be taken seriously given the lifetime impact that exposure has on the health and wellbeing of the most vulnerable.

Limitations. The study uses cross-sectional correlational and regression analyses, preventing causal inference. Its intent is to show demographic data on pediatric BLL in Massachusetts, focusing on potential exposures from firearm licensure compared to other sources. This paper is not trying to explain the variations in BLL across all sub-counties in Massachusetts. Additionally, when running multiple tests of association, there is always the possibility of a statistically significant relationship where there is none. Further, it suffers from the ecological fallacy; we are unable to differentiate children coming from homes with firearms from those who do not when examining BLL. It may be that the greater risk stems from higher numbers of firearm owners who have children, or perhaps the increased firearm presence leads to a greater communal level of lead in high-trafficked areas. Additional research is required to better understand this relationship.

Measurement of environmental toxicants is inherently challenging, and our study contains several related limitations. Available data on water (n = 223) was incomplete. Further, data came from a sampling of one public water source and 25 private homes. This method is reductive and does not control for variability between sites. Another variable of interest not included in the current study is lead levels in air; while obtaining data on air pollution in Massachusetts was explored, over half of the 21 ambient air monitoring stations for 2017 incorrectly measured their data and thus did not provide measurements. The measurements that were provided were done so on a county-level only, thus inhibiting our ability to examine their impact in more detail and ultimately leading us to omit them from analyses. Data collected for BLL did present some risk of measurement error, given that high risk communities are tested more often than all other communities (5% more overall). Children in Massachusetts are tested annually from 9-12 months–47 months, for a total of three testing periods (approximately 1, 2, and 3 years of age). Children who test positive or live-in high risk communities are tested on the same schedule but are tested at an additional period (4 years of age). For our study, only 17 of 351 sub-counties were considered high risk; this group differed significantly in terms of population size (81,489 in high risk v. 15,386 elsewhere), which we were able to control for in our regression. There were also key differences in BLL (2% in high risk vs. 4% elsewhere) and firearm licensure percentage (13% in high risk vs. 6% elsewhere). However, these differences, given their directions, provide some support for our findings above as firearm licensure percentage seems to impact BLL in Massachusetts despite these differences in high risk communities, which would bias in the opposite directionality of our findings. There were some limitations with our firearm variable as well. The variable is a crude proxy for the underlying variable of interest as it measures licenses only. It does not establish how firearms are stored nor the number present on a property. Additionally, individuals without a firearm license are permitted to use firearms at firing ranges under the supervision of a licensed individual; the variable does not account for such usage and information is not publicly available regarding the number of unlicensed individuals who use firearms at ranges. The firearm variable also does not account for illegal firearm ownership. While some data is available on illegal firearms (Massachusetts Data Source, 2017), illegal firearm ownership is inherently difficult to quantify; such data offers information on traced firearms and illegal firearms that are seized by law enforcement, both of which are incomplete measures of illegal firearm ownership. Furthermore, analyses were limited to the sub-county level and lack a closer examination of whether there is a dose-response effect for use of firearms, such as how often they are used or if lead safety precautions are taken when doing so. However, given how closely guarded firearm information is, the firearm licensure percentage variable—despite its limitations—adds important findings to our current understanding of the relationship between firearms and lead exposure.

Implications for future research. These data provide a rationale for continued study into the impact of lead tracking on pediatric BLL, especially given the risks of pediatric lead exposure. The aims of the current study were met as it documented unique objective data on firearm licensure—the best available proxy for firearm ownership and use—in Massachusetts and their relationship to pediatric BLL while considering major sources of exposure in the same community. The preliminary findings suggest a need to educate the public on the possible risks of firearm ownership to the health and wellbeing of children.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgments

The research described in this study was partially supported by NIOSH 1K01 OH011648. The researchers would like to thank the Bureau of Environmental Health and Massachusetts Department of Criminal Justice Information Services for providing the data on firearm licensure and lead exposure that was used in the analysis of this study.

