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Association of Childhood Blood Lead Levels With Cognitive Function and Socioeconomic Status at Age 38 Years and With IQ Change and Socioeconomic Mobility Between Childhood and Adulthood

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IMPORTANCE Many children in the United States and around the world are exposed to lead, a developmental neurotoxin. The long-term cognitive and socioeconomic consequences of lead exposure are uncertain.

OBJECTIVE To test the hypothesis that childhood lead exposure is associated with cognitive function and socioeconomic status in adulthood and with changes in IQ and socioeconomic mobility between childhood and midlife.

DESIGN, SETTING, AND PARTICIPANTS A prospective cohort study based on a population-representative 1972-1973 birth cohort from New Zealand; the Dunedin Multidisciplinary Health and Development Study observed participants to age 38 years (until December 2012).

EXPOSURES Childhood lead exposure ascertained as blood lead levels measured at age 11 years. High blood lead levels were observed among children from all socioeconomic status levels in this cohort.

MAIN OUTCOMES AND MEASURES The IQ (primary outcome) and indexes of Verbal Comprehension, Perceptual Reasoning, Working Memory, and Processing Speed (secondary outcomes) were assessed at age 38 years using the Wechsler Adult Intelligence Scale-IV (WAIS-IV; IQ range, 40-160). Socioeconomic status (primary outcome) was assessed at age 38 years using the New Zealand Socioeconomic Index-2006 (NZSEI-06; range, 10 [lowest]-90 [highest]).

RESULTS Of 1037 original participants, 1007 were alive at age 38 years, of whom 565 (56%) had been lead tested at age 11 years (54% male; 93% white). Mean (SD) blood lead level at age 11 years was 10.99 (4.63) $\mu\text{g}/\text{dL}$. Among blood-tested participants included at age 38 years, mean WAIS-IV score was 101.16 (14.82) and mean NZSEI-06 score was 49.75 (17.12). After adjusting for maternal IQ, childhood IQ, and childhood socioeconomic status, each 5- $\mu\text{g}/\text{dL}$ higher level of blood lead in childhood was associated with a 1.61-point lower score (95% CI, -2.48 to -0.74) in adult IQ, a 2.07-point lower score (95% CI, -3.14 to -1.01) in perceptual reasoning, and a 1.26-point lower score (95% CI, -2.38 to -0.14) in working memory. Associations of childhood blood lead level with deficits in verbal comprehension and processing speed were not statistically significant. After adjusting for confounders, each 5- $\mu\text{g}/\text{dL}$ higher level of blood lead in childhood was associated with a 1.79-unit lower score (95% CI, -3.17 to -0.40) in socioeconomic status. An association between greater blood lead levels and a decline in IQ and socioeconomic status from childhood to adulthood was observed with 40% of the association with downward mobility mediated by cognitive decline from childhood.

CONCLUSIONS AND RELEVANCE In this cohort born in New Zealand in 1972-1973, childhood lead exposure was associated with lower cognitive function and socioeconomic status at age 38 years and with declines in IQ and with downward social mobility. Childhood lead exposure may have long-term ramifications.

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Lead is a ubiquitous pollutant. Policies that eliminated lead from paint and gasoline were thought to have eliminated lead from most communities in the developed world. But the water crisis in Flint, Michigan has triggered renewed concern about lead poisoning.¹ Inhabitants of many US cities are still exposed to high lead levels.²

Exposure to lead in childhood may adversely affect brain health and disrupt cognitive development.³ It is unknown if this disruption results in cognitive decline and altered socioeconomic trajectories by midlife, yet young adults with histories of childhood lead exposure have been reported to have lowered intellectual function^{4,5} and altered brain structure,^{6,7} suggesting that cognitive impairment persists at least to young adulthood. Few studies have yet documented longer-term cognitive consequences of childhood lead exposure, and none appear to have evaluated socioeconomic repercussions, apart from 1 study of highly exposed, lead-poisoned children.⁸ To our knowledge, the longest-term cognitive follow-ups have been to age 30 years in a cohort too small (N=43) to adequately detect associations after adjusting for potential confounders.⁹

The Dunedin Multidisciplinary Health and Development Study observed a population-representative cohort of children born in New Zealand in 1972-1973. The most recent assessment included cognitive and socioeconomic evaluations and was completed when participants were 38 years old. In the 1970s and 1980s, lead exposures in New Zealand cities were consistently higher than international standards, largely due to poor air quality related to motor vehicle emissions.¹⁰ Consequently, childhood blood lead levels in the Dunedin cohort were similar to those of other cohorts tested in the early 1980s from larger developed cities.^{11,12} However, unlike with other cohorts,^{13,14} a social gradient in lead exposure was not observed. This provided an opportunity to test the hypothesis that childhood lead exposure is associated with cognitive impairment and downward socioeconomic mobility by midlife without having to disentangle such exposure from correlated socioeconomic disadvantages. Analyses also tested whether the association between blood lead levels and downward social mobility was mediated by cognitive decline.

