Lead Exposure and Developmental Disabilities in Preschool-Aged Children

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ABSTRACT

Context: Lead is a preventable environmental toxin that has been previously associated with deficits in cognition, academic performance, attention, and behavior in children. Very few studies, however, have examined the relationship between exposure to lead and documented developmental disabilities.

Objective: This study examined the relative risk of lead exposure on developmental disabilities in preschool-aged children.

Design: A statewide lead surveillance data set containing blood lead level (BLL) was integrated with another statewide data set containing developmental disability classifications for special education placement for preschool-aged children.

Participants: The participants were the 85 178 children (average age 2.6 years) whose records in both data sets were able to be linked. Forty-six percent of the participants had an identified developmental disability.

Main Outcome Measure: Developmental disability classification served as the main outcome measure.

Results: A high BLL, defined as 5 μg/dL or more, was associated with significantly increased risk for developmental disabilities (risk ratio [RR] = 1.04; 95% CI = 1.01-1.08), particularly intellectual disability (RR = 1.58, 95% CI = 1.10-2.25) and developmental delay (DD; RR = 1.11, 95% CI = 1.06-1.17).

Conclusions: The results of this study are consistent with previous research identifying an association between lead exposure and numerous intellectual and educational outcomes and demonstrate that high BLL is associated with meeting eligibility criteria for developmental disabilities in young children. Continued research, surveillance, and prevention efforts are needed to further reduce the negative impacts of lead on individuals and society. Reducing or eliminating lead exposure would improve outcomes for individual children (eg, better academic performance) and reduce the burden to society (eg, lower enrollments in special education systems).

KEY WORDS: child health, developmental disabilities, lead

Lead is a pervasive environmental toxin that is associated with numerous adverse health effects in children and adults, including anemia, kidney damage, muscle weakness, brain damage, increased blood pressure, and death.[1,2] The Centers for Disease Control and Prevention estimates that 4 million families in the United States have children who have been exposed to high levels of lead ($\geq$5 μg/dL), although no blood lead levels (BLLs) have been established as safe.[3] The social and economic impacts of lead poisoning include increased health care costs, reduced worker productivity and earnings, special education requirements, delinquent behavior, and increased crime.[4-9] The costs associated with lead exposure in the United States have been estimated to be $181 billion to $269 billion with an estimated $30 million to $146 million of that related to early intervention and special education services.[3,10]

The neurotoxic effects of lead significantly impact cognitive development. A substantial body of research exists indicating that lead exposure, even at low levels, is associated with deficits in intellectual functioning, particularly reduced intelligence quotient (IQ) scores.[11-22] An IQ of approximately 70 or less is

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1 of the 3 criteria (the others being deficits in adaptive functioning and onset in the developmental period) typically required to meet eligibility criteria for an intellectual disability (ID). An association between lead poisoning and ID (formerly mental retardation) has been identified[23-25]; however, classification of ID in these studies was based mainly or solely on IQ and not on current eligibility criteria.

Lead exposure has also been associated with deficits in other areas related to educational outcomes such as attention and behavior problems, reading and language difficulties, and academic skills.[14,16,22;25-32] For some but not all children, these deficits will be substantial enough to qualify them for special education services. Few studies, however, have examined the relationship between lead exposure and documented exceptionality designations. This is likely due in part to difficulties in obtaining sample sizes large enough to adequately study specific developmental disabilities. Administrative data sets with this information exist and provide a feasible way to examine these associations.[13] Miranda and colleagues[33] utilized statewide lead surveillance and educational data from North Carolina to examine the link between childhood lead exposure and exceptionality designations in fourth graders. This study compared children with learning or behavioral disabilities to children with other disabilities, gifted children, and children without an exceptionality designation. Results indicated that higher BLLs were associated with increased likelihood of learning or behavioral disorders. This study did not examine individual disability categories, however. Another study by Evens et al[32] examined associations between academic performance and BLLs using the Chicago birth registry, the Chicago Blood Lead Registry, and third-grade standardized test scores. Results indicated that even at low BLLs of less than 5 μg/dL, lead exposure was associated with lower math and reading standardized test scores. Previous research in Florida indicated that being *screened* for lead exposure was associated with higher rates of special education placement (behavior problems, mental retardation, learning disabilities, and speech-language impairment); however, this study did not examine the level of lead exposure in children.[34] The present study expands on these studies by utilizing administrative data sets to examine the relationship between lead exposure and specific developmental disability classifications (autism spectrum disorder, developmental delay [DD], ID, specific learning disability, language impairment, and speech impairment) in preschool-aged children. Much of the research on the effects of lead on child development has been conducted with older children, but several studies have found associations between lead exposure (both prenatal and postnatal) and lower IQ scores; cognitive, memory, and attention deficits; and behavior problems in children younger than 6 years.[11,12,18,31,35-37] Therefore, we hypothesized that high BLL (defined as $\geq$5 μg/dL) would be associated with developmental disabilities, particularly ID, in preschool-aged children in Florida.

