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## Industry-specific Prevalence of Elevated Blood Lead Levels among Pennsylvania Workers, 2007–2018

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### Abstract

**Objectives:** To use industry-specific denominators to more accurately examine trends in prevalence rates for occupational cases of elevated blood lead levels (eBLLs) in Pennsylvania.

**Methods:** We used adult (aged ≥ 16) blood lead level data from Pennsylvania (2007–2018) and industry-specific denominator data from the US Census Bureau's County Business Patterns to calculate prevalence rates for eBLLs, defined as ≥ 25µg/dL.

**Results:** Of the 19,904 cases with eBLLs, 92% were due to occupational lead exposure, with 83% from workers in the battery manufacturing industry. In 2018, the prevalence rate of eBLLs for battery manufacturing (8,036 cases per 100,000 employed battery manufacturing workers) was 543 times the overall Pennsylvania prevalence rate. The prevalence rate for battery manufacturing steeply declined 71% from 2007 to 2018.

**Conclusions:** The battery manufacturing industry had the highest burden of occupational lead exposure in Pennsylvania, illustrating the importance of using industry-specific denominators to accurately identify sources of lead exposure. Although the prevalence rate of eBLLs declined over time, lead exposure remains a major concern among battery manufacturing workers.

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#### CONTRIBUTORSHIP STATEMENT

RJT and JWL conceptualized the study, analyzed the data, and drafted and revised the article. SAH, SHH, L H-M, and AN contributed to the design, data analysis, interpretation of data, and revision of article. All authors approved the final version of the manuscript

#### COMPETING INTERESTS

None declared

#### DISCLAIMER

The findings and conclusions in this report are those of the authors and do not necessarily represent the views of the National Institute for Occupational Safety and Health, or The Pennsylvania Department of Health

## INTRODUCTION

Lead is a versatile material with many uses in manufacturing (e.g., storage batteries, foundries, casting) and construction (e.g., lead pipes, lead paint) industries.<sup>1 2</sup> Every year, at least 4,000 workers in the United States are found to have elevated blood lead levels (eBLLs) of  $\geq 25$  micrograms per deciliter ( $\mu\text{g}/\text{dL}$ ) and tens of thousands more are exposed to lead at work but are not tested or have lower BLLs.<sup>3</sup> Lead's toxicity to humans is well established. In adults, BLLs of  $\geq 25\mu\text{g}/\text{dL}$  are associated with adverse health effects, such as headache, fatigue, anemia, and memory deficits.<sup>4</sup> Even low BLLs of  $<10 \mu\text{g}/\text{dL}$  are associated increased blood pressure and essential tremors, while BLLs of  $<5 \mu\text{g}/\text{dL}$  are associated with decreased renal function. Reduced fetal growth has also been observed at BLLs  $<5 \mu\text{g}/\text{dL}$ .<sup>1 5</sup>

The National Institute for Occupational Safety and Health's (NIOSH) Adult Blood Lead Epidemiology and Surveillance (ABLES) program, a federal-state partnership, found that 85–90% of adults who are exposed to lead had occupational exposure.<sup>6</sup> In 1978, the Occupational Safety and Health Administration (OSHA) issued a standard (29 CFR 1910.1025) that limited occupational lead exposure and mandated regular blood lead testing through a medical surveillance program for lead-exposed workers.<sup>7</sup> Although the lead standard resulted in an overall decline in lead exposed workers, the increased demand for some leaded products (e.g., lead-acid batteries) perpetuated lead exposure in certain industries.<sup>8</sup> The net effect of these two factors on eBLLs—increased worker protection and increased product demand—varies by industry. Identifying where efforts should be focused to reduce occupational lead exposure requires examination of industry-specific prevalence rates.

To illustrate the importance of industry-specific rates, we used historical data from Pennsylvania. The Pennsylvania Department of Health (PADOH) has been reporting BLL data to ABLES since 1994. Among the 31 states submitting data in 2018, Pennsylvania had the highest count of individuals (N=912) with eBLLs  $\geq 25\mu\text{g}/\text{dL}$  and the highest rate at 14.8 cases per 100,000 employed workers (Figure 1).<sup>3</sup>

Previously, calculations of eBLL prevalence rate used denominators that included all employed workers within a state.<sup>3 9</sup> However, rates using all employed workers are misleading because most workers are not occupationally exposed to lead. Accurate assessment of industry-specific magnitude and trends in occupational lead exposure requires calculation of prevalence rates using industry-specific denominators.

