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Variability and trend of multiple blood lead measures among construction and manufacturing workers

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ABSTRACT

Objectives This study evaluated multiple blood lead measures collected over time and assessed differences arising from exposure and testing variability.
Methods Blood lead data was used to compare individuals from manufacturing and construction occupational cohorts. Trends of blood lead levels (BLLs) over time were analysed using mixed model analysis. Random selection of BLL values was used to determine the improvement in the precision of mean BLL estimates as the number of tests increased.
Results From 2003–2007, there were 619 manufacturing and 657 construction workers with more than one blood lead test reported. Construction workers had much more variability in their blood lead trends. They also tended to have less frequent follow-up blood tests compared with manufacturing workers. Both occupational cohorts had persistent BLLs that resulted in many workers with chronically high blood lead values (>25 μg/dL). Approximately 11.2% of construction workers and 34.8% of manufacturing workers with an initial blood lead test above 25 μg/dL remained above this blood level through the study period. The precision in the mean BLL estimates increased more substantially for construction workers when compared with manufacturing workers as the number of blood lead tests per worker increased.
Conclusions This study confirmed differences in the pattern of blood lead tests and the resulting trends for manufacturing compared with construction workers. It also suggested that the number of blood lead tests performed on a worker is an important consideration in the assessment of a worker's mean blood lead estimate, and this is particularly true for workers with highly variable exposures.

What this paper adds

- It has been well accepted that construction workers experience highly variable exposures to lead as a result of lead-based paint on old structures.
- It has been established that construction workers and manufacturing workers in certain sectors, such as lead-acid battery production, are occupational cohorts requiring targeted interventions because of their frequent and high lead exposures.

What we know as a result of this study

- For the first time, this study investigated the trend and blood lead experience of workers over time in these two occupational cohorts and found that many workers experience persistent blood lead levels despite regulatory interventions designed to protect workers from exposure.
- This study also found that the number of blood lead tests conducted on an individual employee impacts the precision of their mean blood lead estimate and this impact is more significant for workers with highly variable exposures, such as construction workers.

Important policy or practice implications of the research

- Regulatory interventions should be further enhanced to reduce the persistence of elevated blood lead levels (BLLs) (>25 μg/dL) among workers and should account for the workers BLL trend over time rather than single-point measurements.

INTRODUCTION

Occupational exposure to lead continues to be an important health problem among the global workforce. The US National Institute for Occupational Safety and Health has supported a surveillance programme since 1985 that collects and evaluates adult blood lead values through the Adult Blood Lead Epidemiology and Surveillance (ABLES) programme. This surveillance programme is currently administered through 41 state health departments (http://www.cdc.gov/niosh/topics/ABLES/ables.html), including New Jersey. An extensive surveillance database exists as a result of this programme, which contains multiple blood lead measures over time on many individuals occupationally exposed to lead. This longitudinal data offers many potential opportunities to explore the meaningfulness of blood lead measurements on worker health.

Toxicology and clinical studies suggest that blood lead measures are indicative of recent exposures,

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typically within the last several weeks.[1 2] Cumulative and chronic exposures are often better characterised by bone lead measurements using in vivo X-ray fluorescence and can be an indicator of cumulative lifetime lead burden over many years.[1 2] However, in day-to-day practice these bone measures are often not practical to obtain. Therefore, many clinicians are faced with the challenge of interpreting the meaning of multiple blood lead measures in terms of risk and exposure within occupational populations. It has been recognised for some time that single point cross-sectional measurements are not highly predictive of potential adverse health outcomes and therefore many researchers have used various metrics to assess exposure and risk.[3–8] Levin and Goldberg[1] discussed the importance of repeated blood lead measures on occupational cohorts over time for effective medical management. The study presented in this paper builds on this previous research by investigating metrics to assess exposure that use repeated blood lead measures and thus capitalise on the longitudinal nature of the data as it relates to two important groups of workers.

Occupational health professionals demonstrated years ago that blood lead data fluctuates over time and will fluctuate with removal and return to lead-related work tasks.[9] Tak *et al*[10] evaluated workers that triggered the medical removal provisions of the Occupational Safety and Health Administration (OSHA) lead standards and found that less than 50% of the workers who triggered medical removal were retested within 4 weeks of their removal, less than 50% had the appropriate follow-up and less than 29% meet the criteria for eligibility to return to lead work. Recently, the National Institute for Occupational Safety and Health found that manufacturing and construction are currently the most frequently reported industries with elevated blood lead values among their workers.[11] However, the trends of workers' blood lead values over time within these important industrial subsectors have not yet been explored despite the extensive database that exists.