References

COUNCIL ON ENVIRONMENTAL HEALTH, 2016. Prevention of childhood lead toxicity. Pediatrics 138 (1). https://doi.org/10.1542/peds.2016-1493.

Alarcon, W.A., 2016. Elevated blood lead levels among employed adults — United States, 1994–2013. MMWR Morb. Mortal. Wkly. Rep. 63 https://doi.org/10.15585/mmwr.mm6355a5.

Braun, J.M., Hornung, R., Chen, A., et al., 2018. Effect of residential lead-hazard interventions on childhood blood lead concentrations and neurobehavioral outcomes. JAMA Pediatr 172 (10), 934–942. https://doi.org/10.1001/jamapediatrics.2018.2382.

Brink, L.L., Talbott, E.O., Sharma, R.K., et al., 2013. Do US ambient air lead levels have a significant impact on childhood blood lead levels: results of a national study. J Environ Public Health 2013. https://doi.org/10.1155/2013/278042.

Brown, M.J., Margolis, S., 2012. Lead in drinking water and human blood lead levels in the United States. MMWR Suppl 61 (4), 1–9.

Brunekreef, B., 1984. The relationship between air lead and blood lead in children: a critical review. Sci. Total Environ. 38, 79–123. https://doi.org/10.1016/0048-9697(84)90210-9.

Bureau of BEH, 2018. Environmental Health, Massachusetts Department of Public Health, Childhood Lead Poisoning Prevention Program. Screening and Prevalence Statistics: 2017 Calendar Year Data, vol. 24. Massachusetts Deparment of Public Health. https://www.mass.gov/files/documents/2018/09/19/cy17-screening-and-prevalence_0.pdf.

Caito, S., Aschner, M., 2017. Developmental neurotoxicity of lead. Adv Neurobiol 18, 3–12. https://doi.org/10.1007/978-3-319-60189-2_1.

California Becomes First State to Ban Lead Bullets for Hunting. Accessed October 9, 2019. https://news.bloombergenvironment.com/environment-and-energy/california-becomes-first-state-to-ban-lead-bullets-for-hunting.

Centers for Disease Control and Prevention (CDC), 2012. Take-home lead exposure among children with relatives employed at a battery recycling facility - Puerto Rico, 2011. MMWR Morb. Mortal. Wkly. Rep. 61 (47), 967–970.

Childhood Lead Poisoning Prevention Program, 2018. High Risk Community Incidence Rate Statistics: 2013-2017. Massachusetts Deparment of Public Health, p. 3. https://www.mass.gov/doc/high-risk-communities-for-childhood-lead-poisoning-calendar-years-2013-2017/download. (Accessed 8 April 2021).

Chowdhury, S., Kabir, F., Mazumder, M., Zahir, M., 2018. Modeling lead concentration in drinking water of residential plumbing pipes and hot water tanks. Sci. Total Environ. 635, 35–44.

Commonwealth of Massachusetts, 2019. Shooting ranges with public access. Mass.gov. Published. https://www.mass.gov/service-details/shooting-ranges-with-public-access. (Accessed 26 July 2019).

Datko-Williams, L., Wilkie, A., Richmond-Bryant, J., 2014. Analysis of U.S. soil lead (Pb) studies from 1970 to 2012. Sci. Total Environ. 468–469, 854–863. https://doi.org/10.1016/j.scitotenv.2013.08.089.

Dignam, T., Kaufmann, R.B., LeStourgeon, L., Brown, M.J., 2019. Control of lead sources in the United States, 1970-2017: public health progress and current challenges to eliminating lead exposure. J Public Health Manag Pract JPHMP 25, S13–S22. https://doi.org/10.1097/PHH.0000000000000889. Suppl 1 LEAD POISONING PREVENTION.

Ettinger, A.S., Ruckart, P.Z., Dignam, T., 2019. Lead poisoning prevention: the unfinished agenda. J. Publ. Health Manag. Pract. 25, S1. https://doi.org/10.1097/PHH.0000000000000902.

