Dentine lead levels in childhood and criminal behaviour in late adolescence and early adulthood

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ABSTRACT

Introduction: There have been a number of recent claims in the literature that lead exposure may make a strong contribution to criminal behaviour.
Objectives: To examine linkages between exposure to lead in childhood and crime in late adolescence/early adulthood, to: (a) determine whether higher levels of lead exposure were associated with increased levels of criminal behaviour; and (b) estimate the extent to which lead exposure was responsible for increases in criminal behaviour.
Methods: Negative binomial regression models were fitted using data from a longitudinal birth cohort of New Zealand-born children studied from birth to the age of 21.
Results: There were statistically significant ($p < .05$) bivariate associations between dentine lead levels assessed at ages 6-9 and both: (a) officially recorded violence/property convictions (ages 14-21); and (b) self-reported violent/property offending (ages 14-21). The mean rate of official convictions was 1.89 (SD = 6.86) and the mean rate of self-reported offences was 15.24 (SD = 49.24) for those with the highest level of exposure. Those with the lowest level of exposure had a mean rate of convictions of 0.0, and a mean rate of self-reported offending of 1.97 (SD = 6.34). Adjustment for potentially confounding factors reduced the magnitude of these associations, but the associations between lead exposure and crime remained statistically significant. Further analyses suggested that the associations were largely explained by the linkages between lead exposure and educational underachievement. Lead exposure accounted for less than 1% of the variance in criminal behaviour.
Conclusions: The results of the present study suggest that, while lead exposure was associated with criminal behaviour, the associations were somewhat weak, and were largely explained by linkages between lead exposure and educational underachievement.

Over the past 25 years, there has been continued interest and research into the linkages between subclinical exposures to lead and the cognitive and behavioural adjustment of children and young people. Needleman and colleagues were able to show that at relatively low exposure levels lead was associated with detectable deficits in intelligence and increased levels of hyperactive behaviours [1-3]. Despite controversy surrounding Needleman's work [4-6], these findings were confirmed by a growing number of studies leading to a consensus that at low levels of exposure lead had potentially neurotoxic effects [7-11]. Further studies suggest that the deficits seen in childhood extended to adolescence and early adulthood [12, 13].

Recently, interest in the effects of lead exposure has examined the linkages between population lead levels and crime. Nevin [14, 15] examined the links between lead exposure and violent crime in the US and in range of other western countries during the second half of the 20th century. Nevin used national level data on blood lead levels derived from the second and third National Health and Nutrition Examination Survey (NHANESII and NHANESIII) administrations in the United States, and in similar national blood lead measurement surveys in the UK, Canada, France, Finland, Italy, West Germany, Australia, and New Zealand. These were compared with violent crime rates reported by the United States Department of Justice, and with rates reported by similar departments in the above-mentioned countries. Nevin found associations between reductions in average blood lead levels and reductions in violent crime rates, in both US and international data, and concluded that the reduction of lead exposure levels reduced the level of violent crime outcomes in each of the countries studied.

While Nevin's [14, 15] findings suggest possible linkages between lead exposure and crime, this research is subject to two important limitations. First, the analysis was based on ecological data in which the rate of crime in the population was related to changes in average blood lead values. It is well-known that such designs may lead to misleading causal inferences [16, 17]. Second, the study had limited control of confounding factors that may be correlated with lead exposure and crime. For both of these reasons, the findings by Nevin about the contribution of lead levels to crime need to be approached with caution.

In this paper, we examine this issue using data from a 21-year longitudinal study of a birth cohort of New Zealand children born in 1977. The significance of this birth cohort is that previous studies of lead exposure amongst cohort members showed evidence of the effects of lead exposure on academic achievement and behaviour, with these effects extending up to at least the age of 18 [13, 18-20]. The fact that evidence of the effects of lead exposure on cognitive outcomes were found for this cohort makes it a suitable test bed to examine the effects of lead on crime.

The aims of the investigation described in this paper were threefold

1. To describe the statistical linkages between lead exposure in middle childhood (7-9 years) and later crime up to the age of 21;
2. To adjust the associations between lead exposure and crime for confounding factors;
3. To explore the extent to which any linkages between lead exposure and crime were mediated by the known educational deficits associated with lead exposure.