In addition, it is unclear how frequently blood lead testing should be done to accurately characterise exposure over time in occupations, such as construction, that have highly variable exposures. Currently, the US OSHA general industry lead standard[12] and OSHA construction lead standard[13] require blood lead testing every 6 months when airborne exposure limits exceed the action level, which is set at 30 μg/L in air. However, workers medically removed from their job tasks involving lead exposure must have their blood levels monitored every month until their level falls below 40 μg/dL of blood. Despite the regulatory requirements, a significant scientific uncertainty still remains regarding the most optimal blood testing frequency to accurately characterise employees' lead burden over time and prevent overexposure. Levin and Goldberg[1] suggested that for certain occupations, such as construction, it is imperative to conduct blood lead testing more frequently because less frequent testing schemes are likely to miss opportunities to quickly detect and respond to excessive exposures.

This paper focuses on three specific aims: (1) to evaluate and describe the repeated blood lead measures among construction and manufacturing occupational cohorts, (2) to evaluate and compare the longitudinal blood lead trends of workers in each cohort and (3) to conduct an analysis that assesses the precision of worker mean BLL estimates as the number of tests performed on each worker in each occupational cohort increases, where construction represents a group with highly variable exposures and manufacturing represents a group with fairly consistent exposures over time.

METHODS

This study used the ABLES database maintained by the New Jersey Department of Health (NJDOH) and was approved by the Institutional Review Boards (IRBs) of the NJDOH (IRB protocol # 0367), Old Dominion University (Protocol #11-014), and the University of Medicine and Dentistry of New Jersey (protocol #02200900257). This database depends on reporting of blood lead tests directly submitted by commercial and hospital-affiliated laboratories. Prior to 2003, only blood lead tests above specified levels were required to be reported; by mid-2003 universal reporting had been implemented which required reporting of all blood lead test results, primarily in electronic format from large testing laboratories.[14 15] Data was available from the NJDOH for tests conducted from June 2003 through December 2007. Thus, any adult blood lead test analysed by a New Jersey lab or test done on an adult working or residing in New Jersey should have been reported to NJDOH and included in this database. However, some under-reporting was likely as this is a recognised challenge with the ABLES programmes. Laboratory reporting forms ask for employer and the Standardized Industrial Classification (SIC) code for adults in addition to identifying and specimen information. If the employer but not SIC was included, then NJDOH staff would add the SIC code based on industry and commercial databases. For laboratory forms without employers listed, it was not possible to identify whether the test was indicated for occupational or non-occupational reasons. Because the database prior to 2003 did not include blood lead tests under 25 μg/dL, it was not possible to distinguish workers new to the system from 2003–2007 and those who might have had previous tests conducted prior to 2003. Details on the database and on the preparation of the database to construct a longitudinal file of individual and repeat blood lead tests based on a unique identification number for each subject are given by Lu *et al*.[16]

Description of repeated blood lead measures among occupational cohorts

Cases with blood lead tests recorded between 2003 and 2007 that were employed in construction or manufacturing industries were included in this analysis. These groups were identified through the review of the reported SIC codes. Study staff experienced with the ABLES registry and industrial hygiene reviewed all the SIC codes with the goal of grouping similar patterns of exposure. Several SIC codes represented small distinctive industries with a limited number of workers and a small number of tests. Examples included police, telecommunication workers, auto repair workers and stained-glass artists. These smaller groups were excluded (63 individuals). The remaining individuals (N=1577) were associated with two groups of employers assumed to represent two basic patterns of lead exposure in New Jersey: manufacturing and construction. SIC codes related to construction included General Construction (1521, 1522, 1541, 1542, 1742, 1751, 1611, 1622, 1623, 1629, 1799, 1795, 1721, 1752, 1794); Handling Scrap (4953, 4959, 5093, 5051); and Structural Steel (1791, 1796). SIC codes included in this study for manufacturing included Chemical Production & Pigments (2821, 2851, 2816, 2819, 2865, 2869, 2891, 3089, 3087, 3083, 3081, 3082, 2899, 2892, 2893), Storage Battery manufacturing (3691), and Electronic Not Otherwise Specified (3679). Electronic Not Otherwise Specified was frequently used by some NJDOH coders to identify employees working in Battery manufacturing.