Methods

Study Design and Population

Participants are members of the Dunedin Multidisciplinary Health and Development Study, a longitudinal investigation of health and behavior in a birth cohort. The full cohort comprises all individuals born between April 1972 and March 1973 in Dunedin, New Zealand, who were eligible based on residence in the province and who participated in the first assessment at age 3 years. The cohort represented the full range of socioeconomic status in the general population of New Zealand's South Island.¹⁵ On adult health, the cohort matches the New Zealand National Health and Nutrition Survey on key health indicators (eg, body mass index, smoking status, visits to a physician).¹⁵ The cohort is primarily

Key Points

Question Is childhood lead exposure associated with cognitive and socioeconomic outcomes in adults in a country where the degree of childhood lead exposure was not related to socioeconomic status?

Findings In 565 New Zealanders observed for 4 decades, lead exposure in childhood was significantly associated with lower cognitive function and socioeconomic status at age 38 years. Greater childhood lead exposure was also associated with greater declines in IQ from childhood to adulthood and greater declines relative to parents in occupational socioeconomic status.

Meaning Childhood lead exposure was associated with long-term cognitive and occupational ramifications.

white; fewer than 7% self-identify as having ancestry that is not white, which matches the demographics of the South Island.¹⁵ Assessments were carried out at birth and ages 3, 5, 7, 9, 11, 13, 15, 18, 21, 26, 32 years, and the most recent data collection was completed in December 2012 at age 38 years. Written informed consent was obtained from cohort participants and study protocols were approved by the institutional ethical review boards of the participating universities.

Measurement of Childhood Blood Lead Levels

Approximately 30 mL of venous blood was collected from each 11 year old who participated in the assessment (carried out at the research unit) and who freely agreed to give blood; 579 of the 803 children (72%) in attendance agreed to give blood. An additional 122 children, aged 11 years and tending to live outside city limits, were assessed in their schools, where blood could not be drawn. Whole blood samples were analyzed through graphite furnace atomic absorption spectrophotometry. Blood lead level is reported in micrograms per deciliter ($1\mu\text{g}/\text{dL}=0.0483\mu\text{mol}/\text{l}$). Details on the method of blood collection, division, storage, quality assurance, and analysis procedures have been described previously.^{11,12}

Measurement of Cognitive Functioning

Cognitive performance in adulthood was a primary outcome. It was assessed using the Wechsler Adult Intelligence Scale-IV (WAIS-IV; score range, 40-160) at age 38 years.¹⁶ The WAIS-IV generates the overall full-scale IQ, and in addition, 4 WAIS-IV indexes assess abilities that make up the IQ and were considered secondary outcomes: Verbal Comprehension, Perceptual Reasoning, Working Memory, and Processing Speed. Cognitive performance in childhood was assessed using the Wechsler Intelligence Scale for Children-Revised (WISC-R; score range, 40-160)^{17,18} at ages 7 and 9 years (measured prior to blood lead evaluation at age 11 years) and averaged.

Measurement of Socioeconomic Status

Socioeconomic status in adulthood was a primary outcome. Socioeconomic status was assigned based on each participant's current occupation at age 38 years. The New Zealand

Socioeconomic Index (NZSEI-06) codes each occupation based on its associated education level and income in the NZ Census.¹⁹ Socioeconomic status for 19 unemployed participants was assigned based on their most recent occupation in their thirties, and socioeconomic status for 14 homemakers was imputed from their education following the NZSEI-06 algorithm (score range, 10 [low status]-90 [high status]). The NZSEI-06 scores are further grouped into 6 socioeconomic status groups.¹⁹ Examples of occupations in the 6 groups include medical practitioner (NZSEI code 90; group 6), engineering professional (code 66; group 5), database administrator (code 59; group 4), personal assistant (code 44; group 3), office cashier (code 28; group 2), and fish filleter (code 23; group 1). Childhood socioeconomic status was defined as the mean of the highest occupational status level of either parent across study assessments from the participants' birth through age 15 years, measured using the Elley-Irving scale²⁰ (the forerunner of NZSEI), which also assigned occupations into 1 of 6 socioeconomic status groups (6 indicates professional; 1 indicates unskilled laborer).²⁰ A continuous measure was not available when childhood socioeconomic status was measured.