This is the first study that used industry-specific denominators to estimate the prevalence rate of workers with eBLLs in Pennsylvania. Tracking industry-specific prevalence rates is critical for gauging progress towards eliminating lead exposure as a workplace hazard. These data will allow occupational health and safety professionals to plan interventions targeting industries with the highest levels of lead poisoning.

## METHODS

Lead poisoning is a reportable condition in Pennsylvania (28 Pa. Code § 27.34). Prior to 2019, laboratories approved for analyzing blood lead were mandated to report only adult (aged ≥ 16) test results with BLLs ≥ 25 µg/dL to the Division of Environmental Health Epidemiology, Bureau of Epidemiology within PADOH.<sup>10</sup> PADOH collects data from lab reports and stores them in their state-based surveillance system. For this study, PADOH submitted de-identified ABLES data from 2007 to 2018 to NIOSH. The data included age, sex, date of blood draw, BLL, exposure source, and if work-related, the industry of the worker. Cases were defined as adult (aged ≥ 16) residents of Pennsylvania with ≥ 1 blood draw (venous or unknown type) with a BLL ≥ 25 µg/dL from 2007 to 2018. For adults with multiple blood lead tests in a single calendar year, we included in the analysis the blood lead test with the highest BLL. When data are summed across all years, an individual may be counted multiple times, once for each year the individual was a case. We divided the exposure source into occupational lead exposure, non-occupational lead exposure (e.g., recreational activities and hobbies: shooting firearms and making fishing weights), and unknown exposure (i.e., undetermined occupational or non-occupational source). Workers with company-ordered blood lead tests were considered occupationally exposed to lead.

To ensure that we capture the most complete industry profile in Pennsylvania, we used a two-step process to determine the employer for each blood lead test report. First, if available, we used the company's name on the lab report (n=15,553, 85%) as larger companies will directly order blood lead tests from their occupational clinics, resulting in the inclusion of employer information in submitted lab reports. Second, if no company name appeared on the lab report, we obtained the employer's name from follow-up interviews of workers with eBLLs conducted by PADOH (n=2,793, 15%). The follow-up interviews occurred at a single point in time and the employer name remained associated with that person over time. For industry, we consulted with expert industry coders to assign a 2012 North American Industry Classification System (NAICS) code for each company name.<sup>11</sup> NAICS is a 2- to 6-digit hierarchical industry classification system that provides an increasing level of detail with more digits. At the 4- and 5-digit levels, NAICS codes provide information on the economic sector, the subsector, and the industry group.<sup>11</sup>

We calculated the yearly prevalence rate of worker cases for a specific industry in Pennsylvania as (Number of cases with BLL ≥ 25 µg/dL in 4- or 5-digit NAICS code / Number of employed workers in the same 4- or 5-digit NAICS code) x 100,000. We obtained the denominator from the US Census Bureau's County Business Patterns (CBP) state-level data. CBP data are extracted from the Business Register, a database of all known single and multi-establishment employer companies.<sup>12</sup>

Since the denominator (i.e., total number of workers) in Battery Manufacturing (NAICS 33591) was not provided by CBP during our study period; we derived the denominator through subtraction using the provided number of workers at the 4-digit (NAICS 3359: Other Electrical Equipment and Component Manufacturing) and 5-digit (NAICS 33592: Communication and Energy Wire and Cable Manufacturing, 33593: Wiring Device Manufacturing, 33599: All Other Electrical Equipment and Component Manufacturing)

level. Census Bureau notes that, although unprovided data may be derived through subtraction, the result may differ substantially from the unknown population data.<sup>12</sup> To protect the confidentiality of individual employers, the US Census Bureau added data noise to conceal the actual number of workers. The number of workers provided may vary from the actual number of workers by up to 5%.<sup>12</sup>

We estimated the maximum impact of data noise by approximating the yearly upper and lower bounds of the estimated number of workers for NAICS 33591. For each year, we estimated the number of workers for NAICS 3359, 33592, 33593, and 33599 as  $\pm 5\%$  or  $\pm 2\%$ , dependent on the data noise flag provided by US Census Bureau. To obtain the upper bound NAICS 33591 estimate, we subtracted the sum of the 5-digit lower bound numbers from the upper bound 4-digit number. Conversely to obtain the lower bound NAICS 33591 estimate, we subtracted the sum of the 5-digit upper bound numbers from the lower bound 4-digit number. We then calculated the yearly percent change between the derived NAICS 33591 number of workers and the corresponding upper/lower bound. The maximum impact of the data noise for the derived NAICS 33591 was between 8 and 15% for each year. This level of noise was not found to significantly influence the NAICS 33591 trend observed in this study.

