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Haley E. Stevens Date

An Assessment of Factors Associated with Increased Blood Lead Levels (BLL) Among Workers in the State of California

By

Haley E. Stevens

Master of Public Health

Epidemiology

Kyle Steenland

Faculty Thesis Advisor

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Haley E. Stevens

Bachelor of Science, University of Michigan, 2013

Faculty Thesis Advisor: Kyle Steenland, PhD

An abstract of

A thesis submitted to the Faculty of the
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Abstract

An Assessment of Factors Associated with Increased Blood Lead Levels (BLL) Among Workers in the State of California

By Haley E. Stevens

Background: Elevated blood lead levels (BLL) can cause a multitude of adverse health effects. Lead use has dramatically been reduced in the past 50 years, however Americans are still occupationally exposed in many industries. NIOSH currently conducts an adult blood lead surveillance program (ABLES) in most US states for those with higher exposure.
Methods: The ABLES database for California from 2003-2013 was used for this analysis to evaluate which demographic factors are associated with high BLL's among workers in California, as well as whether there are factors associated with significant trend changes in BLLs. Multiple linear regression was used to model BLL over time within 12 industries while controlling for age, sex, and Hispanic ethnicity.
Results: There were 508 workers with BLLs above 25 μg/dl, and 58 with levels above 40 μg/dL, indicating a small proportion of workers in California have levels associated with high risk of adverse effects. In California, there was a mean of 9.4 μg/dL among all industries and a downward trend in BLLs over time with a 9% decrease annually. Although BLLs have been decreasing and a majority are relatively low, there may still be adverse health effects associated with low level exposures. Additionally, there are some industries which show slower rates of decrease in BLL levels. Workers in firing ranges actually had increasing BLLs, at 0.5% per year, and also had the highest average BLLs among all industries (15.4 μg/dL). Secondary smelting had the second highest average (15.1 μg/dL) with a low annual decrease of 2.8%. Though copper foundries had a lower mean BLL (10.7 μg/dL), the industry barely saw decreases between 2003 and 2013 with an annual decrease of only 1% per year.
Conclusion: Occupational related BLLs are on average below elevated levels (<10 μg/dL) and decreasing over time in California, however, there are industries with significantly higher mean BLLs than the overall average and are not decreasing with a similar rate. It will be important to continue lowering BLLs in California overall as well as put specific focus on lowering BLLs within those industries with higher mean BLLs and low rates of decrease.

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Background

Lead is a toxic metal that is used in burning fossil fuels and is often combined with other metals to produce alloys which are used to make batteries, ammunition, and other metal products (5). Exposure to lead can cause both acute and chronic adverse health outcomes which increase in severity in response to high doses and/or prolonged exposure. Adverse effects include perturbation of multiple physiologic processes, and organ pathology including but not limited to the heart, bones, intestines, kidneys, reproductive, hematologic, and nervous systems (4). Higher single dose exposures can lead to symptomatic life-threatening intoxication. Even at low level exposures lead can cause cardiovascular and renal effects, cognitive dysfunction, and adverse reproductive outcomes (5). Inorganic lead is also a Group 2A probable carcinogen and has been shown to be associated with higher cancer mortality rates (9).

Common routes of exposure to lead include contaminated air, water, soil, food, and consumer products (5). Notably, occupational exposure is a common cause of lead poisoning in adults. In the United States, approximately 95% of BLLs ≥25 μg/dL in adults are work related (1). Though its use has been dramatically reduced in the past 50 years, lead is still common in many industries, including construction, mining, and manufacturing. In each of these industries, workers are at risk of exposure through inhalation, ingestion, and direct contact (7). Blood lead levels in the US decreased from 12.2 to 2.8 μg/dL from 1976 to 1991 and then to 1.3 μg/dL in 2008 (1). However, some adults still have high occupational exposure to lead. According to estimates made by the National Institute of Occupational Safety and Health, "more than 3 million workers in the United States were potentially exposed to lead in the workplace in the 1980s" (5). National estimates since then are unavailable. However, NIOSH currently conducts an adult blood lead surveillance program (ABLES) in most US states for those with higher exposure (3). In 2005 data from 37 states indicated that approximately 130,000 adults had been tested for blood lead under the ABLES program (2). The current study is based on a sub-set of the ABLES data from California.