Statistical Analysis

First, sample descriptive statistics were generated for the sample as a whole and separately for study members with and without blood lead data. Differences between those with and without blood lead data were examined using *t* tests or χ^2 tests as appropriate. Pearson correlations between all study variables were calculated using standard procedures (PROC CORR) in SAS version 9.3.

Second, the association between childhood blood lead levels and adult outcomes was tested using ordinary least-squares multiple regression. The 2 prespecified primary outcome variables were adult IQ (WAIS-IV) and adult socioeconomic status (NZSEI-06). Each outcome was examined using a sex-adjusted model (outcome was regressed on childhood blood lead levels and sex) and a fully adjusted model (outcome was regressed on childhood blood lead levels and the following covariates: sex, childhood IQ, maternal IQ [assessed via the Science Research Associates verbal test²¹ administered to the study mothers when the participants were 3 years old], and childhood socioeconomic status). The goal of the fully adjusted model was to evaluate the association between childhood blood lead levels and adult IQ and socioeconomic status using an analysis of covariance model of IQ and socioeconomic status change. Lead level was analyzed as a continuous measure; however, it is presented in 5- $\mu\text{g}/\text{dL}$ units, the current reference level for clinical attention and therefore a measure that is meaningful to clinicians and policymakers. Moreover, 5 $\mu\text{g}/\text{dL}$ represents approximately 1 standard deviation of blood lead level in the cohort. We also compared mean primary outcomes for participants with childhood blood lead levels above the historic international level of concern during their childhood (>10 $\mu\text{g}/\text{dL}$) vs below.²²

Prespecified exploratory analyses tested associations between childhood blood lead level and the 4 constituent

abilities making up the IQ. No adjustments were made for the 4 multiple comparisons of secondary outcomes; these results should be interpreted as exploratory.

Only participants who had complete data on all covariates for each outcome were included in each model; no data were imputed. For adult IQ, 533 (94%) participants were analyzed; for adult socioeconomic status, 541 (96%) participants were analyzed.

Third, in addition to the analysis of covariance, for illustrative purposes, change in IQ from childhood to adulthood as well as socioeconomic mobility were evaluated using change scores. Childhood IQ was subtracted from the adult IQ with both IQs measured on matched scales. IQ decline, relative to cohort norms, was indicated using negative scores. Childhood (ie, parental) socioeconomic status was subtracted from adult socioeconomic status with both variables measured on matched 6-category scales.^{19,20} Downward mobility was indicated using negative scores.

Fourth, whether cognitive decline from childhood to adulthood mediated the association between childhood blood lead levels and downward change in socioeconomic status was tested. Ordinary least-squares regression was used to estimate a single-mediator model using the Sobel test²³ to estimate the significance of the mediation effect (see eFigure in the Supplement).

Sensitivity analyses were conducted repeating all statistical analyses after subjecting the lead measure to a logarithmic transformation and a correction for hematocrit levels,²⁴ and after incorporating 2 additional covariates into the fully adjusted analysis of covariance: maternal smoking during pregnancy (assessed via maternal interview) and child birthweight (from hospital records).

Analyses were conducted using SAS version 9.3. Regression coefficients refer to dose increments of 5 $\mu\text{g}/\text{dL}$ in childhood blood lead level. The threshold for statistical significance was 2-tailed, *P* value of less than .05.

Results

Of 1037 participants in the original cohort, 1007 were still alive at age 38 years, 565 (56%) of whom had been lead tested at age 11 years (303 [54%] male; 525 [93%] white). Participants alive at age 38 years with childhood blood lead data (*n*=565) and without childhood blood lead data (*n*=442) did not differ to a statistically significant extent from each other in terms of their mothers' IQ scores or their social class origins, but those without blood lead data did have lower mean childhood IQ scores as a group (98.91 vs 101.01; difference for children without blood lead data vs with blood lead data, -2.10 [95% CI, -3.99 to -0.19]; *P*=.03; [Table 1]). Children not tested at the unit tended to live outside city limits and such nonurban residents tended to have marginally lower IQ scores.²⁵ Correlations among primary study variables are shown in Table 2.