Statistical methods

We defined the baseline blood lead level (BLL) as that of the first blood test within the years of 2003 to 2007. All statistical analyses were conducted by stratifying individuals into one of the following strata according to the baseline blood lead distribution: (1) 0 to less than or equal to 5 μg/dL, (2) greater than 5 to less than 10 μg/dL, (3) greater than or equal to 10 to less than 25 μg/dL and (4) greater than or equal to 25 μg/dL. These strata were chosen for several reasons related to the logistics of the laboratories and the goals of public health programmes. The less than or equal to 5 μg/dL category was thought to be representative of the upper limit of the limit of quantitation (LOQ) for many commercial laboratories and therefore crude values reported likely lacked precision. The greater than 5 μg/dL to 10 μg/dL category was chosen because that represents adult blood lead values not requiring interventions by many public health agencies. The greater than 10 μg/dL to 25 μg/dL category was chosen because many public health agencies may recommend an intervention to reduce lead exposure. The >25 μg/dL category was chosen because the Healthy People 2010 goals aim to reduce all lead exposures below this level and because values above this level typically result in an intervention by many public health agencies. Descriptive statistics were computed for each of the two occupational groups studied here, construction and manufacturing. In addition, mixed model analysis was used to calculate and compare the length of time between blood tests. A simple correlation analysis was also conducted by computing the average length of time between tests for each individual and then computing the Pearson correlation coefficient between actual baseline BLL values and average length of time between tests.

Longitudinal trend analysis

The trend of BLLs among the construction and manufacturing groups was assessed using mixed model analysis to effectively describe the shape of the trend for each group. Specifically, BLL trends, stratified by the category of the baseline values, were modelled using natural splines with knots at every 60 days in the follow-up period. A sensitivity analysis with knots at every 30 days and 180 days in the follow-up showed a similar result. A random intercept was included to account for the intrasubject correlation between repeated measures of the same subject. Residuals and Akaike's information criterion[17] were used to evaluate the model fit. The fixed effects represented the population average trend based on the independent random error assumption of the random effects linear regression.

Impact of the number of blood lead tests

Only individuals with at least four BLL measurements between 2003 and 2007 were included in this analysis (n=907) and only their blood samples collected between 2003 and 2007 were included in the calculation of the mean. The 907 individuals included in this analysis corresponded to a total of 9417 blood tests between 2003 and 2007. Data prior to 2003 was not used because during this time it was common practice to ignore blood lead tests below 25 μg/dL, resulting in significant missing data for individuals in the dataset and potentially inflating their apparent mean value. Therefore, we used the sampling frame of 2003 through 2007 because this dataset contained all blood lead tests conducted on each individual during that time period. The mean was calculated by using the value reported by the laboratory, even if the sample was thought to be below the LOQ. A decision was made to use the crude value reported by the laboratory to calculate the mean, even in the 0–5 μg/dL strata, because there was great variability among the laboratories with respect to their LOQ. The LOQ could range anywhere from 1 μg/dL to 5 μg/dL and could even vary among the sample dates of the same laboratory.

The impact of the number of tests on the variability of a worker's mean BLL estimate was determined by an empirical experiment using random selection. SAS V.9.2 'Proc Surveyselect' procedure using simple random sampling was used to randomly select the data points for this analysis. Specifically, we evaluated the impact on the variability of the mean BLL estimate by randomly selecting two, three or four BLL measurements, following a simple two-step procedure: Step (1) we randomly selected two, three or four BLL measurements per person using simple random sampling and obtained the differences between the mean calculated from these randomly selected tests for each person and the mean calculated using all their BLL measurements; Step (2) We repeated the first step 1000 times to account for sampling variability. Histograms were generated to evaluate changes in the distribution of differences between the means for construction and manufacturing workers when the randomly selected BLL tests per person increased from two to four. Precision is represented as the difference between the mean estimate of a worker's entire set of BLL tests and the worker's mean estimate derived from the randomly selected BLL tests.

RESULTS

Comparisons between the manufacturing group and the construction group for the years 2003–2007 were limited to 10 609 blood lead tests conducted on 1577 workers. Of these workers, 1276 workers had more than one blood lead test and these workers served as the focus of this study. Of the individuals with more than one BLL test, 619 were manufacturing workers and 657 were construction workers. Descriptive statistics for all individuals in each of the occupational groups that had at least two blood lead measures between 2003 and 2007 are presented in table 1. Baseline blood lead value was defined as the first blood lead test recorded between 2003 and 2007.

Table 1 demonstrates that in all baseline BLL strata, construction workers with multiple blood lead tests generally have higher SDs compared with manufacturing workers. The range of BLLs among construction workers was from below the LOQ to 100 μg/dL and the range of BLLs for manufacturing workers was from below the LOQ to 49 μg/dL. The range in the number of tests for the construction group was 2–47 tests per person and the range in the number of tests for the manufacturing group was 2–34 tests per person. However, construction workers have fewer tests per person than manufacturing workers on average across all strata. Manufacturing workers had an average of 18.02 tests per person and construction workers had an average of 8.9 tests per person in the ≥25 μg/dL baseline BLL category. Construction workers also tend to have higher mean values when the baseline is less than 25 μg/dL whereas manufacturing workers had a higher mean value above 25 μg/dL. The maximum value observed among both occupational groups was among a construction worker and this value was double the maximum value in manufacturing.