US workers continue to be exposed to high levels of lead. For example, in California in the years 2003-2013, based on the data used here, 508 workers were still exposed to lead levels above 25 μg/dl, and 58 to levels above 40 μg/dL. These levels can cause adverse health effects (4). The current US OSHA standard calls for workers to be removed from exposure when they have a blood lead of 50 μg/dL (construction workers), or have 60 μg/dL (other workers) on a single test, or an average of 50 μg/dL or greater on a series of recent tests, and to not return to work until their blood lead drops below 40 μg/dL (7).

There is little literature which explores the trends of BLLs over time within major US industries where lead exposure is common. While it is generally known that occupational BLLs have been decreasing over time, this may not give a full picture of what is going on within industries or different demographic groups (7). Therefore, there is a need to investigate both demographic and occupational factors that may be associated with or direct contributors to higher exposures of lead among workers in California. This will provide the California Department of Public Health (CDPH) better insight into which groups need better protection and intervention to reduce workplace environmental lead exposure. This analysis aims to address these gaps in the literature, by evaluating what demographic factors are associated with high BLL's among workers in California as well as if there are factors associated with significant changes in trends of blood lead levels.

Methods

The Adult Blood Lead Epidemiology and Surveillance program, sponsored by NIOSH, began collecting state-level data on blood lead levels in 1987 (3). Originally, States began collecting data only for individuals with blood lead levels greater than 25 μg/dL, but later began to also collect data for lower levels. Lab based blood lead tests were primarily conducted in response to occupational exposure. ABLES coverage expanded from 4 states to 41 states between the years of 1987 and 2012 (3). The state of California's de-identified ABLES dataset was obtained for this analysis. Observations between the years of 2003 and 2013 were used in order to analyze only years in which BLLs were collected at all levels of exposure and not just those greater than 25 μg/dL, which was done prior to 2003 in California (3).

Observations were restricted to those based on known occupational exposure, within fee-paying industries (employers in industries with 10 or more employees where there is evidence of a potential for lead poisoning are required to pay prevention fees), and non-owner-operators. Participants had to be of legal working age (16) when the first BLL was taken and restricted to ages <70 for their last BLL observation recorded. Only BLLs within the 12 highest frequency industry categories (>1000 BLL observations) were used in the final model analysis by industry since there were over 200 total industry categories with recorded BLLs. BLLs which were below detection levels were divided by 2;. 46 observations were cut which had "below detection" coding but had BLL of >5μg/dL and were therefore considered incorrect data points.

After restrictions the final sample size for total BLL observations was N=81,112. However, individuals could have more than one BLL recorded between 2003 and 2013, and there were N=20,020 individual workers in the dataset.

BLLs were obtained in laboratories across the state, assembled by CDPH. Industry was reported by employers and coded to an industry category by the standard NAICS code guidelines. Age, gender, and ethnicity were self-reported. Data on race was mostly missing and was not used in this analysis.

Most data on Ethnicity however had a high percentage of missing data (76% unknown) so Hispanic surname was used as a proxy to estimate Hispanic ethnicity as this is often used in analysis by CDPH.

Data analysis was performed using SAS 9.4 statistical software. Multiple linear regression, with log blood lead level as the outcome, was used to model the change in blood lead levels over time among different industries while controlling for age, gender, and Hispanic surname. BLL was a continuous variable measured in μg/dL; it was log transformed for normality (Figure 3.). Date of BLL test was categorized into one year intervals from 2003-2013 and assessed as both a continuous and categorical variable. Industry was a categorical variable with 12 categories based on the highest frequency NAICS categories in this dataset. Age was categorized to ten year intervals from ages 10-19 through 60-69. Hispanic Ethnicity Surname was assigned by CDPH and was a binary categorical variable indicating an individual has a Hispanic surname.

Descriptive statistical analysis for both the outcome variable (BLL) and independent variables (BLL test year, age, gender, and Hispanic surname) was performed. BLL observations are not all independent as many individuals have multiple BLLs recorded during the time period (2003-2013), so a "repeated" statement in SAS GENMOD was used during model construction to account for correlated observations. The full model was checked by examining collinearity diagnostics to check for multicollinearity, examining residual plots to check error variance assumptions (i.e., normality and homogeneity of variance), examining influence diagnostics to check for outliers, and examining significance of coefficient estimates to trim the model. Variables were selected due to their availability in the dataset. Race was not included due to the high proportion of missing. The final model used the variables described above, i.e., age, sex, Hispanic surname, industry, and year of testing. Trends with time were tested by including year as a continuous variable. The final model fit was evaluated by r-square and residuals to check for normality. The residuals appeared random with no apparent trend, indicating good-fit and were approximately normally distributed.