Childhood blood lead levels ranged from 4 to 31 $\mu\text{g}/\text{dL}$ (mean [SD], 10.99 [4.63]). There were 259 participants (46%) with blood lead levels above the historic international

Table 1. Comparison of Participants With and Without Lead Data at Age 11 Years on Primary Study Variables

	Full Sample (N=1037)		Alive at Age 38 Years				P Value for Lead vs No Lead
			Lead Data at Age 11 Years (n=565)		No Lead Data at Age 11 Years (n=442)		
	No.	Mean (SD)	No.	Mean (SD)	No.	Mean (SD)	
Male, No.	535 ^a		303 ^a		214 ^a		.10
Childhood blood lead level			565	10.99 (4.63)			
Maternal verbal IQ ^b	1011	39.75 (14.77)	557	40.41 (14.22)	425	39.19 (15.42)	.20
WISC-R childhood full-scale IQ	986	100.00 (15.00)	563	101.01 (14.22)	398	98.91 (15.53)	.03
Childhood socioeconomic status ^c	1031	3.75 (1.14)	563	3.80 (1.12)	438	3.69 (1.17)	.13
WAIS-IV full-scale IQ at age 38 y	942	100.00 (15.00)	542	101.16 (14.82)	400	98.43 (15.11)	.006
Socioeconomic status at age 38 y ^c	953	48.83 (17.11)	550	49.75 (17.12)	403	47.58 (17.03)	.05

Abbreviations: NZSEI-06, New Zealand Socioeconomic Index-2006; WAIS-IV, Wechsler Adult Intelligence Scale-IV; WISC-R, Wechsler Intelligence Scale for Children-Revised.

^a The number of males comprises 51.7% of the full sample, 53.6% of participants with lead data at age 11 years, and 44.8% of participants with no lead data at age 11 years.

^b Maternal verbal IQ was assessed using the Thurstone scale, which is not scaled to a mean of 100.

^c Socioeconomic status was assessed in childhood using the Elley-Irving scale (range 1 [lowest]-6 [highest]) and at age 38 years using the NZSEI-06 (range 10 [lowest]-90 [highest]).

Table 2. Pearson Correlations Among Primary Study Variables

Variable	Childhood Blood Lead Level ^a	Maternal Verbal IQ	WISC-R Childhood IQ	Childhood Socioeconomic Status ^b	WAIS-IV Full-Scale IQ at Age 38 y	Socioeconomic Status at Age 38 y ^b
Childhood blood lead level						
Maternal verbal IQ	-0.06					
WISC-R childhood IQ	-0.03	0.38 ^c				
Childhood socioeconomic status ^b	0.03	0.36 ^c	0.41 ^c			
WAIS-IV full-scale IQ at age 38 y	-0.11 ^d	0.44 ^c	0.76 ^c	0.38 ^c		
Socioeconomic status at age 38 y ^b	-0.11 ^e	0.24 ^c	0.43 ^c	0.35 ^c	0.49 ^c	

Abbreviations: NZSEI-06, New Zealand Socioeconomic Index-2006; WAIS-IV, Wechsler Adult Intelligence Scale-IV; WISC-R, Wechsler Intelligence Scale for Children-Revised.

^a Data without footnote symbols indicate nonsignificant *P* values ($\geq .05$).

^b Socioeconomic status was assessed in childhood using the Elley-Irving scale (range 1 [lowest]-6 [highest]) and at age 38 years using the NZSEI-06 (range 10 [lowest]-90 [highest]).

^c *P* < .001.

^d *P* < .05.

^e *P* < .01.

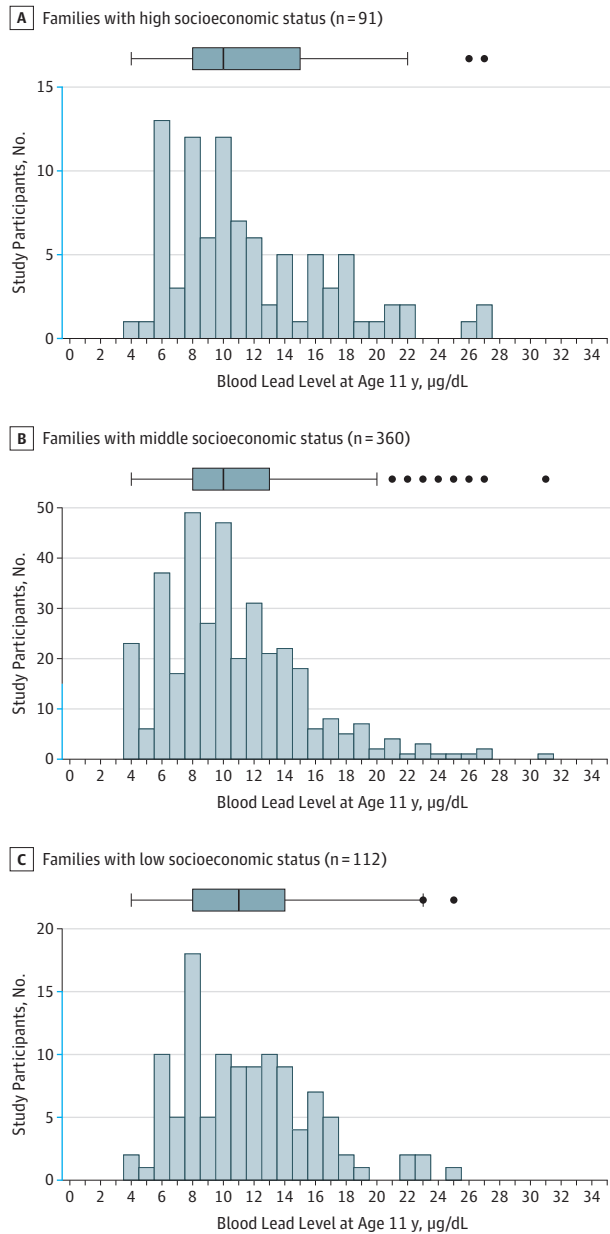
level of concern (10 $\mu\text{g}/\text{dL}$) of whom 157 (61%) were male, and 531 participants (94%) with blood lead levels above the current normal reference value (5 $\mu\text{g}/\text{dL}$) of whom 288 (54%) were male. Females ($n=262$) had lower mean lead levels (10.42) than males ($n=303$); mean lead level, 11.49 [difference in female vs male participants, -1.07 {95% CI, -1.82 to -0.30 }; $P=.007$]. There was no significant socioeconomic gradient in lead exposure in the cohort children. High blood lead levels were observed among children from all socioeconomic status groups (Figure 1).