The length of time between blood lead tests for individuals within each occupational group was also determined and evaluated. It was found that the length of time between blood lead tests among workers with multiple blood lead measures differed

Table 1 Descriptive statistics for the manufacturing and construction cohort stratified by baseline blood lead level (BLL) value for individuals with more than one BLL test

	Baseline BLL≤5 µg/dL		5 µg/dL<baseline BLL<10 µg/dL		10 µg/dL≤baseline BLL<25 µg/dL		Baseline BLL≥25 µg/dL		Total
	Manufacturing	Construction	Manufacturing	Construction	Manufacturing	Construction	Manufacturing	Construction	
n (# subjects)	151	141	118	88	233	139	117	289	1276
N (# tests)	649	548	752	496	2173	1011	2108	2571	10 308
Tests per subject	4.30	3.89	6.37	5.64	9.33	7.27	18.02	8.90	8.08
Mean* (µg/dL)	–†	–	10.60	12.17	16.78	17.41	26.39	25.39	
Std* (µg/dL)	–	–	6.48	9.61	6.70	9.28	6.19	10.40	
Median (µg/dL)	–	–	9.00	9.00	17.00	16.00	28.00	25.00	
25%centile (µg/dL)	–	–	7.00	7.00	13.00	11.00	24.00	16.00	
75%centile (µg/dL)	–	–	14.00	16.00	22.00	23.00	31.00	30.00	
Max (µg/dL)	–	–	41.00	52.00	47.00	69.00	49.00	100.0	
# of observations with baseline BLL≤5 µg/dL (%)	397 (61.17%)	330 (60.22%)	46 (6.12%)	62 (12.50%)	29 (1.33%)	40 (3.96%)	7 (0.33%)	34 (1.32%)	945 (out of 10 308)

*Estimates obtained by the mixed model analysis.
†Calculations not provided due to large number of observations under detection limit.

by occupational group and by the employee's baseline blood lead value (figure 1). Among workers with higher baseline blood lead values, it can be seen that construction workers had almost twice the amount of time between their tests compared with manufacturing workers. Figure 1 demonstrates that the mean time between blood lead tests was significantly longer for construction workers than manufacturing workers ($p \leq 0.001$) for employees with blood lead values greater than or equal to 10 µg/dL but not statistically significant for workers with BLL values less than 10 µg/dL. The correlation analysis also found negative correlation coefficients with an r value of −0.19 for construction workers and −0.37 for manufacturing workers, where the difference in the r values was significantly different between the two occupational groups ($p<0.0001$). The negative values indicate that the mean length of time decreased with baseline BLL value and the length of time decreased more for manufacturing workers than construction workers.

The trend analysis of multiple blood lead values over time provided useful information for the characterisation of employee exposure histories. Differences were found between the occupational groups when the longitudinal trends were analysed using a mixed-model approach. Figure 2 demonstrates that over time both groups had persistent BLLs within each baseline strata and the construction group had substantially more variability. It is important to note that the follow-up period is not calendar time but rather the time from their first baseline test within our sampling frame. The data in figure 2 is presented with a maximum of 36 months of follow-up time because there were too few people with longer follow-up times once the data was categorised into the occupational groups and stratified by