Results

After restrictions the final dataset used in analysis contained 81,260 BLL observations among 20,020 individuals. Of those 20,020 individuals, 47.2% only had one BLL recorded between 2003 and 2013, with the mean number of BLL observations being 4, the median being 2, and the max being 121 BLLs recorded for one individual. There was an average of 7,387 BLL observations among an average of 4,173 individuals per year. The continuous variable age was normally distributed (mean 40.8, std 11.6). Table 1. shows approximately 60% of individuals had a Hispanic surname while the rest did not and most of the individuals in the dataset were male (96%) The correlation coefficient of BLL and year is -0.17 and the correlation coefficient of BLL and year is -0.22; both significant with a p-value <.0.0001.

Among the 12 industry categories (Table 2.), Secondary Smelting (battery recycling, lead recovery from scrap) had the largest number of BLL observations while Copper Foundries (except die casting) had the smallest number of BLL observation. However, the Remediation Services (lead paint abatement, environmental clean-up) category had the most number of individuals and the Other Metal Valve and Pipefitting Manufacture category had the smallest number of individuals. The overall mean BLL for all observations from 2003 to 2013 was 9.4 μg/dL with a minimum of 0.05 μg/dL and maximum of 79. The industry category with the highest mean BLL from 2003 to 2013 was All Other Amusement (firing ranges) with a mean of 15.4 μg/dL and the industry category with the lowest from was Remediation Services (lead paint abatement, environmental clean-up) with a mean BLL of 3.1 μg/dL.

Table 3. shows the estimates for the full model of log BLL over time adjusting for age, Hispanic ethnicity, and sex. The overall observed mean BLL decreased over time beginning with an observed mean BLL of 12.8 μg/dL in 2003 and ending with an observed mean BLL of 6.8 μg/dL in 2013. Figure 1. shows the observed mean BLLs over time and a smooth curve of predicted BLLs over time

from the model. 5% of BLL observations where greater than 25 μg/dL and 41% of observations were less than 5 μg/dL.

Figure 2. displays the industry-specific change over time of BLLs, beginning with the industry-specific model predicted level in 2003 (adjusted for age, gender, and Hispanic ethnicity). All industries have decreasing estimated BLLs over time, with an average yearly decrease of 9%. One exception was the category, All Other Amusement (firing ranges), which have notably higher BLLs than other industries, and furthermore had increasing BLL estimates over time. The average decrease in BLLs in copper foundries also showed little decrease over time (1% per year). All other industries showed a notable decrease over time, which was largely similar among industries with the exception of 'Heavy Construction' which had a much sharper decline over time than other industries (22% per year).

Discussion

Overall, occupational related BLL levels in California within fee-paying industries known to be using lead, and non-owner-operators, have been significantly decreasing from 2003-2013. When adjusted for age, gender, and Hispanic surname (an estimate of Hispanic ethnicity), the exponentiated regression line of logBLL over time in Figure 1. models the observed trend. The decrease in overall average BLLs however is not steady and appears to be leveling out as the curve approaches 2013. If the trend of the curve continues, occupational related BLLs will continue to decrease but at a progressively slower rate, and will not approach 0 μg/dL for many years. The model estimating overall average BLL over time is consistent with both national data and CDPH reports which state occupational exposure related BLLs have been significantly decreasing since the 1980's (7).

Figure 2. reveals all the industries except one, have decreasing BLLs overtime, consistent with the overall combined trend. The industry of All Other Amusement (firing ranges) however, has increasing average BLL levels from 2003 to 2013 (.5% per year) and also had the highest average BLL (15.4 μg/dL). Although overall occupational related BLL levels in California have been decreasing, it is important to note that not all BLLs are decreasing. Pin pointing BLLs that are still increasing will be important in order for CDPH to implement the proper interventions or policies to protect all of their workers. All Other Amusement (firing ranges) will be a key industry to keep an eye on in the coming years to assess whether the trend is changing.