MATERIALS AND METHOD

The data were gathered during the course of the Christchurch Health and Development Study (CHDS). In this study a birth cohort of 1265 children (635 males, 630 females) born in the Christchurch (New Zealand) urban region in mid-1977 has been studied at birth, 4 months, 1 year and annually to age 16 years, and again at ages 18, 21 and 25 years [21, 22]. The study has collected information from a variety of sources including: parental interviews, teacher reports, participant self-reports, psychometric assessments, medical, and other record data. Most interviews were conducted face-to-face using trained interviewers. At age 21, 1011 participants were interviewed (79.9% of the original sample). All study information was collected on the basis of signed and informed consent from study participants.

Dentine lead levels

When children were aged 6-8 years, attempts were made to obtain shed deciduous teeth. This process resulted in over 90% of children in the birth cohort supplying at least one tooth by the age of 8 years. For each child, two estimates of dentine lead levels ($\mu g\ g^{-1}$) were obtained by sampling two chips of dentine from an incisor tooth. Lead levels were measured using flameless atomic absorption spectrophotometry. An account of this measurement process and estimates of error in lead levels has been given in a previous paper [23]. The estimated lead level for each child was based on the average of the two chip values. The mean dentine lead level for the sample was 6.2 $\mu g\ g^{-1}$. The reliability of the average chip value has been previously estimated at 0.90 [19].

Officially-recorded violence/property convictions, ages 14-21

Data on convictions over the period 14-21 years were obtained from records held by the New Zealand Police. These records were obtained following signed and informed consent from the young person. Of the 1,011 cohort members asked for permission to search their police records, 97.3% agreed to provide permission and 2.7% declined. For each participant, a record of the date of arrest, type of offence, date of court appearance, number of convictions and sentence was gathered. For the purposes of the present analysis, data on convictions were classified to provide a measure of convictions for property or violent offences. Property offences included theft, burglary, breaking and entering, wilful damage, fire setting, and related offences. Violent offences included assault, fighting, robbery, use of a weapon, threats of violence against a person, and similar offences. The number of convictions for property and violent offences were summed over the period 14-21 years.

Self-reported violent/property offending, ages 14-21

At ages 15, 16, 18 and 21 years, respondents were questioned about their criminal behaviours since the previous assessment. At ages 15 and 16, assessment was made using the Self-Report Early Delinquency Scale [24]. At ages 18 and 21, offending was assessed using an instrument based on the Self-Report Delinquency Inventory [SRDI: 25] supplemented by additional custom-written survey items. This information was used to derive count measures of the number of self-reported property/violent offences committed in each year over the period to age 21 years, which were then summed over the period 14-21 years. Property offences were defined to include theft, burglary, breaking and entering, vandalism, fire setting, and related offences; violent offences included assault, fighting, use of a weapon, or threats of violence against a person.

Covariate factors

A number of covariate factors were chosen from the study database on the basis of: (a) their association with lead exposure in previous studies of this cohort (18-20); and (b) their association with officially-recorded and self-reported offending. Preliminary analyses suggested that the majority of covariate factors were no longer associated with crime when entered into the negative binomial regression models alongside the measure of lead exposure . These factors included:

Lead exposure factors. Traffic density exposure to age 7.

Socio-demographic factors. Maternal age; paternal education level; average family living standards ages 0-8 years; average family income to age 5 years; school decile (relative deprivation) level.

Family functioning factors. Number of family changes to age 8 years; family exposure to stress; maternal use of punishment; parental illicit drug use; parental bonding.

Individual factors. Early-onset cannabis use (by age 15); frequency of alcohol use at age 15.

The final models included the following covariate factors:

Socio-demographic factors.

1. Maternal education level was assessed at birth and represented by a three-level variable corresponding to the mother's highest level of educational attainment. This

classification was: 1 = no formal educational qualifications; 2 = high school qualifications; 3 = tertiary level qualifications (university degree, technical diploma). Socio-economic status at birth was assessed using the Elley-Irving Scale [26]. This scale classifies families into six levels on the basis of paternal occupation.