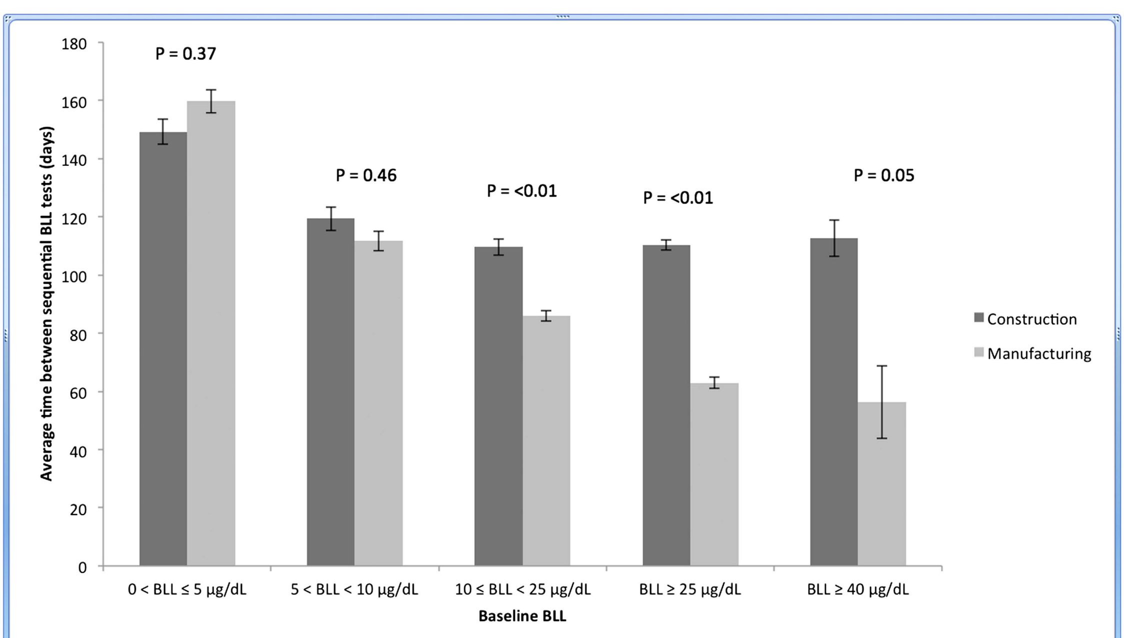

Figure 1 Time between blood lead tests for construction and manufacturing cohorts.