Secondary smelting (battery recycling, lead recovery from scrap) had the second highest mean BLL (15.1 μg/dL). BLLs are decreasing within this industry but only at a rate of 3% per year which is the second slowest rate of all the industries included in this study. With such a high mean BLL and slow percent decrease from 2003-2013, Secondary smelting should be a second important industry for CDPH to monitor and focus on reducing the BLLs in.

Another key industry to keep an eye on is Copper Foundries (except die casting), which although it exhibits decreasing BLLs over time, has the smallest yearly BLL decrease (1%) compared to all other industries and appears almost flat compared to the other industry models over time illustrated in Figure 2. The combined "All industries" BLL estimate regression model can be misleading when it shows greater percent decreases in BLLs over time than what all industries are experiencing. Though occupational related BLLs are decreasing overall in California, some industries are not decreasing as rapidly as the rest and may indicate areas for CDPH to focus on, in order to reduce BLLs in all industries equally.

While there are industries that either have increasing BLLs or slower rates of decrease than what is seen overall, there is one industry that is doing exceptionally well and shows the most rapid decrease in BLLs comparatively from 2003 to 2013, which is Other Metal Valve and Pipefitting Manufacture (heavy construction contractors incl bridge seismic retrofit). Figure 2. Illustrates this trend with a very steep curve which shows a dramatic decrease in BLLs from 2003 to 2013 at a rate of 22% a year. This industry shows decreasing BLL levels at a faster rate than any other industry or all industries combined which may mean the industry could provide insight into why their rate of decrease is the greatest, and possibly ways to better reduce BLLs within other industries.

Further directions of this study include looking more closely at the trends of average BLLs over time for each industry and investigating why the trends differ among industry, with all industries combined, and with the national trends. Exploring why some industries have increasing or slower decreasing average BLLs while others have had very rapid decreases comparatively can help provide evidence for successful methods of reducing BLLs. Additionally, it would be beneficial to collect more data involving demographics as well job title and duties for the industries of All Other Amusement (firing ranges), Secondary smelting (battery recycling, lead recovery from scrap), and Copper Foundries (except die casting) in order to look more closely at their increasing BLL rate and slowly decreasing BLL rates respectively. More information within these industries could potentially lead to explanations of their observed trends. Finally, it would be interesting to look at similar analyses of ABLES datasets within other states to see how the overall trends and trends within industry compare. This would show whether certain industries have similar trends nationwide or if each state has specific industry trends over time that may or may not be similar to the national rate of BLL decrease among those occupationally exposed.

The strengths of the California ABLES data set are the large number of observations, over a wide range of years, allowing assessment of long term trends. In addition, industry is available for most observations, enabling assessment of trends within industries however, an important limitation is lack of occupation within industry. Industry alone is less of predictor than type of job within industry, but these data are not available for this data set. Other limitations include the lack of some potentially important demographic variables, such as level of education (SES), which might affect both blood lead levels and type of industry, and hence act as a confounder for assessment of BLL by industry.   However, the lead levels in this data set are mostly due to occupational exposure, and likely were be less influenced by demographic variables. Additionally there were a high proportion of unknown race as well as Hispanic ethnicity data which prevented them from being included in the model. Hispanic surname was an appropriate proxy for Hispanic ethnicity which allowed it to somewhat be controlled for, however race could not be considered in the model at all which makes it a potential unmeasured confounder.

This analysis found that occupational related BLL levels in California are decreasing over time which is consistent with both California specific trends reported by the CDPH as well as national trends reported by NIOSH. While most industries did exhibit similar decreasing BLLs over time as the trend found in all industries combined, three industries stood out as having significantly different trends. All Other Amusement (firing ranges) was found to have increasing BLLs over time, and Secondary Smelting and Copper Foundries (except die casting) were found to have a much slower rates of decreasing BLLs over time comparatively.

References

1. Centers for Dieases Control and Prevention. Adult Blood Lead Level Epidemiology & Surveillance (ABLES*)*. NIOSH Workplace Safety and Health Topics: http://www.cdc.gov/niosh/topics/ABLES/pdfs/. Accessed March 17, 2015

2. Centers for Disease Control and Prevention. Blood lead level data, 2002-2005. http://www.cdc.gov/niosh/topics/ABLES/pdfs/2002-2005lead_data.pdf. Accessed March 15, 2015.