We used SAS®, 9.4 (copyright 2002–2012, SAS institute Inc., Cary NC) to analyze data. To summarize case data, we used descriptive statistic procedures (SAS PROC FREQ, SAS PROC MEAN); to compare occupational and non-occupational exposure cases by age (16–24; 25–34; 35–44; 45–54; 55+) and sex, the ANOVA and Chi-square statistics and, to assess trends in BLLs over time, the Mann-Kendall test. PROC CORR, using function Kendall, at a 0.05 level of significance assesses whether a time-ordered dataset exhibits a monotonic increasing or decreasing trend. We also examined the trend data for presence of autocorrelation or partial autocorrelation.

This activity was reviewed by CDC and was conducted consistent with applicable federal law and CDC policy (45 C.F.R. part 46.102(1)(2), 21 C.F.R. part 56; 42; U.S.C. §241(d); 5 U.S.C. §552a; 44 U.S.C. §3501 et seq).

## RESULTS

From 2007 to 2018, we identified 19,904 cases of eBLL  $\geq 25$   $\mu\text{g}/\text{dL}$  in Pennsylvania. Of these cases, 18,346 (92%) were due to occupational lead exposure, 129 (1%) were due to non-occupational exposure, and 1,429 (7%) were due to unknown sources of exposure. Table 1 shows case demographics by the three sources of lead exposure. The mean age of all cases was 39.6 years with notable differences in mean age by source of lead exposure (p-value  $<0.0001$ , ANOVA F Value = 435.3 with two degrees of freedom). The mean age of cases with occupational exposure was much lower (38.9 years) than cases with non-occupational exposure (61.9 years). Cases with an unknown source of lead exposure averaged 46.5 years. Over 95% of cases were male. There was no difference in source of lead exposure by sex (p-value 0.16, chi-square = 3.7 with two degrees of freedom), with men accounting for approximately 95% of each type of exposure. The number of cases for all five age groups declined over time from 2007 to 2018 (Figure 2).

Among cases with occupational lead exposure, 18,346 distributed into 85 different 4-digit NAICS codes and 24 into an unknown NAICS category. Eighty-three percent of cases (n=15,231) worked in the Other Electrical Equipment and Component Manufacturing industry (NAICS 3359). The other top industries were: Foundries (NAICS 3315) (n=768, 4%); Nonferrous Metal (except Aluminum) Production and Processing (NAICS 3314) (n=640, 4%); Building Finishing Contractors (NAICS 2383) (n=280, 2%); Highway, Street, and Bridge Construction (NAICS 2373) (n=143, 1%); Other General Purpose Machinery Manufacturing (NAICS 3339) (n=121, 1%); Residential Building Construction (NAICS 2361) (n=111, 1%); and Glass and Glass Product Manufacturing (NAICS 3272) (n=102, 1%). Lab reports provided employer information for the top industry (NAICS 3359), while the PADOH system provided most of the employer information for the remaining industries (Table 2). Although NAICS is revised every five years, there were no significant NAICS classification changes to the top eight NAICS codes during the study period. The 1429 workers with unknown exposure sources also had unknown NAICS codes.

### Prevalence Rates

We focus our results on the Other Electrical Equipment and Component Manufacturing (NAICS 3359) industry, which has the largest number of cases over the study period. NAICS 3359 is composed of four subindustries: Battery Manufacturing (NAICS 33591), Communication and Energy Wire and Cable Manufacturing (NAICS 35592), Wiring Device Manufacturing (NAICS 33593), and All Other Electrical Equipment and Component Manufacturing (NAICS 33599). With the industry-specific denominator for Other Electrical Equipment and Component Manufacturing (NAICS 3359) used to calculate the prevalence rate,<sup>12</sup> the rate declined 57% from 10,889.3 cases per 100,000 workers in 2007 to 4682.5 cases in 2018 (Figure 3) (Mann-Kendall coefficient =  $-0.8182$ ,  $p=0.0002$ ). From the beginning to the end of the study period, the denominator for NAICS 3359 increased by 2%, although year-to-year fluctuation was as high as 10%.

### Battery Manufacturing

During the study period, over 99% (n= 15,229) of cases in Other Electrical Equipment and Component Manufacturing (NAICS 3359) worked in Battery Manufacturing (NAICS 33591). When applying the industry-specific denominator for Battery Manufacturing (NAICS 33591) to calculate the prevalence rate,<sup>12</sup> the rate declined steeply (70.8%), from 27,687.7 cases per 100,000 workers in 2007 to 8036.4 cases in 2018 (Mann-Kendall coefficient =  $-0.848$ ,  $p=0.0002$ ) (Figure 3). During this same period, the denominator for NAICS 33591 increased by 50%.