Higher childhood blood lead level was associated with poorer adult cognitive performance. Children with higher blood lead levels at age 11 years scored lower than cohort peers on mean IQ tested at age 38 years (Table 3). After controlling for participants' own childhood IQ score, their mothers' IQ score, and their socioeconomic background, each 5- $\mu\text{g}/\text{dL}$ higher level of blood lead in childhood was associated with an additional 1.61-point lower score (95% CI, -2.48 to -0.74 ; $P<.001$) in the full-scale IQ. Prespecified exploratory analyses of the 4 constituent abilities making

up the IQ showed children with higher levels of blood lead at age 11 years scored lowest on indexes tapping perceptual reasoning and working memory (Table 3). Figure 2 depicts the mean IQs at age 38 years of participants at each childhood blood lead level. Participants with childhood blood lead levels above the historic international level of concern ($>10\mu\text{g}/\text{dL}$) tested 4.25 mean IQ points lower in adulthood (95% CI, -6.75 to -1.75 ; $P<.001$) than their peers with lower blood lead levels (after adjusting for childhood IQ and the other covariates, 2.73 IQ points lower [95% CI, -4.34 to -1.12 ; $P<.001$]). To evaluate IQ decline from childhood to adulthood, participants' adult IQ scores were compared with their childhood IQ scores (Figure 3). Participants above the level of concern exhibited a mean decline of 1.68 IQ points from childhood to adulthood. In contrast, those at or below the level of concern exhibited a mean increase of 1.22 IQ points from childhood to adulthood, a significant difference of 2.90 IQ points (95% CI, 1.20 to 4.61; $P<.001$).

Higher childhood blood lead level was also associated with lower adult socioeconomic status. Children with higher

Figure 1. Distribution of Blood Lead Levels at Age 11 Years in Dunedin Cohort Grouped by Socioeconomic Status



Box and whisker plots and histograms depict the distribution of childhood blood lead levels for participants from families of low-, middle-, and high-socioeconomic status based on the 6-point Elley-Irving scale (categories 1 and 2 [low status], 3 and 4 [middle status], 5 and 6 [high status]), which codes participants' parents' occupations and their associated income and education levels. High blood lead levels were observed in all status groups. Of the 563 participants, 2 were not assigned a childhood socioeconomic status score. The box and whisker plots show the median (vertical black line inside the box), lower and upper interquartile ranges (IQRs; left and right borders of the box), lower-bound value equal to the 25th percentile minus 150% of the IQR and upper-bound value equal to the 75th percentile plus 150% of the IQR (whiskers), and outlier observations (black circles). The histogram interval bins represent whole integers of blood lead level, and the blue segment on each y-axis indicates the numeric range from 0 to 15.