3. Centers for Disease Control and Prevention. Data into action. NIOSH blood lead surveillance program contributes to a decline in national prevalence.The National Institute for Occupational Safety and Health (NIOSH): http://www.cdc.gov/niosh/docs/2012-164/. Accessed March 15, 2015.

4. Centers for Disease Control and Prevention. Lead. http://www.cdc.gov/nceh/lead/. Accessed December 15, 2015

5. Centers for Disease Control and Prevention. Workplace Safety and Healh Topics. Lead. http://www.cdc.gov/niosh/topics/lead/. Accessed December 15, 2015

6. Centers for Disease Control and Prevention. Toxic Substances Portal. Lead. http://www.atsdr.cdc.gov/substances/toxsubstance.asp?toxid=22. Accessed December 15, 2015

7. Occupational Safety and Health Administration. Lead standards. https://www.osha.gov/SLTC/lead.Accessed March 17, 2015.

8. Staudinger KC, Roth VS (February 1998). "Occupational lead poisoning".Am Fam Physician **57** (4): 719–26, 731–2. PMID 9490995.Accessed March 17, 2015.

9. World Health Organization International Agency for Research on Cancer. IARC Monographs on the Evaluation of Carcinogenic Risks to Humans. Volume 87. Inorganic and Organic Lead Compounds. Retrieved from http://monographs.iarc.fr/ENG/Monographs/vol87/mono87.pdf. Accessed April, 7, 2015

Tables

Table 1. Characteristics of the California ABLES dataset 2003-2013

	BLL Observations (n=81260)		Individuals (n=20020)	
	No.	**%**	**No.**	**%[a]**
Year				
2003	7946	9.8	3877	-
2004	7802	9.6	4159	-
2005	7405	9.1	4213	-
2006	7077	8.7	4145	-
2007	7423	9.1	4350	-
2008	8086	10.0	4480	-
2009	7649	9.4	4079	-
2010	7973	9.8	4488	-
2011	8143	10.0	4602	-
2012	8023	9.9	4657	-
2013	3733	4.6	2856	-
Age				
10-19	1383	1.7	959	4.8
20-29	15533	19.1	5570	27.8
30-39	20452	25.2	5650	28.2
40-49	23225	28.6	4875	24.4
50-59	16204	19.9	2477	12.4
60-69	4463	5.5	489	2.4
Hispanic Surname				
Yes	24739	30.4	11879	59.3
No	56521	69.6	8141	40.7
Gender				
Male	77984	96.0	19109	95.7
Female	3223	4.0	858	4.3

[a.] Individuals can have observations in more than one year and multiple observations per year

Table 2. Characteristics of Industry Categories in the California ABLES dataset 2003-20013

	BLL Observations (n=81260)		Individuals (n=20020)	BLL (µg/dL)				
	No.	**%**	**No.**	**Mean(SD)**	**Median**	**Min**	**Max**	**Decrease Per Year**
Industry								
All Other Amusement (firing ranges)	1452	1.8	547	15.4 (10.5)	13.7	0.05	65.4	-0.5%
Commercial and Institutional Bldg Construction	2902	3.6	1,530	5.9 (6.0)	3	0.05	47	14%
Copper Foundries (except die casting)	1,080	1.3	321	10.7 (7.9)	9	0.05	70	1%
Highway, Street, and Bridge Construction	3261	4.0	1,053	3.3 (4.0)	2.4	0.05	46	5%
Other Heavy and Civil Engineering Contractors (heavy construction contractors incl bridge seismic retrofit)	1931	2.4	727	10.3 (9.5)	7	0.05	46.3	22%
Other Metal Valve and Pipefitting Manufacture	1069	1.3	165	9.1 (5.5)	8	0.05	48.3	4%
Paint and Wall Covering Contractors	7747	9.5	3,032	6.6 (8.3)	3	0.05	76	9%
Recyclable Material (scrap metal and electronics recycling)	5332	6.6	2,333	7.7 (8.4)	5	0.05	63	9%
Remediation Services (lead paint abatement, environmental clean-up)	13530	16.7	4,993	3.1 (3.8)	2	0.05	79	10%
Secondary Smelting (battery recycling, lead recovery from scrap)	18974	23.4	997	15.1 (7.8)	14.7	0.1	66	3%
Site Preparation Contractors (wrecking and demolition)	5530	6.8	2,182	3.5 (3.9)	2.4	0.05	59	12%
Storage Battery Manufacture	18452	22.7	2,873	12.5 (7.6)	11.5	0.15	60.5	6%
All Industry	81260	-	*	9.4 (8.4)	7	0.05	79	9%