Methods

Data sources

Lead exposure and developmental disability data were obtained from extant statewide data sets. Lead exposure data were obtained from the Florida Department of Health, Bureau of Epidemiology, Lead Poisoning Prevention Program (LPPP) database. The LPPP was created in 1992 to screen children for elevated BLLs, ensure that lead-poisoned infants and children receive medical and environmental follow-up, and develop neighborhood-based efforts to prevent childhood lead poisoning. Laboratories, hospitals, or providers who conduct blood lead analyses are required to report those results to the LPPP.

Preschool developmental disability data were obtained from the Florida Department of Education, Bureau of Exceptional Education and Student Services, Children's Registry and Information System (CHRIS) database. The CHRIS database was developed in 1990 in response to the need to track children who are potentially eligible for services under Part B of the Individuals with Disabilities Education Act and is used to document Child Find efforts to locate, evaluate, and provide necessary services to preschool-aged children at risk for developmental disabilities. The CHRIS database contains referral, screening, evaluation, and eligibility information for preschool-aged children throughout Florida who were referred to the Florida Diagnostic and Learning Resources System (FDLRS).

Lead exposure

Lead exposure was the risk factor of interest. Since not all Florida children have a high risk for lead exposure, LPPP recommends targeted screening (focusing on high-risk children) rather than universal screening. Risk factors were established on the basis of a screening questionnaire or the child's Medicaid status. Lead exposure was determined through a blood test. The blood specimens were drawn from either capillaries or veins (venous specimens). Screening tests on capillary blood were conducted using a portable point of care instrument called a Lead Care II Analyzer. This instrument uses a finger prick to collect a capillary sample of blood and then analyzes that sample for the amount of lead present. It allows the determination of the patient's BLL in approximately 3 minutes from a 50-μL capillary sample. The reportable range of BLLs is 3.3-65 μg/dL. Use at the point of care allows for immediate venous blood draw for confirmation of elevated lead levels by a certified laboratory. The LPPP works closely with laboratories and health care providers to collect the results of all blood lead tests. Laboratories and health care providers submit results to the LPPP, as mandated by chapter 64D-3, Florida Administrative code. The LPPP receives all positive and negative BLL results via electronic laboratory reporting (ELR), Excel files, or paper. The majority of the blood lead results are received via ELR and are imported into an ELR database. Excel and paper files are uploaded into the same ELR database. Data in the ELR database are processed by the Florida reportable disease surveillance system (Merlin) to create lead poisoning cases for BLLs $\geq$ 10 μg/dL. Merlin is used for tracking and monitoring trends in BLLs in adults and children in Florida. The data are used to ensure that environmental and medical follow-up are provided to children with elevated BLLs.

In this study, BLL was dichotomized into 2 groups. A BLL $<$ 5 was defined as "low BLL" and a BLL $\geq$ 5 was defined as "high BLL."[38] The groups were split at 5 μg/dL because that BLL is currently considered the level of elevated BLL.[12] The small number of children with a BLL $\geq$ 10 μg/dL (138 children with a developmental disability and 164 children in the comparison group) precluded the evaluation of individual disabilities at a third level of lead exposure ($\geq$10 μg/dL). However, Chiodo and colleagues[15] found that dichotomizing lead exposure at 10 μg/dL was no more likely to be significant than dichotomizing exposure at 5 μg/dL for analyses.