blood lead levels at age 11 years attained lower levels of socioeconomic status as adults than cohort peers (Table 3). After

controlling for participants' own childhood IQ score, their mothers' IQ score, and their socioeconomic background, each 5-µg/dL higher level of blood lead in childhood was associated with an additional 1.79-unit lower score (95% CI, -3.17 to -0.40; $P=.01$) in socioeconomic status. Figure 2 shows the mean socioeconomic status at age 38 years of participants at each childhood blood lead level. Participants with childhood blood lead levels above the historic international level of concern (>10 µg/dL) attained a mean socioeconomic level 4.51 points lower in adulthood (95% CI, -7.38 to -1.64; $P=.002$) than their peers with lower blood lead levels (after adjusting for childhood socioeconomic status and the other covariates, 3.42 units lower, 95% CI, -5.98 to -0.85; $P=.009$).¹¹ To evaluate socioeconomic mobility directly, participants' adult socioeconomic status was compared with that of their parents on the same 6-point social class scale (Figure 3). Participants above the level of concern exhibited an absolute mean decline of 0.18 social class scale points on the 6-point scale. In contrast, those at or below the level of concern exhibited a mean increase of 0.12 social class scale points from childhood to adulthood, a significant difference of 0.30 scale points (95% CI, 0.04 to 0.55; $P=.02$).

The association between childhood blood lead levels and socioeconomic status decline from childhood to adulthood was partially but significantly mediated by decline in IQ from childhood to adulthood after adjusting for covariates. IQ decline accounted for 40% of the association between childhood blood lead levels and downward socioeconomic mobility, significantly reducing the association between childhood blood lead levels and socioeconomic status change, Sobel test of mediation $P=.002$ (eFigure in the Supplement).

Descriptive statistics for study variables used in sensitivity analyses are presented in eTable 1 in the Supplement along with the results of the sensitivity analyses (eTable 2 in the Supplement). Subjecting the lead measure to a logarithmic transformation, correcting for hematocrit levels, and adding additional covariates did not materially alter the results.

Discussion

This longitudinal analysis of the association between childhood blood lead levels and adult cognitive function and socioeconomic status revealed 3 findings. First, childhood blood lead level was associated with lower adult IQ scores nearly 3 decades later, reflecting cognitive decline following childhood lead exposure. There were significant associations between childhood blood lead levels and lower scores on the Perceptual Reasoning IQ and the Working Memory IQ, but no significant association with the Verbal Comprehension IQ or the Processing Speed IQ. These associations remained significant after adjusting for the participants' childhood IQs, their mothers' IQs, and their social class backgrounds.

Second, childhood blood lead level was associated with lower adult socioeconomic status, reflecting downward social mobility following childhood lead exposure. These associations too remained significant after adjusting for the

Table 3. Association Between Childhood Blood Lead Levels at Age 38 Years and Adult IQ and Adult Socioeconomic Status^a

	Adjusted by Sex		Fully Adjusted ^b	
	Regression β Coefficient (95% CI)	P Value	Regression β Coefficient (95% CI)	P Value
WAIS-IV Adult IQ ^c				
Full-scale IQ ^d	-1.97 (-3.34 to -0.59)	.005	-1.61 (-2.48 to -0.74)	<.001
Verbal Comprehension IQ ^e	-1.39 (-3.01 to 0.23)	.09	-1.01 (-2.18 to 0.16)	.09
Perceptual Reasoning IQ ^e	-2.36 (-3.69 to -1.03)	<.001	-2.07 (-3.14 to -1.01)	<.001
Working Memory IQ ^e	-1.52 (-2.95 to -0.08)	.04	-1.26 (-2.38 to -0.14)	.03
Processing Speed IQ ^e	-0.91 (-2.19 to 0.37)	.16	-0.70 (-1.85 to 0.45)	.23
Adult socioeconomic status ^{d,f}	-1.94 (-3.50 to -0.37)	.02	-1.79 (-3.17 to -0.40)	.01

Abbreviations: NZSEI-06, New Zealand Socioeconomic Index-2006; WAIS-IV, Wechsler Adult Intelligence Scale-IV.

^a Of the study participants alive at age 38 years with childhood blood lead measured, 94% (n=533) also had present data on all the covariates and the IQ outcome measures, and 96% (n=541) had present data on all the covariates and the socioeconomic status outcome measure. Regression coefficients indicate change in outcome per 5 μ g/dL increase in childhood blood lead level.

^b Covariates in the fully adjusted model were sex, maternal IQ, participants' childhood IQ, and childhood socioeconomic status.