When comparing the prevalence rates of eBLLs between NAICS 3359 and NAICS 33591 during the study period, the rate for NAICS 33591 was consistently higher than that for NAICS 3359, with a larger difference in earlier years. In 2007, the prevalence rate for NAICS 33591 was 2.5 times higher than for NAICS 3359 (27,687.7 vs. 10,889.3 cases per 100,000), while in 2018, the prevalence rate for NAICS 33591 was not quite twice as high as the prevalence rate for NAICS 3359 (8036.4 vs. 4682.5 cases per 100,000).

## DISCUSSION

This first analysis of ABLES data to estimate prevalence rates for eBLLs using industry-specific denominators highlights the crucial role appropriate denominators (i.e., population at risk) play in producing industry-based estimates. According to data collected through PADOH in 2018, the overall prevalence rate for BLLs  $\geq 25 \mu\text{g/dL}$  in the state is 14.8 cases per 100,000 employed workers, which is four times as high as the rate (3.5) from all states, including Pennsylvania, reporting to the ABLES program.<sup>3</sup> The 2018 industry-specific prevalence rate for the Other Electrical Equipment and Component Manufacturing industry (NAICS 3359) was 316.4 times (4,682.5 vs. 14.8) as high as the state rate, and the prevalence rate for the Battery Manufacturing industry (NAICS 33591) was 543 times as high (8036.4 vs. 14.8), with 8% of battery manufacturing workers having a BLL  $\geq 25 \mu\text{g/dL}$ . These differences in prevalence rates demonstrate the importance of using industry-specific denominators to assess the burden of occupational lead exposure. In addition, industry-specific denominators allow us to account for changes in industry workforce patterns (e.g., fluctuation in market demands and global trade for new and spent lead-acid batteries)<sup>13</sup> that could significantly influence results. The use of a denominator (i.e., total number of workers in a specific industry) that closely corresponds with the population underlying the numerator (e.g., number of workers with eBLLs in the same specified industry) will produce a more relevant prevalence rate.

Compared to the prevalence rate for Other Electrical Equipment and Component Manufacturing (NAICS 3359), the prevalence rate for Battery Manufacturing (NAICS 33591) showed a steeper decline from 2007 to 2018. As the industry-specific denominator for Other Electrical Equipment and Component Manufacturing (NAICS 3359) remained relatively stable over the study period, the decline is mostly attributable to the decline in the number of cases. However, the steeper decline seen in Battery Manufacturing (NAICS 33591) may be explained by a nearly identical decline in the number of cases (i.e., almost all cases in NAICS 3359 were in NAICS 33591), along with a 50% increase in the number of employed battery manufacturing workers (denominator) over our study period. These denominator trends for NAICS 3359 and NAICS 33591 may account for the larger difference between the prevalence rates during the earlier years. Multiple factors, such as improvement in engineering controls, workplace hygiene practices, and the use of personal protective equipment, could have lowered the worker's personal exposure to lead.

Most of the identified cases (92.2%) were presumably exposed to lead at work. Some may have had non-occupational exposures through recreational activities and hobbies such as shooting firearms, making bullets or fishing weights, and home renovations.<sup>14</sup> Since this study population was predominately younger males, take home lead exposure is of concern. Lead's detrimental effect on a developing nervous system makes fetuses and young children particularly vulnerable.<sup>1</sup>

The ABLES program, the only state-based surveillance system of adult BLLs in the United States, plays a crucial role in monitoring occupational lead exposure trends. In Pennsylvania, this is significant as tens of thousands of workers continue to be exposed to lead at work. However, this study has several limitations that can affect the interpretation of our findings.