Disability classification

Developmental disability was the child outcome of interest. Developmental disability classifications were based on the criteria specified in the *Florida Statutes and State Board of Education Rules*.[39] The CHRIS database indicates the primary exceptionality for preschool-aged children found eligible for special education services based on these criteria. The primary exceptionalities of interest for this study are autism spectrum disorder, DD, emotional/behavioral disability, ID, language impairment, specific learning disability, and speech impairment. The CHRIS database also indicates other disabilities that were not the focus of this study including sensory impairments (deaf or hard of hearing, visual impairment, dual sensory impairment) and physical impairments (orthopedic impairment, other health impairment, traumatic brain injury). The comparison group for analysis was defined as children in the linked data set who did not have any identified disability.

Data linkage

For the purposes of this study, we integrated lead exposure data from the LPPP database with preschool disability data from the CHRIS database for children born January 1, 2000, to December 31, 2012. The databases were linked using an SQL Server Integrated Services environment. Records were matched on first name, last name, and date of birth by using a probabilistic algorithm known as Fuzzy Lookup. In this method, each record is assigned a similarity score for each matching variable (first name, last name, and date of birth) as well as an overall similarity score based on the commonality between the input record and the possible match records. Similarity values range from 0 to 1, with 1 representing a perfect match. Records with a date-of-birth similarity score of 0.874 or more (dates off by no more than one digit) and an overall similarity 0.9 or more were included in this study. The overall similarity cutoff was determined following a hand review of the linked data set. Records selected using this conservative cutoff were considered to be consistently accurate. The linked data set contained 123 550 records. This data set included multiple records per child because some children received more than 1 blood test for lead. Records were grouped by child and the record with the highest overall similarity score (or earliest test date in the case of equivalent similarity scores) was selected as the main record for the child. The highest BLL across all records for each child was determined. The main record (including highest BLL) was extracted to create a data set with one record per child (86 860 records). This data set was deidentified to maintain confidentiality. Records for the 1195 children with disabilities not of interest for this study and for the 487 children whose highest BLL level was not able to be accurately categorized were excluded, resulting in the 85 178 records used to conduct the reported analyses.

Analysis plan

Risk ratios (RRs) were used to evaluate the risk for developmental disability associated with lead exposure. The RRs reported represent the ratio of risk of developmental disability among those with a high BLL over the risk among those with a low BLL. Risk ratios and corresponding confidence intervals were computed using Epi Info 7 statistical software.[40] This study was reviewed and approved by the Florida Department of Health Institutional Review Board.

Results

The average age of the children when they were tested for lead exposure was 2.6 (SD = 2.03) years. Demographic information was obtained from the CHRIS data set. The majority of children (67%) were male. The predominance of males reflects the greater proportion of males in the CHRIS data set due to the higher prevalence of disabilities among males. Race and ethnicity were not required fields in the data set and, as a result, there is a high rate of missing data for those fields (49% and 63%, respectively). Based on reported race and ethnicity information, 54% of the sample was white, 40% was black or African American, 4% was more than 1 race, 1.3% was Asian, 0.5% was another race, 59% were non-Hispanic, and 41% were Hispanic. Additional demographic information for children with and without a disability is provided in Table 1.

TABLE 2
Number of Children in Each Disability Group by BLL Group

	Lead Level, n	
Developmental Disability	Low BLL (<5 μg/dL)	High BLL (≥5 μg/dL)
Autism spectrum disorder	2780	137
Developmental delay	19 997	1135
Emotional/behavioral disability	75	1
Intellectual disability	417	32
Language impairment	6538	308
Speech impairment	7377	329
Specific learning disability	338	16
All disabilities	37 524	1958
Comparison group	43 587	2109

Abbreviation: BLL, blood lead level.

The distribution of children in each developmental disability group by BLL group is provided in Table 2. Two children were classified with speech-language impairment and were included in the All