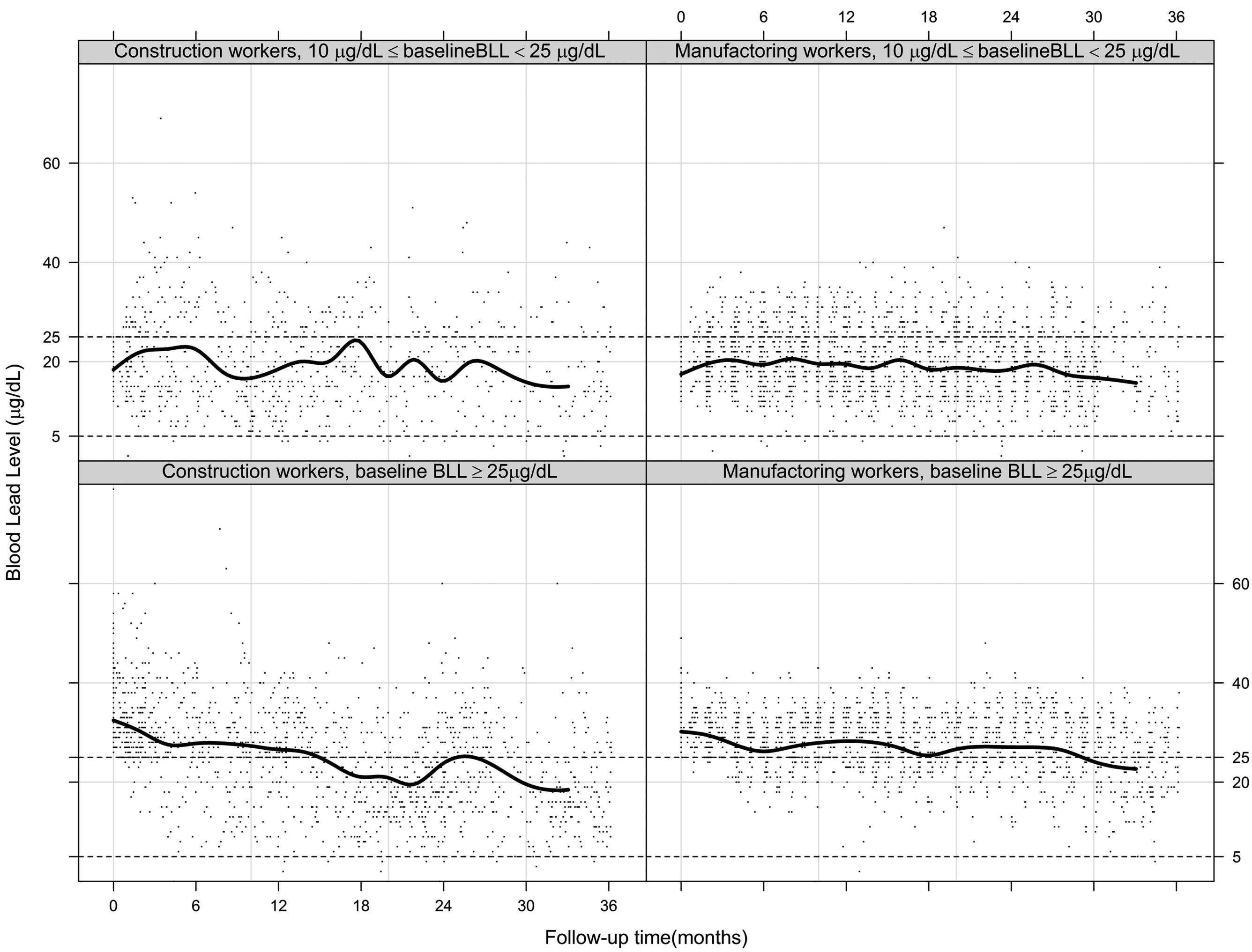

Figure 2 Blood lead trends of workers over time; (A) Upper left—construction workers with initial baseline blood lead level (BLL) greater than or equal to 10 μg/dL and less than 25 μg/dL; (B) Upper right—manufacturing workers with initial baseline BLL greater than or equal to 10 μg/dL and less than 25 μg/dL; (C) Lower left—construction workers with initial baseline greater than or equal to 25 μg/dL; (D) Lower right—manufacturing workers with initial baseline greater than or equal to 25 μg/dL.

baseline BLL. Use of data on follow-up times longer than 36 months could have resulted in unreliable estimates in the mixed model analysis using natural splines due to sparse data above 36 months. Approximately 11.2% of construction workers and 34.8% of manufacturing workers with an initial blood lead test above 25 μg/dL remained above this blood level through their follow-up period. The construction group with an initial baseline BLL >25 μg/dL also had a substantial number of individuals that fell below 25 μg/dL over time while the manufacturing group did not have as large a number of individuals with trends resulting in BLLs below 25 μg/dL over time. Likewise, when looking at the dots in the figure that represent individual BLL tests, construction also had more individuals in the <25 μg/dL initial baseline BLL strata that over time exceeded 25 μg/dL while in the manufacturing cohort the trend of most individuals that started out below 25 μg/dL did not result in an eventual excess of 25 μg/dL.

Figure 3 shows the impact the number of tests has on the precision of the mean blood lead estimates for construction and manufacturing workers. There were 907 workers with more than four blood lead tests. The distribution of the differences between the mean estimates for each occupational cohort changes as the number of tests per worker changes, where fewer randomly selected tests resulted in a wider distribution (figure 3). The major differences observed were that the construction group had a substantially larger variance in their distributions compared with the manufacturing group and the variance decreased as the number of randomly selected BLL tests increased. As noted in figure 3, the SD of the difference in the mean estimates among the construction group was 0.24 when only two randomly selected BLL tests were used to compute the mean compared with a SD of 0.13 when four randomly selected BLL tests were used to compute the mean. The manufacturing group SD was 0.12 when two tests were used to compute the mean and 0.075 when four tests were used to compute the mean. Therefore, the SD of the construction group decreased by 45.8% while the manufacturing group decreased by 37.5% when the number of randomly selected tests used to compute the mean estimate was increased from two to four.

DISCUSSION

By analysing a longitudinal file of repeat blood lead tests among workers, our study showed that substantially different patterns existed in the longitudinal blood lead trends and times between blood tests for manufacturing and construction workers. The fact that construction workers generally had higher SDs among their multiple blood lead measures compared with manufacturing workers is likely a result of more variable exposures among