First, the reported case count for eBLLs is likely underestimated. For example, not all lead-exposed workers are in a medical surveillance program and may not be tested for blood lead. Second, between 2007 and 2018, Pennsylvania's mandatory reporting requirement of BLLs  $\geq 25 \mu\text{g}/\text{dL}$  was high. Comparatively, in 2015, CDC, NIOSH, and CSTE lowered the case definition for eBLLs to  $\geq 5 \mu\text{g}/\text{dL}$ .<sup>6 15 16</sup> This limited our ability to identify cases at lower BLLs and restricted our analysis to industries that contributed to severe cases. Starting in February 2019, the mandatory reporting requirement in Pennsylvania was lowered to BLLs  $\geq 5 \mu\text{g}/\text{dL}$ . Third, the use of company name to classify NAICS codes may lead to misclassification. With the increased emphasis on secondary lead production and recycling in Pennsylvania, it is likely that even within the same company, battery recycling operations are used to support the battery manufacturing process. Since we were unable to differentiate between battery recycling and battery manufacturing, both processes were classified under battery manufacturing. Fourth, the use of employer's name extracted from PADOH's database, as opposed to from lab reports, could lead to industry misclassification because the employer's name was not necessarily captured at or near the same time as blood lead collection. As such, records from multiple years are classified under a single employer and may not reflect the workplace or industry where the worker's actual exposure occurred. Additionally, the employer information was obtained by interviews and the resources to conduct interviews over time has varied. Fifth, if the source of the large number of cases with unknown exposure were known, the distribution of cases among industries might change. Sixth, when data are summed across all years, an individual may be counted multiple times, leading to an overestimation of the reported cumulative case count. Seventh, despite the use of industry-specific denominators, workers classified under battery manufacturing (NAICS 33591) do not have equal occupational exposure to lead. Workers who perform certain tasks (e.g., breaking open old lead batteries, melting lead, casting and molding lead plates) are more likely to have higher occupational lead exposure.<sup>17</sup> Unfortunately, the ABLES program does not record specific job tasks associated with BLLs, preventing further analysis by work tasks. Finally, the declining prevalence rate trend for battery manufacturing was not smooth but punctuated by dips and peaks over our study period. Further examination by PADOH did not identify an external explanation for these data variations. These limitations do not negate the main study findings. The methods developed here can be used in both national and international occupational health programs to identify industry-specific prevalence rates. This may be particularly useful for developing countries, where resources to mitigate exposure are limited and occupational lead exposure may be high.

## CONCLUSION

Battery manufacturing continues to be the most frequently reported source of occupational lead exposure to ABLES in Pennsylvania and the rest of the United States. This study illustrates the importance of calculating industry-specific rates to assess trends in the burden of occupational lead exposure on workers. Although the prevalence rate of eBLLs for Pennsylvania's battery manufacturing workers declined 71% from 2007–2018, many battery manufacturing workers continue to have high BLLs.

More can be done to enhance protections for these workers. Due to the toxic effect of lead exposure, industries in electronic and cable manufacturing, have transitioned from using lead to plastics, tin, steel or zinc.<sup>18</sup> However, since lead-acid batteries are still prominently used in many transportation and storage systems, they will likely remain as a preferred source of energy storage for many years to come. Therefore, workplaces with occupational lead exposures should continue to educate their workers on the dangers of lead and eliminate hazardous environments and processes.<sup>19</sup> Engineering and administrative controls to reduce exposures should be implemented when elimination of hazards is not feasible.<sup>20</sup> Proper personal hygiene remains an important preventative measure for controlling lead exposure for both workers and their families.<sup>16 20</sup> Moreover, individual states are encouraged to routinely report state-based industry-specific rates. This information could be used to target and plan public health interventions in high-risk industries.