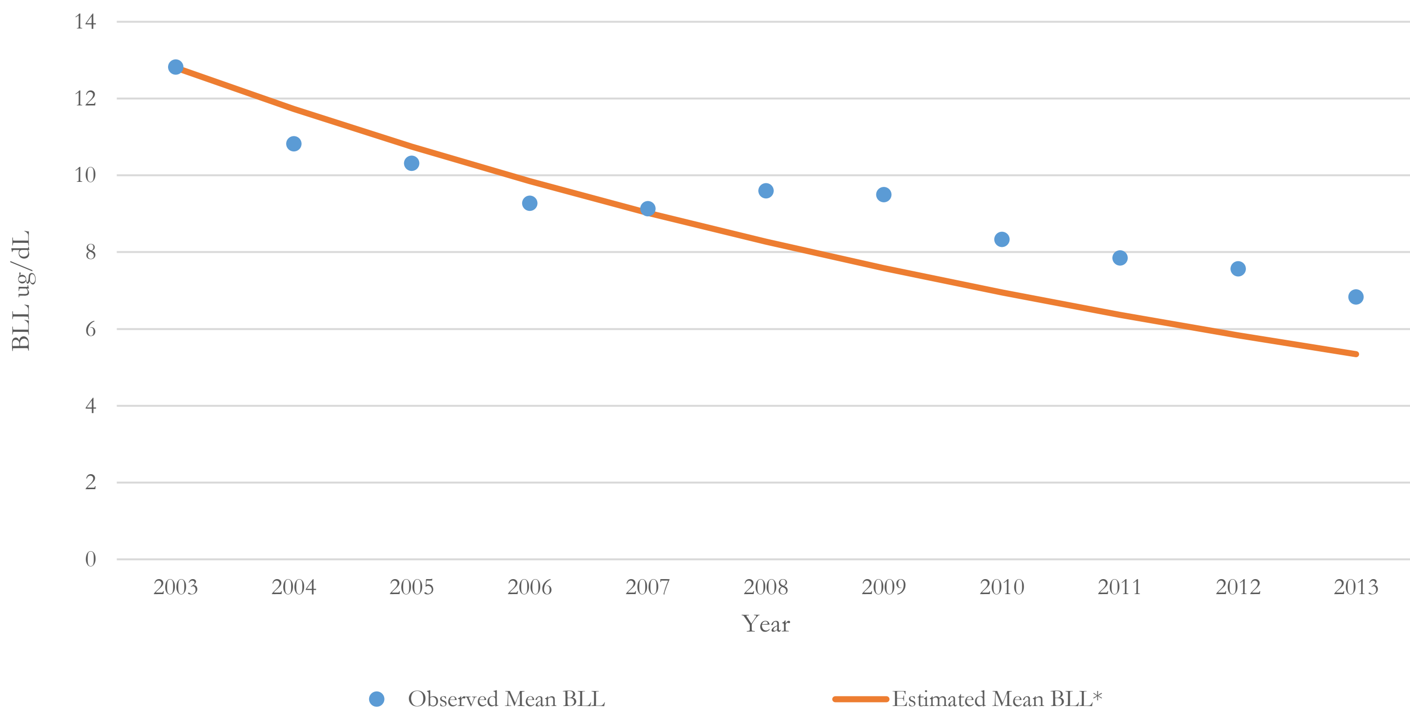
* Individuals do not add up to 20,020 because some individuals have BLLs recorded for more than one industry at one or more time points

Table 3. Full Multiple Linear Regression Model
Model: LogBLL=Year agecat hispsurn sex[a]