Evens, A., Hryhorczuk, D., Lanphear, B.P., et al., 2015. The impact of low-level lead toxicity on school performance among children in the Chicago Public Schools: a population-based retrospective cohort study. Environ. Health 14. https://doi.org/10.1186/s12940-015-0008-9.

Farooqui, Z., Bakulski, K.M., Power, M.C., et al., 2017. Associations of cumulative Pb exposure and longitudinal changes in Mini-Mental Status Exam scores, global cognition and domains of cognition: the VA Normative Aging Study. Environ. Res. 152, 102–108. https://doi.org/10.1016/j.envres.2016.10.007.

Home Find Shooting Ranges Near You | Where To Shoot. Accessed July 26, 2019. https://www.wheretoshoot.org/.

Fustinoni, S., Sucato, S., Consonni, D., Mannucci, P.M., Moretto, A., 2017. Blood lead levels following consumption of game meat in Italy. Environ. Res. 155, 36–41. https://doi.org/10.1016/j.envres.2017.01.041.

Galea, S., Vaughan, R.D., 2018. Learning from the evolving conversation on firearms: a public health of consequence, july 2018. Am. J. Publ. Health 108 (7), 856–857. https://doi.org/10.2105/AJPH.2018.304490.

Glasmeier, A.K., Nadeau, C.A., Schultheis, E., 2014. Living Wage Calculator. Published online. https://immagic.com/eLibrary/ARCHIVES/GENERAL/MIT_US/M140914N.pdf.

Gonzalez-Chica, D.A., Bastos, J.L., Duquia, R.P., Bonamigo, R.R., Martínez-Mesa, J., 2015. Test of association: which one is the most appropriate for my study? An. Bras. Dermatol. 90 (4), 523–528. https://doi.org/10.1590/abd1806-4841.20154289.

Gottesfeld, P., Pokhrel, A.K., 2011. Review: lead exposure in battery manufacturing and recycling in developing countries and among children in nearby communities. J. Occup. Environ. Hyg. 8 (9), 520–532. https://doi.org/10.1080/15459624.2011.601710.

Gulson, B.L., Mahaffey, K.R., Jameson, C.W., et al., 1998. Mobilization of lead from the skeleton during the postnatal period is larger than during pregnancy. J. Lab. Clin. Med. 131 (4), 324–329. https://doi.org/10.1016/s0022-2143(98)90182-2.

He, K., Sakran, J.V., 2019. Elimination of the moratorium on gun research is not enough: the need for the CDC to set a budgetary agenda. JAMA Surg 154 (3), 195–196. https://doi.org/10.1001/jamasurg.2018.4211.

Indoor Firing Ranges and Elevated Blood Lead Levels — United States, 2002–2013, 2014. Centers for Disease Control and Prevention (CDC). https://www.cdc.gov/mmwr/preview/mmwrhtml/mm6316a3.htm?s_cid=mm6316a3_w. (Accessed 11 March 2019).

Kennedy, C., Lordo, R., Sucosky, M.S., Boehm, R., Brown, M.J., 2016. Evaluating the effectiveness of state specific lead-based paint hazard risk reduction laws in preventing recurring incidences of lead poisoning in children. Int. J. Hyg Environ. Health 219 (1), 110–117. https://doi.org/10.1016/j.ijheh.2015.09.009.

Koh, D.-H., Locke, S.J., Chen, Y.-C., Purdue, M.P., Friesen, M.C., 2015. Lead exposure in US worksites: a literature review and development of an occupational lead exposure database from the published literature. Am. J. Ind. Med. 58 (6), 605–616. https://doi.org/10.1002/ajim.22448.

Laidlaw, M.A.S., Filippelli, G., Mielke, H., Gulson, B., Ball, A.S., 2017. Lead exposure at firing ranges—a review. Environ. Health 16. https://doi.org/10.1186/s12940-017-0246-0.

Landrigan, P.J., Todd, A.C., 1994. Lead poisoning. West. J. Med. 161 (2), 153–159. https://www.ncbi.nlm.nih.gov/pmc/articles/PMC1022528/. (Accessed 9 March 2019).