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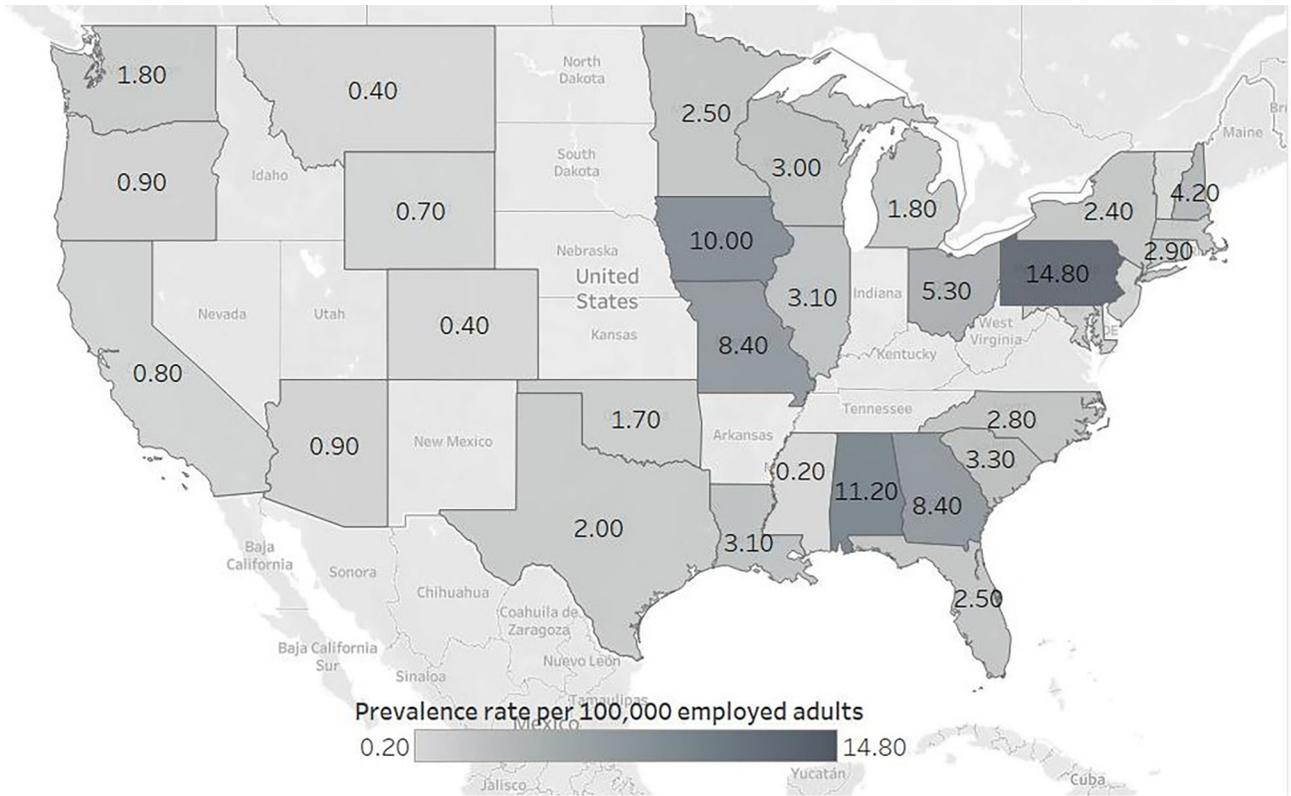
## DATA AVAILABILITY STATEMENT