Parameter	Group	Estimate	Standard Error	95% Confidence Interval		P-value
Intercept		1.41	0.05	1.32	1.51	<0.0001
year		-0.09	0	-0.09	-0.08	<0.0001
agecat	20-29	0.36	0.05	0.26	0.45	<0.0001
agecat	30-39	0.35	0.05	0.26	0.50	<0.0001
agecat	40-49	0.56	0.05	0.47	0.66	<0.0001
agecat	50-59	0.91	0.05	0.81	1.01	<0.0001
agecat	60-69	1.16	0.06	1.03	1.29	<0.0001
hispsurn	yes	0.29	0.03	0.23	0.34	<0.0001
sex	female	-0.26	0.07	-0.39	-0.13	<0.0001

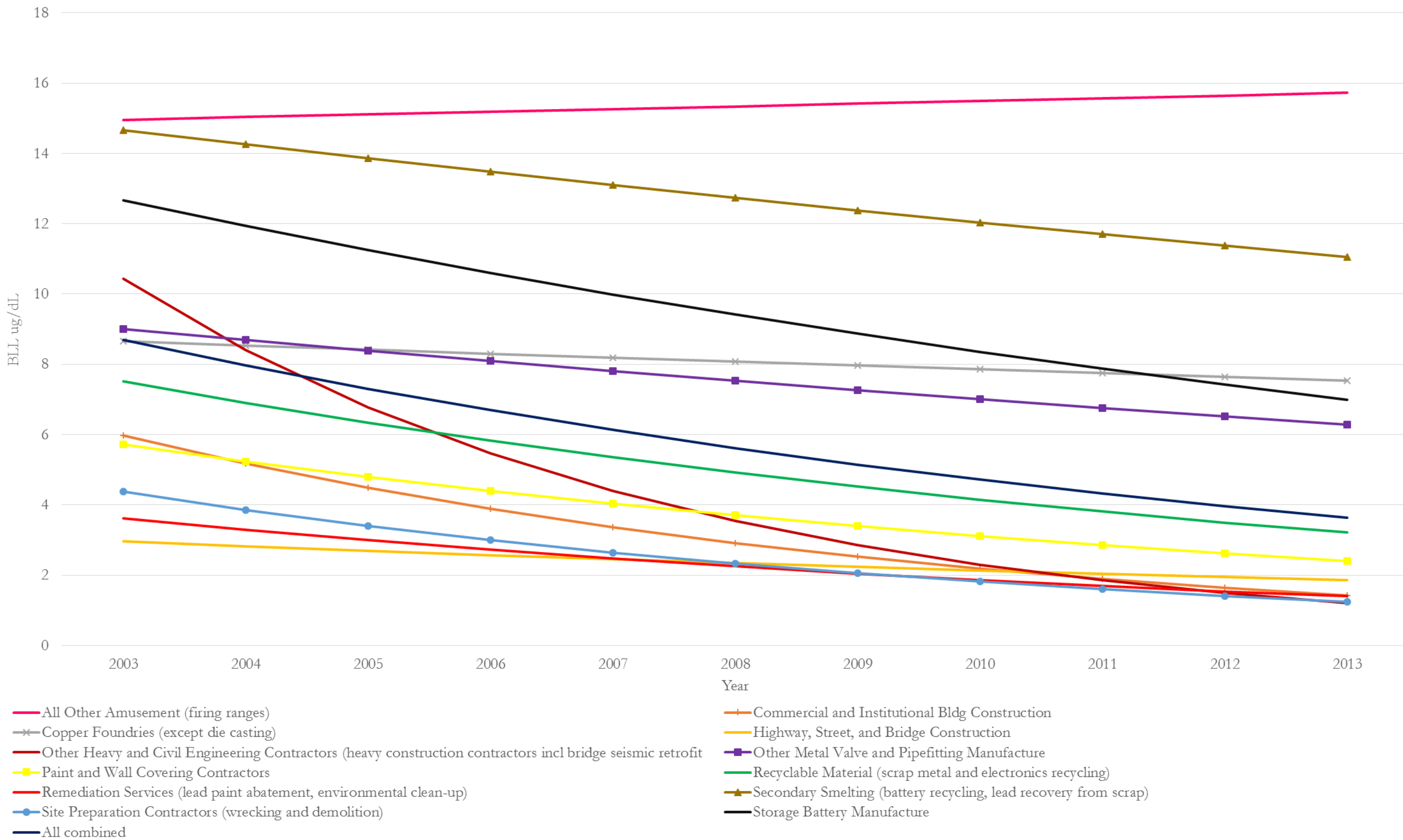
[a.] The referent groups are year: 2003, agecat: 10-19, non-Hispanic surname, and male.