2. Child ethnicity: At birth, the children were classified as either Maori or non Maori on the basis of parental reports of ethnicity. If either natural parent was Maori or part Maori in descent then the child was classified as Maori, otherwise the child was classified as non Maori.

Family functioning factors.

3. Family conflict: Parents were questioned annually on three items which described the quality of marital relationships. These items were: a) whether the parents had engaged in prolonged arguments during the last 12 months; b) whether the child's mother reported being assaulted by her spouse in the last 12 months and; c) whether the child's mother had reported experiencing sexual difficulties in the last 12 months. These items were combined to produce a scale measure of the extent to which the child was exposed to marital conflict during the interval from birth to the age of ten years. (Fergusson, Horwood & Lynskey, 1992).
4. Maternal smoking during pregnancy: Assessed at birth via parental report, and measured as the average number of cigarettes smoked daily during pregnancy.
5. Exposure to childhood physical abuse: A four-level categorical measure of the extent to which participants were exposed to harsh and abusive discipline during childhood, assessed retrospectively at ages 18 and 21 [27].
6. Parental alcohol problems and parental offending: Assessed via parental report at age 15. All participants whose parents reported a history of alcohol abuse/dependence or criminal offending were classified as having been exposed to parental alcohol problems or parental criminal offending, respectively.

Intervening factors

Two intervening factors were chosen on the basis of their association with lead exposure and outcomes in a previous study of the present cohort [28]. These factors were:

Leaving school without qualifications: Sample members who had never attained any high school qualifications by age 18 were classified as having no high school qualifications (19.2% of the sample).

Grade point average, ages 11-13: at each assessment from 11-13 years, teacher ratings were obtained of the child’s school performance in each of five curriculum areas (reading, handwriting, written expression, spelling, mathematics). Ratings were made using a 5-point scale ranging from very good to very poor. The teacher ratings were summed across years and curriculum areas and then averaged to provide a teacher rating grade point average for each child (α= .96).

Statistical analyses

The associations between dentine lead levels and both: (a) officially-recorded convictions; and (b) self-reported offending were modelled in several steps. In the first step, the bivariate associations between lead exposure levels and criminal offending outcomes were tested for significance using negative binomial regression models in which the rate of offending was modelled as a log inear function of childhood lead level. In the second step, the bivariate models were extended to include the range of covariate factors listed above (socio-demographic and family functioning factors), using forward and backward elimination of variables to arrive at stable and parsimonious models. The parameter estimates of the associations between lead exposure and criminal behaviour outcomes derived from these models were then used to calculate the adjusted rates of both officially-recorded convictions and self-reported offending were obtained using the methods described by Lee [29]. Then, to estimate the consequences of lead exposure on rates of crime, pseudo-R^2 statistics were computed for each model [30]. Finally, these models were extended to include the measures of potentially intervening factors (school achievement) listed above, with adjusted rates of both officially-recorded convictions and self-reported offending once again being obtained from the parameter estimates of the fitted models.

Sample size and sample bias

The present analyses were based on the sample members with available data concerning lead exposure and both: (a) official conviction records for the period 15-21 years (n = 853; 67.4% of the original sample); and self-reported violent and property offending for the period 15-21 years (n = 871; 68.9% of the original sample). Preliminary analyses showed that there were slight but statistically significant ($p < .05$) tendencies for the obtained sample to under-represent individuals from more socially disadvantaged backgrounds (low parental education, low socioeconomic status, single-parent family). To take these biases into account, the sample was poststratified into a series of groups on the basis of these characteristics, and the probability of study participation estimated for each group using the methods described by Carlin, Wolfe, Coffey, and Patton [31]. All analyses were then repeated with the data for the analysis samples weighted by the inverse of the probability of study participation. In all cases, these reanalyses produced essentially the same pattern of results to those reported here, suggesting that the conclusions of this study were unlikely to have been influenced by missing data and selection bias.