No data are available

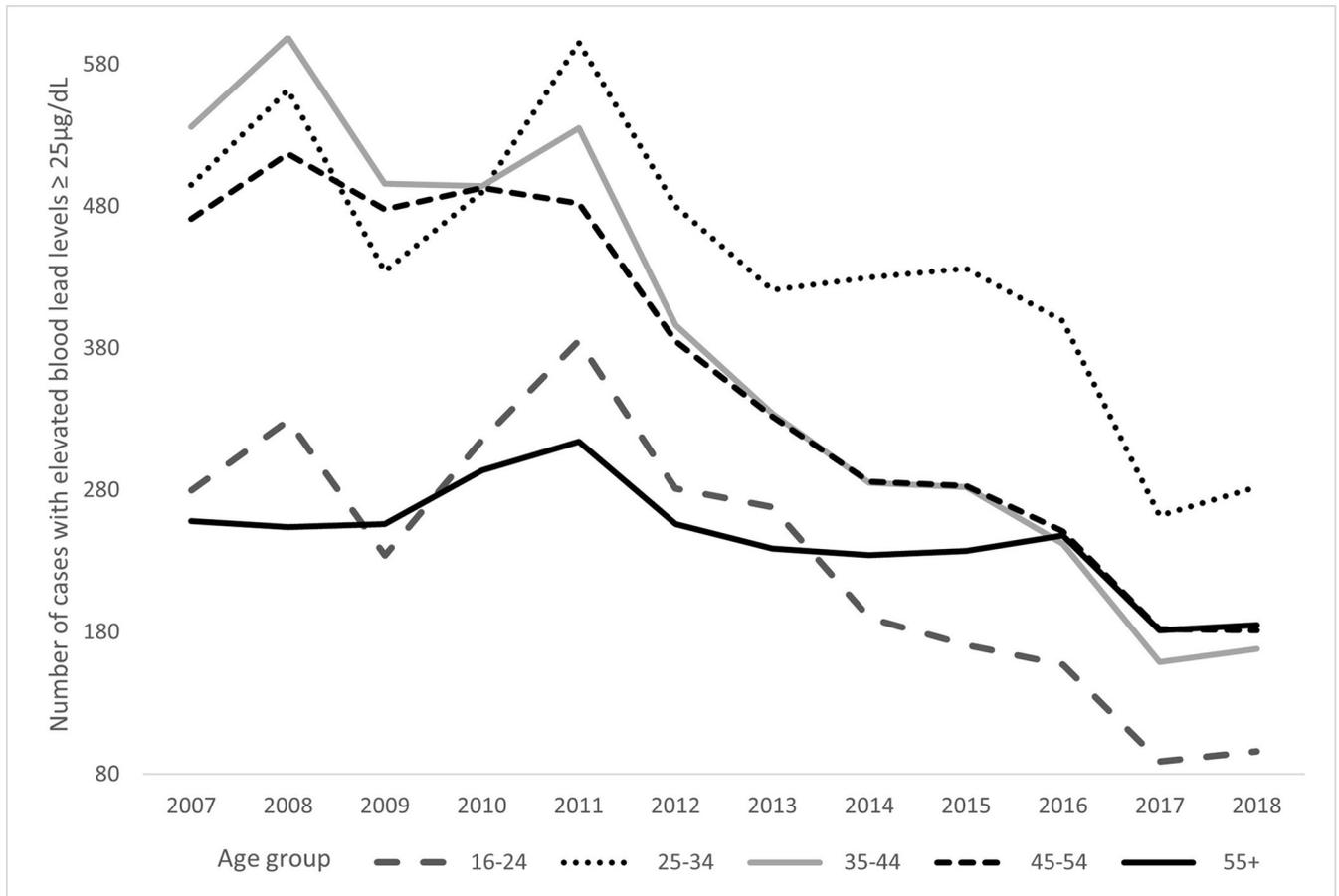
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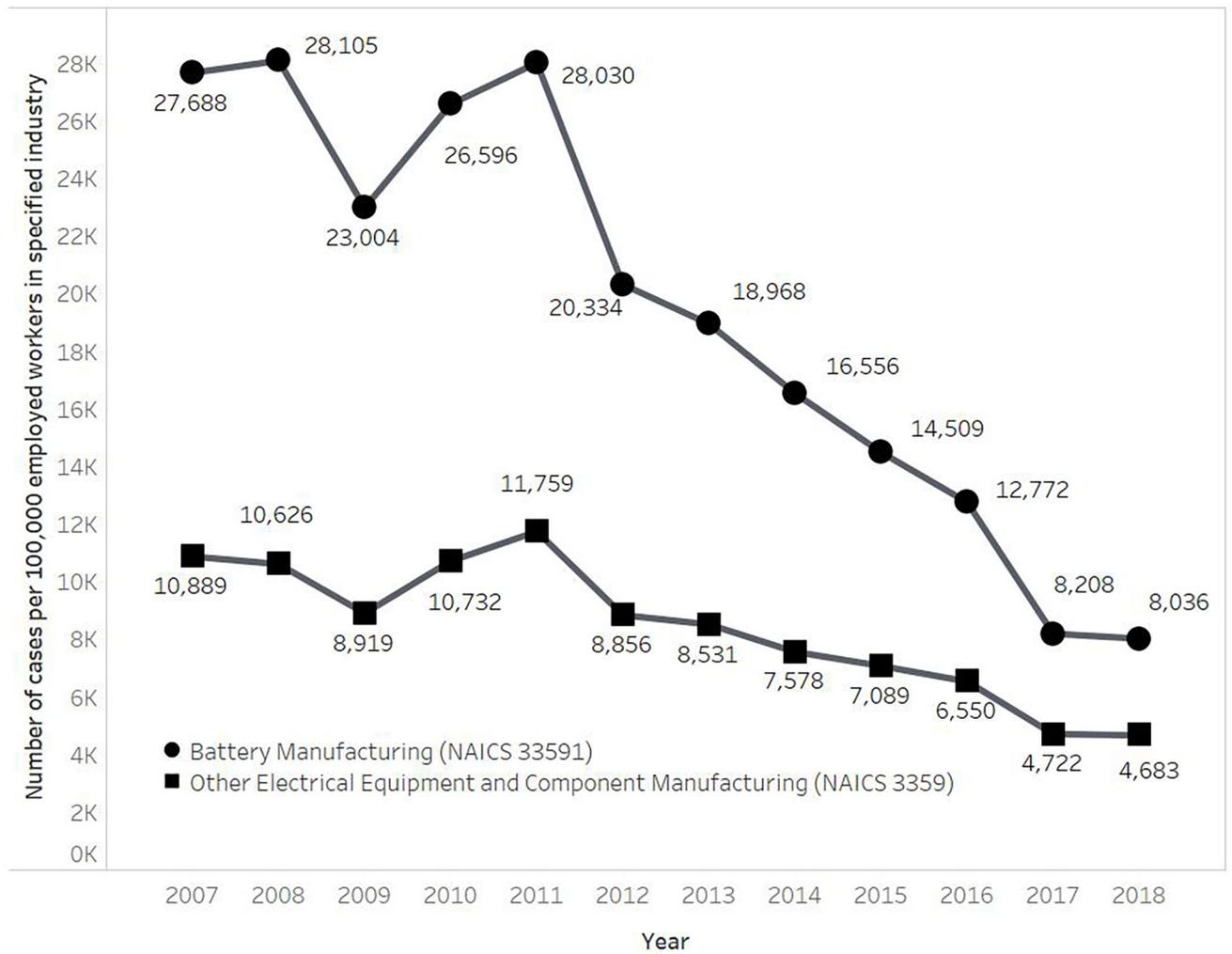
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**Figure 1.** Prevalence rate of elevated Blood Lead Levels  $\geq 25 \mu\text{g/dL}$  per 100,000 employed workers by reporting ABLES states, 2018.  
 Note. ABLES = Adult Blood Lead Epidemiology and Surveillance Program