Lanphear, B.P., 2017. Low-level toxicity of chemicals: No acceptable levels? PLoS Biol. 15 (12) https://doi.org/10.1371/journal.pbio.2003066.

Lanphear, B.P., Hornung, R., Ho, M., 2005. Screening housing to prevent lead toxicity in children. Publ. Health Rep. 120 (3), 305–310. https://www.ncbi.nlm.nih.gov/pmc/articles/PMC1497723/. (Accessed 17 September 2019).

Lanphear, B.P., Rauch, S., Auinger, P., Allen, R.W., Hornung, R.W., 2018. Low-level lead exposure and mortality in US adults: a population-based cohort study. Lancet Public Health 3 (4), e177–e184. https://doi.org/10.1016/S2468-2667(18)30025-2.

Latorre, F.G., Hernández-Avila, M., Orozco, J.T., et al., 2002. Relationship of blood and bone lead to menopause and bone mineral density among middle-age women in Mexico city. Environ. Health Perspect. 111 (4), 631–636. https://doi.org/10.1289/ehp.5149.

Leech, T.G., Adams, E., Weathers, T., Staten, L., Filippelli, G., 2016. Inequitable chronic lead exposure: a dual legacy of social and environmental injustice. Fam. Community Health 39 (3), 151–159. https://doi.org/10.1097/FCH.0000000000000106.

Levin, R., Brown, M.J., Kashtock, M.E., et al., 2008. Lead exposures in U.S. Children, 2008: implications for prevention. Environ. Health Perspect. 116 (10), 1285–1293. https://doi.org/10.1289/ehp.11241.

Liu, J., Liu, X., Wang, W., et al., 2014. Blood lead concentrations and children's behavioral and emotional problems: a cohort study. JAMA Pediatr 168 (8), 737–745. https://doi.org/10.1001/jamapediatrics.2014.332.

Low Level Lead Exposure Harms Children: A Renewed Call for Primary Prevention, 2012. Centers for Disease Control and Prevention (CDC), p. 65.

Manton, W.I., Angle, C.R., Stanek, K.L., Kuntzelman, D., Reese, Y.R., Kuehnemann, T.J., 2003. Release of lead from bone in pregnancy and lactation. Environ. Res. 92 (2), 139–151. https://doi.org/10.1016/S0013-9351(03)00020-3.

Massachusetts Data Source: Firearms Tracing System, 2017. Published online. https://www.atf.gov/docs/undefined/mawebsite17183904pdf/download.

Massachusetts Department of Public Health, 2019. Data Brief: Childhood Lead Exposure in Massachusetts - December 2019. Data Brief Ser, p. 3, 2017.

Massachusetts Department of Public Health, Bureau of Environmental Health, 2019. Massachusetts Environmental Public Health Tracking: Explanation of UMass DOnahue Institute Population Data, vol. 1. Massachusetts Deparment of Public Health. https://cognos10.hhs.state.ma.us/cv10pub/cgi-bin/cognosisapi.dll?b_action=cognosViewer&ui.action=run&ui.object=%2fcontent%2ffolder%5b%40name%3d%27MEPHTN%27%5d%2ffolder%5b%40name%3d%27health%27%5d%2freport%5b%40name%3d%27umass-population-info%27%5d&ui.name=umass-population-info&run.outputFormat=&run.prompt=true&cv.header=false&cv.toolbar=false.

Massachusetts Environmental Public Health Tracking Home Page | MEPHT. Accessed February 2, 2021. https://matracking.ehs.state.ma.us/?utm_source=Outreach&utm_medium=behlandingpage&utm_campaign=community-profiles.

Mateo, R., Rodríguez-de la Cruz, M., Vidal, D., Reglero, M., Camarero, P., 2007. Transfer of lead from shot pellets to game meat during cooking. Sci. Total Environ. 372 (2–3), 480–485. https://doi.org/10.1016/j.scitotenv.2006.10.022.