Figure 1. Observed and Estimated BLL Over Time



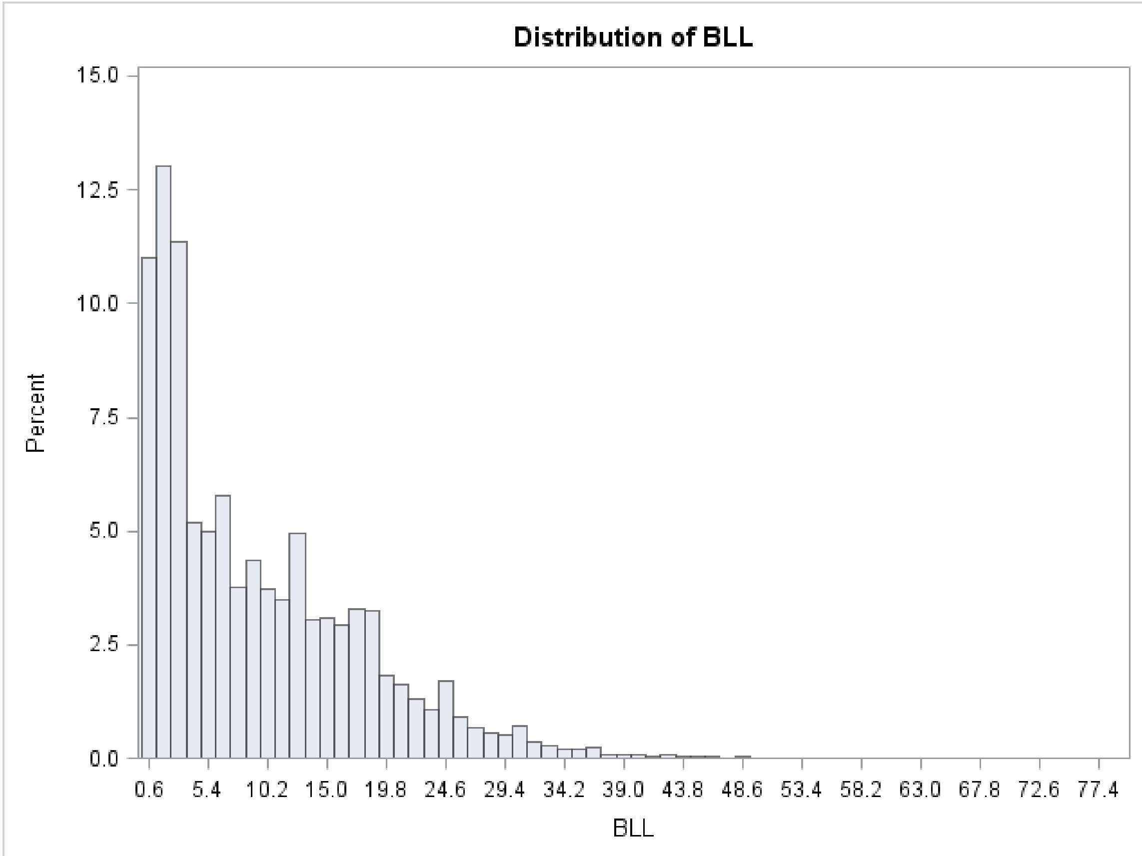
*Estimated mean BLL uses the slope of Year variable from full regression model of logBLL over time, adjusted for age, hispanic surname, and gender with year: 2013, agecat: 10-19, male, and non-hispanic surname as the referent groups. Intecept for estimated mean BLL is the observed mean value for 2003.

Figure 2. Adjusted BLL Estimate Among Industry Over Time, Begining at Average Estimated BLL within each Industry in 2003*



*Estimated mean BLL uses the slope of Year variable from full regression model within each industry of logBLL over time, adjusted for age, hispanic surname, and gender. Intecept is the estimate within each industry for the year 2003, average age within industry, weighted sex, and weighted hispanic surname.

Figure 3.



Distribution of BLL
Percent
15.0
12.5
10.0
7.5
5.0
2.5
0.0
0.6
5.4
10.2
15.0
19.8
24.6
29.4
34.2
39.0
43.8
48.6
53.4
58.2
63.0
67.8
72.6
77.4
BLL