**Figure 2.** Number of Cases with Elevated Blood Lead Levels  $\geq 25\mu\text{g/dL}$  by Age Group, Pennsylvania, 2007–2018.



**Figure 3.** Annual Prevalence Rate of Elevated Blood Lead Levels  $\geq 25\mu\text{g/dL}$  per 100,000 workers: Other Electrical Equipment and Component Manufacturing (NAICS 3359) and Battery Manufacturing (NAICS 33591) Workers, Pennsylvania, 2007–2018. Note: County Business Patterns data was used to determine the denominator for Battery Manufacturing (NAICS 33591) and Other Electrical Equipment and Component Manufacturing (NAICS 3359)

**Table 1 -**

Demographics of Adults, Aged >16 years, with Elevated Blood Lead Levels  $\geq 25\mu\text{g/dL}$  by Source of Lead Exposure: Pennsylvania, 2007–2018.

Demographics	Total No. (%)	Lead Exposure Source: Occupational No. (%)	Lead Exposure Source: Non-Occupational No. (%)	Lead Exposure Source: Unknown No. (%)	p-value
Total cases <sup>*</sup>	19904	18346 (92)	129 (1)	1429 (7)	
Age					
Mean age (years)	39.6	38.9	61.9	46.5	<0.0001 <sup>†</sup>
Age group					
16–24	2795 (14)	2682 (15)	10 (8)	103 (7)	
25–34	5286 (27)	5024 (27)	4 (3)	258 (18)	
35–44	4526 (23)	4234 (23)	4 (3)	288 (20)	
45–54	4341 (22)	3990 (22)	11 (9)	340 (24)	
55+	2956 (15)	2416 (13)	100 (78)	440 (31)	
Sex <sup>‡</sup>					
Male	19021 (96)	17553 (96)	122 (95)	1346 (94)	0.16 <sup>§</sup>
Female	862 (4)	780 (4)	7 (5)	75 (5)	

<sup>\*</sup>Total cases of with Elevated Blood Lead Levels  $\geq 25\mu\text{g/dL}$  in Pennsylvania were 19,904; 92% were occupational; 1% was non-occupational; 7% were from unknown exposure source.

<sup>†</sup>ANOVA test

<sup>‡</sup>There were 21 cases with other or unknown sex.

<sup>§</sup>Chi-square test

**Table 2 -**

Number of Adult Cases with Elevated Blood Lead Levels  $\geq 25\mu\text{g/dL}$  by Top Eight NAICS Industries and Source of Employer Industry 2007–2018.

NAICS	Source of Employer Industry		Total Cases
	Lab Report * No. (%)	PADOH System † No. (%)	
Other Electrical Equipment and Component Manufacturing industry (NAICS 3359) ‡	15066 (99)	165 (1)	15231
Foundries (NAICS 3315)	6 (1)	762 (99)	768
Nonferrous Metal (except Aluminum) Production and Processing (NAICS 3314)	280 (44)	360 (56)	640
Building Finishing Contractors (NAICS 2383)	2 (1)	278 (99)	280
Highway, Street, and Bridge Construction (NAICS 2373)	0 (0)	143 (100)	143
Other General Purpose Machinery Manufacturing (NAICS 3339)	62 (51)	59 (49)	121
Residential Building Construction (NAICS 2361)	0 (0)	111 (100)	111
Glass and Glass Product Manufacturing (NAICS 3272)	31 (30)	71 (70)	102
Total	15447 (89)	1949 (11)	17396

\* Employer's name was the facility recorded on the individual blood lead test results.

† Employer's name was obtained from PADOH's database from worker interviews and not recorded on the individual blood lead test.

‡ 99% of the cases in NAICS 3359 worked in Battery Manufacturing (NAICS 33591)