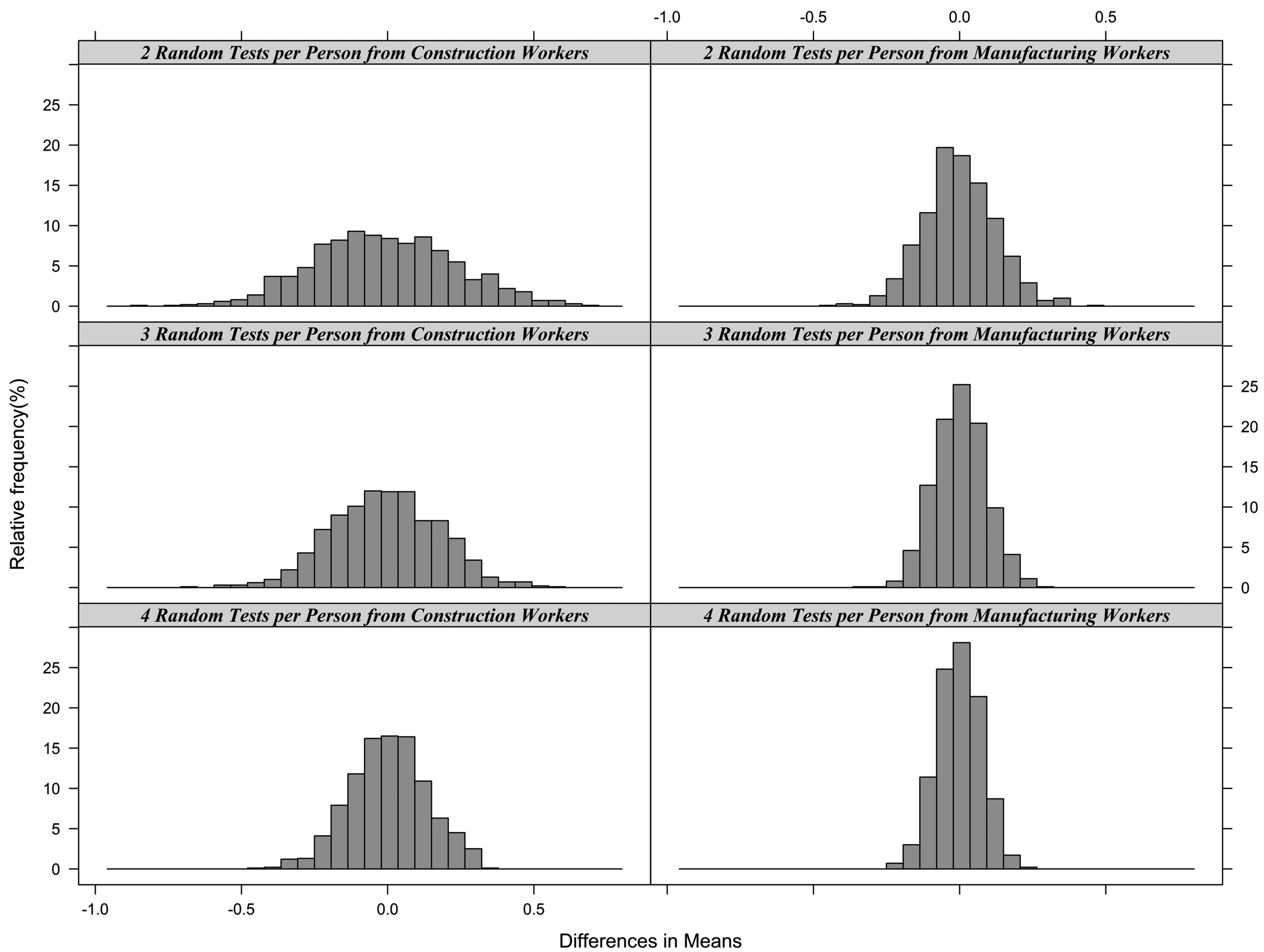

Figure 3 Sampling distribution of the difference in the mean values of randomly selected blood lead level (BLL) measurements and all BLL measurements per person, stratified by occupation and number of selected tests per person. (A) top left—construction: two random samples (mean = −0.0121 ; SD = 0.2428); (B) top right—manufacturing: two random samples (mean = −0.0006 ; SD = 0.1229); (C) Middle left—construction: three random samples (mean = −0.0075 ; SD = 0.1832), (D) middle right—manufacturing: three random samples (mean = 0.0024 ; SD = 0.0884), (E) bottom left—construction: four random samples (mean = 0.0014; SD = 0.1326), (F) bottom right—manufacturing: four random samples (mean = −0.0014 ; SD = 0.0755).

construction workers. Manufacturing workers are more likely to have fairly consistent exposures over time since these workers generally repeat similar tasks throughout their workday while the construction group variability is likely indicative of exposures that can vary widely over time since their work environments and work tasks are constantly changing. Longer times between testing of blood lead among construction workers is also indicative of less follow-up among construction workers. Construction workers are a more transient population because jobs occur in various locations, employment is 'boom or bust' and can have high activity in warmer months and low activity in colder months, high turnover among the construction workforce is commonplace, many companies employ few workers and small construction firms have a high percentage of undocumented, temporary and immigrant workers. This population has historically been difficult to reach for public health interventions, as evidenced by many studies with low participation rates among the construction workforce.[18] In addition, bridge construction workers tend to travel significantly to jobs that may be located in different states and as such, all follow-up tests may not be captured in any one individual state ABLES registry.