TABLE 1
Demographic Characteristics by Disability Category and BLL Group

	All Disabilities				Comparison Group			
	Low BLL (<5 μg/dL) (n = 37 524)		High BLL (≥5 μg/dL) (n = 1958)		Low BLL (<5 μg/dL) (n = 43 587)		High BLL (≥5 μg/dL) (n = 2109)	
	n	%	n	%	n	%	n	%
Gender								
Male	26 807	71.4	1 432	73.1	27 149	62.3	1 347	63.9
Female	10 710	28.5	526	26.9	16 431	37.7	762	36.1
Unknown	7	0.0	0	0.0	7	0.0	0	0.0
Race								
White	11 687	31.1	525	26.8	11 111	25.5	523	24.8
African American	8 634	23.0	535	27.3	7 892	18.1	461	21.9
Asian	319	0.9	18	0.9	218	0.5	15	0.7
More than 1 race	848	2.3	43	2.2	807	1.9	43	2.0
Other	96	0.3	9	0.5	90	0.2	5	0.2
Unknown	15 940	42.5	828	42.3	23 469	53.8	1 062	50.4
Ethnicity								
Non-Hispanic	8 766	23.4	480	24.5	8 797	20.2	517	24.5
Hispanic	6 542	17.4	274	14.0	5 910	13.6	226	10.7
Unknown	22 216	59.2	1 204	61.5	28 880	66.3	1 366	64.8
Age								
<3 y	26 230	69.9	1 365	69.7	29 584	67.9	1 459	69.2
3-6 y	8 368	22.3	465	23.7	10 539	24.2	510	24.2
6 y and older	2 854	7.6	125	6.4	3 366	7.7	132	6.3
Unknown	72	0.2	3	0.2	98	0.2	8	0.4

Abbreviation: BLL, blood lead level.

TABLE 3
Risk Ratios and 95% Confidence Intervals for Disability Categories

Disability Group	RR (95% CI), Full Sample
All disabilities	1.04 (1.01-1.08)[a]
Autism spectrum disorder	1.02 (0.86-1.20)
Developmental delay	1.11 (1.06-1.17)[a]
Intellectual disability	1.58 (1.10-2.25)[a]
Language impairment	0.98 (0.88-1.09)
Speech impairment	0.93 (0.84-1.03)
Specific learning disability	0.98 (0.59-1.61)

Abbreviations: CI, confidence interval; RR, risk ratio.
[a] Significantly increased risk.

Disabilities category but were not included in analyses of individual disabilities. The sample size for emotional/behavioral disability was too small to include in individual analyses, but those cases were included in the All Disabilities category. The distribution of disability categories in the linked sample closely resembles the distribution in Florida, although the rate of DD is slightly higher in the linked sample (53.5%) compared with Florida (47.2%).[41]

Risk ratios and 95% confidence intervals were calculated. The confidence intervals indicate the lower and upper limits of the RR that contain the true parameter 95% of the time over unlimited repetitions of the study, assuming that there is no bias. Thus, RRs for which either confidence limit was equal to or crossed 1.0 are not considered meaningful because they do not reach the conventional 5% level of significance. In these cases, one cannot be confident that the rate of disability is truly different from the rate found in the comparison group.

Results indicated significantly increased risk associated with high BLL for the All Disabilities group (RR = 1.04; 95% CI = 1.01-1.08) as well as the DD and ID groups individually (RR = 1.11, 95% CI = 1.06-1.17, and RR = 1.58, 95% CI = 1.10-2.25, respectively). Risk ratios for the other disabilities were not statistically significant (see Table 2).

Discussion

Awareness of the dangers associated with lead has increased substantially since the 1970s, yet lead still remains one of the most ubiquitous neurotoxins found in the environment. Although much progress has been made in reducing exposure to the general population (eg, removal of lead from gasoline), children remain especially vulnerable to other lead-based hazards such as deteriorating paint found in older homes and contaminated house dust and soil. Children can also be exposed to lead through prenatal exposure, breastfeeding, consumption of food or drinks containing lead, or parental occupational exposure.[42] Playing on the ground and increased hand-to-mouth behavior increase the likelihood of lead exposure in children, especially 2- to 3-year-olds.[13,43] Furthermore, children absorb lead to a greater degree than adults, and because the nervous system of children is in the process of developing, it is more vulnerable to the effects of lead than the adult nervous system. Lead interferes with many processes associated with brain development, including synaptic pruning and neuronal migration, which can result in permanent alterations in brain development that result in significant long-term deficits.[1,21,37]

Although the reference value for elevated BLL was lowered from 10 μg/dL to 5 μg/dL in 2012,[13] it is commonly recognized that the safe level of lead exposure is essentially zero.[13,16,19,33,44] Even low levels of lead exposure can result in damage to the brain and nervous system and lead to significant impairments. The association between lead exposure and ID in this study is consistent with a wealth of research linking lead and intellectual/IQ deficits[11,12,14,16-22] and confirms that these deficits are substantial enough to meet specific eligibility criteria for ID even in young children.