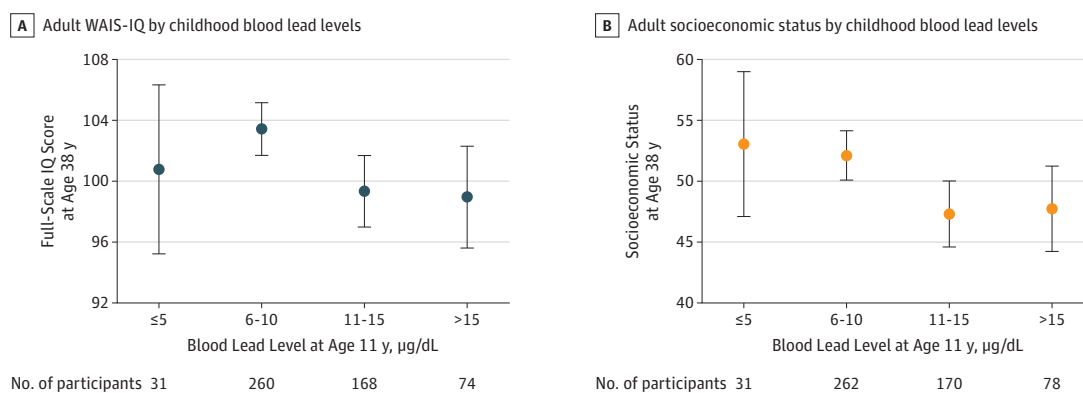
^c IQs were assessed using the WAIS-IV (score range, 40-160) and standardized to a mean SD of 100 (15).

^d Primary outcome.

^e Secondary outcome.

^f Socioeconomic status was assessed at age 38 years using the NZSEI-06 (range, 10 [lowest]-90 [highest]).

Figure 2. Association of Childhood Blood Lead Level With WAIS-IV IQ and Socioeconomic Status in Adulthood



Both panels are unadjusted for covariates and show mean outcomes in adulthood (circles) and 95% CIs (error bars) for each 5- μ g/dL higher level of blood lead in childhood. For panel A, each 5- μ g/dL higher level of blood lead in childhood was associated with an additional 1.97-point lower score (95% CI, -3.34 to -0.59; $P=.005$) in adult Wechsler Adult Intelligence Scale-IV (WAIS-IV)

full-scale IQ and (in panel B) an additional 1.94-unit lower score (95% CI, -3.50 to -0.37; $P=.02$) in adult socioeconomic status (assessed at age 38 years using the New Zealand Socioeconomic Index-2006 [range, 10 {lowest}-90 {highest}]; see Table 3).

participants' childhood IQs, their mothers' IQs, and their social class backgrounds.

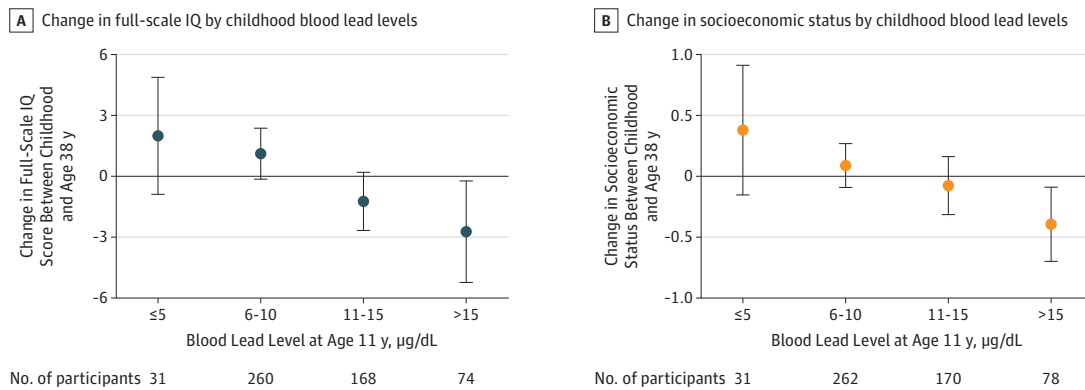
Third, the relationship between childhood lead exposure and downward social mobility by midlife was partially but significantly mediated by cognitive decline following childhood lead exposure.

These results suggest that cognitive impairment associated with childhood lead exposure can persist and may worsen somewhat across decades (27 years in this study) to age 38 years. Each 5- μ g/dL higher blood lead level in childhood was associated with an additional 1.61-point lower score in adult IQ after adjusting for covariates. The effect sizes for adult cognitive impairment that were detected are small and do not constitute the extent of impairment that would attract clinical treatment. They are, however, similar to IQ deficits associated with other notable childhood risk factors, such as

very low birth weight.²⁶ Despite being mild, the cognitive decline evident among lead-exposed children was accompanied by altered socioeconomic life trajectories, measurable as small but detectable downward social mobility by midlife for the most-exposed children regardless of their origins.