In addition, the 2.7% of individuals who had not give permission to access criminal records were compared with other participants with regard to self-reported criminal offending. There were no significant differences in self-reported offending between those who had not give permission to access official criminal records, and those who had given permission, suggesting that the results of the study were unlikely to have been subject to bias stemming from a failure to give permission to access official criminal records.

RESULTS

Associations between lead levels (6-9 years) and criminal offending (ages 14-21)

Table 1 shows the relationships between dentine lead levels at ages 6-9 years and crime between ages 14 and 21. Lead levels are measured in $\mu g\ g^{-1}$ and classified into five class intervals ranging from 0-2 to 12+. The cells of the Table give the mean number of: (a) official convictions for violent or property offending during ages 14-21; and (b) self-reported violent and property offences during the interval ages 14-21. The Table shows that for both officially-recorded and self-reported crime, increasing lead levels were associated with statistically significant increases in rates of offending ($p = .02$ for convictions; $p < .001$ for self-reported offending).

Table 1: Associations between dentine lead levels (ages 6-9) and: (a) convictions for violent/property offenses; and (b) self-reported violent/property offending, ages 14-21

	Lead levels ($\mu g\ g^{-1}$)					Regression parameters [1]		
Outcome	0-2	3-5	6-8	9-11	12+	B	(SE)	p
Mean (SD) number of violent/property convictions ages 14-21	0.00 (0.00)	0.33 (2.31)	0.23 (1.34)	0.28 (1.57)	1.89 (6.86)	.52	.22	=.02
N	86	409	231	83	44			
Mean (SD) number of self-reported/violent/ property offences, ages 14-21	1.97 (6.34)	6.97 (17.17)	6.96 (25.28)	13.25 (33.42)	15.24 (42.94)	.38	.10	<.001
N	88	416	239	84	44			

[1] Negative binomial regression

Adjustment for covariates

Examination of the correlates of childhood lead exposure identified a range of factors that were significantly (all p values < .05) associated with lead levels (see Method). These factors included: factors associated with lead exposure; socio-demographic factors; factors related to family functioning; and individual factors. To adjust the associations between lead exposure and crime for confounding factors, the negative binomial models used in Table 1 were extended to include the socio-demographic and family functioning measures listed above as confounding factors (see Method). The results of covariate analysis are shown in Table 2, which shows the rates of criminal behaviour outcomes after adjustment for confounding factors. The Table shows that while control for confounding factors reduced the size of association between dentine lead levels and crime, for both officially recorded crime and self reported crime the associations with lead levels remained statistically significant (both p values <.05). Pseudo-R^2 statistics computed for each model suggested that lead levels accounted for less than 1% of the variance in criminal convictions and self-reported crime.

Table 2: Associations between dentine lead levels and crime, after adjustment for covariate factors

Outcome	Lead levels ($\mu g\ g^{-1}$)					Regression parameters [1]		
	0-2	3-5	6-8	9-11	12+	B	(SE)	p
Adjusted mean number of violent/property convictions ages 14-21[2]	0.24	0.39	0.63	1.03	1.67	.49	.17	=.005
Adjusted mean number of self-reported/violent/ property offences, ages 14-21[3]	5.91	7.22	8.81	10.76	13.13	.20	.10	=.047

[1] Negative binomial regression

[2] Significant covariate factors: family socio-economic status at birth (B = .48, SE = .14, p < .0001); ethnicity (B = -1.8, SE = .53, p < .001); parental criminal offending (B = 2.4, SE = .54, p < .0001); parental alcoholism (B = 1.4, SE = .53, p = .01).

[3] Significant covariate factors: maternal education (B = .25, SE = .12, p = .04); ethnicity (B = -.77, SE = .31, p = .01); family conflict (B = .003, SE = .002, p = .02); exposure to childhood physical abuse (B = .45, SE = .15, p = .003); maternal smoking during pregnancy (B = .04, SE = .02, p = .004).

The role of educational underachievement as an intervening factor

The results in Table 2 suggest a possible causal link in which early lead exposure may have small but detectable effects on later crime. One explanation of this association is that the relationship reflects a causal chain process in which lead exposure leads to impaired educational performance, which, in turn, is reflected in increased risks of crime. To examine these issues, the regression models described in Table 2 were extended to include a series of educational factors as intervening variables. The educational factors were: leaving school without qualifications; and grade point average ages 11-13 (see Method).