The differences observed in blood testing between the manufacturing and construction cohorts may also be due to the fact that the general industry lead standard covering manufacturing (29 CFR 1910.1025) requires more frequent monitoring if a measured blood lead value is greater than 40 μg/dL. The lead in construction standard (29 CFR 1926.62) waits until the employee is medically removed before requiring more frequent sampling. As a result, there appears to be less scrutiny on follow-up among the construction workers making blood lead testing less effective at promptly raising awareness about overexposures among construction workers. This implies weaker surveillance and follow-up among construction workers, who are notoriously difficult to track due to the transient nature of their work and the decentralised nature of their employment.

Many of the workers in figure 2 were below the OSHA threshold for medical removal and it does not appear that interventions to reduce their exposures were implemented because the manufacturing workers had a relatively consistent BLL over time and the construction workers remained at a relatively high BLL over time despite their variable exposures. It appears that workers chronically exposed to lead continue to experience undesirable BLLs over a long period of time and the OSHA lead standards do not appear to effectively prevent workers from having these persistent elevated levels. Workers are removed from exposure only when workers have the average of three recent tests greater than 50 μg/dL or one sample of 60 μg/dL under the general industry lead standard (29 CFR 1910.1025) or one sample greater than 50 μg/dL under the lead in construction standard (29 CFR 1926.62), but they are returned to work once their BLL falls below 40 μg/dL.[12 13] As a result, workers covered under this removal and return to work framework tend to have persistent BLLs well above the general population background. It should also be noted that many occupational health specialists believe that the OSHA medical removal criteria are too high and some have recommended that workers be removed if one sample exceeds 30 μg/dL or two samples over a 4 week period exceed 20 μg/dL and that the long term goal is to maintain workers at levels less than 10 μg/dL.[19] In addition, it is useful to note that the National Toxicology Program[20] and the California Department of Public Health[21] have also reported health effects of lead exposure below 10 μg/dL.

The analysis that investigated the impact of testing on the precision in the mean BLL estimates showed that there was greater variability in the construction cohort compared with the manufacturing cohort, and increasing the number of tests for construction workers improved the precision of mean BLL estimates more than that for the manufacturing workers. This study finding suggests that the number of tests is an important parameter to consider when using BLL values to estimate and assess long-term exposures based on multiple samples. When blood lead testing is appropriate, clinicians may want to consider more frequent testing for workers with variable lead exposures to better assess their long-term burden. It also suggests that occupations with highly variable exposures, such as construction, are more subject to variation and lower precision in long-term mean estimates as a result of testing variability and that more frequent testing may be necessary for these occupations with more variable exposures.

This study had several limitations including the lack of comprehensive SIC code assignment to the majority of study case ID numbers in the full NJ ABLES dataset. Although this was problematic, it was not a catastrophic limitation in the study design because it was likely that many cases lacking SIC codes, often cases below 10 μg/dL, were not occupational cases and therefore their exclusion from our analysis was reasonable. Misclassification of workers into our occupational groups analysed in this study was minimised by only including workers with definitive SIC codes. The blood lead reporting system only includes tests that were actually ordered and completed by individual workers; many workers with lead exposure are tested infrequently or not at all. The industrial sectors represented in the NJ database may also not be inclusive of all industries throughout the world where lead exposure is problematic.

CONCLUSION

This study revealed several important characteristics of adult blood lead testing and these findings may be applicable to other biological markers used to characterise exposures. First, it was noted that differences in occupations significantly impact the nature of blood lead values measured over time. Construction tended to have fewer blood lead measures taken over time, the time between tests was significantly longer for construction workers compared with a stable work environment like manufacturing, and yet construction still has some very high BLL values among some workers. The trend of blood lead measures taken over time was also significantly more variable for construction workers compared with manufacturing workers. Both occupational groups had trends that were elevated well above population background levels and the workers in these industries tended to have elevated BLL values over an extended period of time. This is of particular concern due to recent reports of health effects in adults below 10 μg/dL.[18] This study also found that the number of BLL tests significantly impacted the precision of mean BLL estimates. Mean blood lead value estimates in occupations that have highly variable exposures, such as construction, are more significantly impacted by this testing bias than occupations with more stable exposures, such as manufacturing. Blood lead measurements are an important mechanism to assess and track employee exposures over time and their utility is greatly improved when factors influencing their trends over time are understood in the context of the assessment of chronic occupational exposures.

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Contributors JB conceived the study, wrote the paper, analysed and interpreted the data, and drew conclusions about the data. SEL developed and oversaw the statistical analysis of the data, interpreted the data, assisted with writing the paper and drew conclusions about the data. HG ran the statistical tests, contributed to the paper and drew conclusions about the data. YL assisted with the development of the statistical tests, drew conclusions about the data and edited the final paper. EGM assisted with interpreting the data, edited the paper and assisted with writing several sections of the paper.

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