This study had the advantage of being able to use lead assays archived 3 decades ago, in a representative sample of children that is relatively large by the standards of research studies on lead exposure and that has been observed to midlife. A strength of this study was the lack of social gradient in lead exposure observed in the Dunedin cohort. This afforded the opportunity to examine the long-term association between childhood lead exposure and adult outcomes without having to first disentangle exposure to lead from exposure to other harmful and often intertwined adversities, particularly poverty. The study's findings are thus consistent

Figure 3. Association of Childhood Blood Lead Level With Cognitive Decline and Downward Socioeconomic Mobility Into Adulthood



Both panels are unadjusted for covariates and show mean change in outcome from childhood to adulthood (circles) and 95% CIs (error bars) for each 5- $\mu\text{g}/\text{dL}$ higher level of blood lead in childhood. To create IQ change scores, childhood IQ was subtracted from the adult IQ, with both IQs measured on matched scales (Wechsler Intelligence Scale for Children-Revised [WISC-R] for child IQ and Wechsler Adult Intelligence Scale-IV [WAIS-IV] for adult IQ). To create socioeconomic status change scores, childhood (ie, parental) socioeconomic status was subtracted from adult socioeconomic status with both status

variables measured on comparable 6-category scales (the Elley-Irving scale for childhood and the New Zealand Socioeconomic Index [NZSEI-06] for adulthood) assessing socioeconomic status in New Zealand by assigning occupations into 1 of 6 socioeconomic status groups (range, 1 [lowest, eg, unskilled laborer]-6 [highest, eg, professional]). For panel A, each 5- $\mu\text{g}/\text{dL}$ higher level of blood lead in childhood was associated with a 1.61-point decline (95% CI, -2.48 to -0.74; $P < .001$) in full-scale IQ and (in panel B) a 1.79-unit decline (95% CI, -3.17 to -0.40; $P = .01$) in socioeconomic status (see Table 3).

with, but cannot prove, the hypothesis that lead exerts a degradative effect on cognitive ability and a downward pull on socioeconomic status over time regardless of childrens' cognitive ability or socioeconomic status in early life. That said, these findings may not generalize to those settings where, as in the United States, lead exposure is concentrated among the poor in larger cities and near former lead-emitting industry sites.²⁷ Because this study's sample was primarily white, the findings also require replication in more ethnically diverse samples.

There are limitations to this study. Although mean blood lead levels in this New Zealand cohort were comparable with other developed-city cohorts born in the early 1970s, the lead level gradient observed in the Dunedin cohort was almost entirely (94% of participants) above the current blood lead reference value for clinical attention (5 $\mu\text{g}/\text{dL}$).²⁵ This study's results may not, therefore, be informative about the long-term consequences of very low lead exposures (<7.5 $\mu\text{g}/\text{dL}$).²⁸ Because the only measure of childhood lead exposure was taken at age 11 years, this study could not evaluate sensitive periods of vulnerability to lead or evaluate cumulative exposure across childhood, although blood lead level measured at school age may be "a reasonable proxy for lifetime exposure" up to that point.³ There were also no measures of cumulative lead exposure to midlife, such as cortical bone-lead level. This study could not, therefore, evaluate the differential influences of early-life vs later-life lead exposure. Recent studies of older adults suggest that lead exposure in adulthood is associated with impaired cognitive function and accelerated cognitive decline in late life.²⁹⁻³¹ Although cumulative lead exposure in adulthood is an important metric for understanding the potential harms of lead absorbed across the lifespan, this study was focused on understanding the long-term consequences of early-life lead exposure. During the lifetime of the Dunedin

cohort participants, lead exposure was reduced after childhood, as New Zealand began to phase lead out of its gasoline in the late 1980s and removed it entirely in 1996.¹⁰ In many similar cities in developed countries, adults now in middle age will have also experienced their greatest lead exposures during childhood.^{3,12,13} In addition, this study was observational and correlational, and therefore does not establish a causal relation between lead exposure and outcomes, such as would be the case in a hypothetical experiment with children randomly assigned to lead exposure.

Notwithstanding its limitations, this study may hold implications for clinical practice and public policy. The results indicate that childhood exposures to lead can be linked with cognitive and socioeconomic outcomes detectable more than 3 decades later. For the clinician, evidence of cognitive decline from childhood to adulthood may argue for increased attention to possible early intervention with lead-exposed children.³² For communities that have experienced collective lead exposure events and for countries where lead exposures are still routinely above health standards, the findings raise questions about the reasonable duration and magnitude of public responses. Just as the problem of toxic lead exposure in homes appears to persist, so too do the poor outcomes associated with such exposure. Short-lived public responses to community lead exposure may not be enough.

Conclusions

In this cohort born in New Zealand in 1972-1973, childhood lead exposure was associated with lower cognitive function and socioeconomic status at age 38 years and with declines in IQ and with downward social mobility. Childhood lead exposure may have long-term ramifications.

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