Lead exposure was also associated with DD, an exceptionality category that characterizes preschool-aged children who demonstrate significant delays in cognitive, emotional, and/or physical development. Determination of the exact nature of deficits in young children is difficult, especially for children with less severe impairments. The use of the DD category allows young children to receive early intervention services without being assigned a conventional disability classification such as ID, specific learning disability (SLD), or autism spectrum disorder (ASD). The majority of children identified with DD will later be identified with a conventional disability, most commonly ID (formerly mental retardation) or SLD.[45-48] Of preschool-aged children identified with DD who were classified with a conventional exceptionality in third grade, 26% were classified as ID and 34% were classified as SLD.[47] The intellectual and educational deficits associated with these disability outcomes are consistent with deficits associated with lead exposure in previous research.[22,29,30]

Population-based studies using administrative data sets such as this one provide the large sample sizes necessary to examine lower incidence occurrences that cannot be feasibly studied by other means.[49] However, such studies do have limitations. Administrative data sets vary in data quality (completeness and accuracy),

Implications for Policy & Practice

- Although statistically significant, the relative risk associated with lead exposure on developmental disabilities in preschool-aged children is small. This is consistent with previous research indicating that the decrement in IQ points in children associated with lead exposure is small.[12,20,21] The impact on the population, however, is substantial due to the large number of children exposed to lead. In the United States, 37.1 million homes are considered significant lead hazards.[50] It has been estimated that 12 million children are exposed to lead via paint, 5.9 million to 11.7 million via dust and soil, 3.8 million via drinking water, and more than 5.8 million via other sources.[51] The percentage of children aged 1 to 5 years with a BLL greater than or equal to 5 μg/dL is 2.6%, which is equivalent to 535 000 US children.[38]
- Fortunately, lead is a preventable risk factor. Reducing or eliminating lead exposure would improve outcomes for individual children and reduce the burden to society. With regard to education, the prevention of lead poisoning in children should result in fewer children being classified with developmental disabilities, which would lower the burden on special education systems. The cost to educate children with disabilities has been estimated at 2.2 times the cost to educate students receiving general education,[52] resulting in an economic burden of $30 million to 146 million for special education services due to lead exposure.[10] The estimated benefit of controlling lead exposure, however, can result in a $17 to $221 return for every dollar spent.[10] Past and existing prevention efforts such as removing lead from gasoline, paint, food containers, and pipes have been effective at lowering BLLs and have been demonstrated to be cost-effective.[1,5,10,53-56] This progress is evident in our sample, which included very few children with BLLs greater than 10 μg/dL. However, lead exposure remains a significant issue in the United States and around the world. Continued prevention efforts are necessary, especially primary prevention efforts focused on eliminating lead from the environment and thereby preventing exposure entirely.[13] Additional resources are also needed to develop and maintain high-quality lead surveillance programs at the state and national levels. These programs can provide valuable information about the prevalence of lead exposure, sociodemographic risk factors, geographical hot spots for lead exposure, ideal targets for prevention efforts, and the effectiveness of prevention efforts. They can also be integrated with other data sets (eg, health, education, employment, crime) to meet the need identified by the Centers for Disease Control and Prevention Advisory Committee on Childhood Lead Poisoning Prevention to utilize existing population-based data sets to assess the impacts of lead poisoning.[13]

which can lead to issues with missing data (eg, race and ethnicity) and linkage to other data sets. Probabilistic linkage techniques can help overcome some issues with data quality, particularly inconsistencies in names and dates that occur as a result of data entry errors. Another limitation in our study specifically is that the children were not representative of the population as a whole. Lead testing was targeted to high-risk children. Also, the comparison group was composed of children who did not have an identified disability at the time the data were obtained. Some of these children will be identified with a disability in the future. In addition, children are entered into CHRIS following a referral to FDLRS. Children can be referred to FDLRS by a person (parent, teacher, doctor) or agency for various concerns such as identified conditions, diagnoses or syndromes, suspected delays in motor skills, cognition, social/emotional skills, speech-language skills, or behavior. These issues, however, would be expected to make finding significant effects more difficult. Therefore, it is likely that the association between lead and developmental disabilities in the population is greater than we were able to identify using these data. Finally, it is important to note that lead exposure testing did not necessarily precede developmental disability determination. As such, the results of the study demonstrate an association between elevated BLL and developmental disability, but not necessarily a temporal or causal relation.

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