Mateo, R., Baos, A.R., Vidal, D., Camarero, P.R., Martinez-Haro, M., Taggart, M.A., 2011. Bioaccessibility of Pb from ammunition in game meat is affected by cooking treatment. PloS One 6 (1), e15892. https://doi.org/10.1371/journal.pone.0015892.

Navas-Acien, A., Guallar, E., Silbergeld, E.K., Rothenberg, S.J., 2007. Lead exposure and cardiovascular disease—a systematic review. Environ. Health Perspect. 115 (3), 472–482. https://doi.org/10.1289/ehp.9785.

Newman, N., Jones, C., Page, E., Ceballos, D., Oza, A., 2015. Investigation of childhood lead poisoning from parental take-home exposure from an electronic scrap recycling facility — Ohio, 2012. MMWR Morb. Mortal. Wkly. Rep. 64 (27), 743–745.

Nie, H., Sánchez, B.N., Wilker, E., et al., 2009. Bone lead and endogenous exposure in an environmentally exposed elderly population: the normative aging study. J. Occup. Environ. Med. 51 (7), 848–857. https://doi.org/10.1097/JOM.0b013e3181aa0106.

O'Flaherty, E., 1999. A physiologically based kinetic model for lead in children and adults. Environ. Health Perspect. 106 (Suppl. 6), 1495–1503. https://doi.org/10.1289/ehp.98106s61495.

Power, M.C., Korrick, S., Tchetgen Tchetgen, E.J., et al., 2014. Lead exposure and rate of change in cognitive function in older women. Environ. Res. 129, 69–75. https://doi.org/10.1016/j.envres.2013.12.010.

Rajan, S., Branas, C.C., Hargarten, S., Allegrante, J.P., 2018. Funding for gun violence research is key to the health and safety of the nation. Am. J. Publ. Health 108 (2), 194–195. https://doi.org/10.2105/AJPH.2017.304235.

Riedt, C.S., Buckley, B.T., Brolin, R.E., Ambia-Sobhan, H., Rhoads, G.G., Shapses, S.A., 2009. Blood lead levels and bone turnover with weight reduction in women. J. Expo. Sci. Environ. Epidemiol. 19 (1), 90–96. https://doi.org/10.1038/jes.2008.5.

Rinsky, J.L., Higgins, S., Angelon-Gaetz, K., et al., 2018. Occupational and take-home lead exposure among lead oxide manufacturing employees, North Carolina, 2016. Public Health Rep Wash DC 1974 133 (6), 700–706. https://doi.org/10.1177/0033354918795442.

Rostron, A., 2018. The Dickey amendment on federal funding for research on gun violence: a legal dissection. Am. J. Publ. Health 108 (7), 865–867. https://doi.org/10.2105/AJPH.2018.304450.

Tabachnick, B.G., Fidell, L.S., 2013. Using Multivariate Statistics. Pearson Education.

Thiboldeaux, R., 2008. Health Consultation: the Potential for Ingestion Exposure to Lead Fragments in Venison in Wisconsin, vol. 24. Wisconsin Department of Health Services https://www.atsdr.cdc.gov/HAC/pha/LeadFragmentsinVenison/Venison%20and%20Lead%20HC%20110408.pdf.

Tsuji, L.J.S., Wainman, B.C., Martin, I.D., et al., 2008. Lead shot contribution to blood lead of First Nations people: the use of lead isotopes to identify the source of exposure. Sci. Total Environ. 405 (1–3), 180–185. https://doi.org/10.1016/j.scitotenv.2008.06.048.

Weisskopf, M.G., Jain, N., Nie, H., et al., 2009. A prospective study of bone lead concentration and death from all causes, cardiovascular diseases, and cancer in the VA Normative Aging Study. Circulation 120 (12), 1056–1064. https://doi.org/10.1161/CIRCULATIONAHA.108.827121.

Wu, Y., Sun, J., Wang, M., Yu, G., Yu, L., Wang, C., 2018. The relationship of children's intelligence quotient and blood lead and zinc levels: a meta-analysis and system review. Biol. Trace Elem. Res. 182 (2), 185–195. https://doi.org/10.1007/s12011-017-1093-0.