Table 3 shows the adjusted rates of official convictions and self-reported crime, after adjustment for both confounding and intervening factors. The results in Table 3 show that further control for intervening factors reduced the association between lead levels and self-reported crime to the point of statistical non-significance ($p = .52$), whereas the relationship with officially-recorded crime was reduced in magnitude, but remained statistically significant ($p = .02$).

Table 3: Associations between dentine lead levels and crime, after adjustment for both: (a) covariate factors; and (b) intervening education measures

	Lead levels ($\mu g\ g^{-1}$)					Regression parameters [1]		
Outcome	0-2	3-5	6-8	9-11	12+	B	(SE)	p
Adjusted mean number of violent/property convictions ages 14-21[2]	0.16	0.23	0.35	0.52	0.79	.41	.18	=.02
Adjusted mean number of self-reported/violent/ property offences, ages 14-21[3]	7.40	7.93	8.49	9.10	9.74	.07	.11	=.52

[1] Negative binomial regression

[2] Covariate factors: family socio-economic status at birth (B = .37, SE = .14, p = .01); ethnicity (B = -1.5, SE = .53, p = .004); parental criminal offending (B = 1.7, SE = .51, p < .001); parental alcoholism (B = 1.1, SE = .52, p < .001); Intervening factors: leaving school without qualifications (B = 1.89; SE = .50, p < .0001); grade point average, ages 11-13 (B = -.23, SE = .25, p = .35).

[3] Covariate factors: maternal education (B = .41, SE = .13, p = .002); ethnicity (B = -.52, SE = .32, p = .11); family conflict (B = .004, SE = .001, p = .02); exposure to childhood physical abuse (B = .44, SE = .15, p = .004); maternal smoking during pregnancy (B = .03, SE = .02, p = .05); Intervening factors: leaving school without qualifications (B = 1.03; SE = .28, p < .0001); grade point average, ages 11-13 (B = -.16, SE = .13, p = .21).

DISCUSSION

This study has used data gathered over the course of a 21-year longitudinal study to examine the linkages between subclinical lead exposures in middle childhood and later crime. The key findings of the analysis are reviewed below.

First there was clear evidence of dose/response relationships between childhood exposure to lead and rates of officially-recorded and self-reported violent and property crime, with those having lead levels in excess of 12 $\mu g\ g^{-1}$ having substantially higher rates of crime than those with lead levels in the range of 0-2 $\mu g\ g^{-1}$. These associations were explained, to some extent, by control for a series of confounding factors. However, even following control for confounding there was evidence of significant dose/response relationships between lead levels and later crime, suggesting a possible causal linkage in which early lead exposure led to increased risks of crime. These findings were in general agreement with a number of studies linking lead exposure to aggressive behaviour and delinquency [32-34].

One pathway that might explain this link involves the well-established linkages between lead and educational achievement [1-3, 13, 19]. Specifically, it may be proposed that the linkages between lead and crime arise from a causal chain process in which lead exposure leads to educational underachievement, with educational underachievement in turn increasing risks of crime. To test this theory, the analysis was extended to include measures of educational achievement as mediating variables. That analysis showed that control for the intervening role of educational variables explained much, but not all, of the association between lead and crime after control for confounding. These results are generally consistent with the conclusion that the adverse effects of childhood lead exposure on later crime may be largely, but not wholly explained, by the adverse effects of childhood lead exposure on educational achievement.

While the present study suggests possible linkages between lead exposure and crime, these findings need to be placed in context. Specifically, the association between lead levels and crime after adjustment for confounding proved to be weak, and it was estimated that variations in lead levels explained less than 1% of the variance in individual rates of crime. This estimate contrasts sharply with claims based on contemporaneous data made by Nevin [14, 15], who reported that changes in lead levels explained 65% to 90% of the variance in violent crime in western nations during the second half of the 20th century. The difference between the individual-level finding reported in this paper and the estimates reported by Nevin highlights the way in which studies may suggest strong associations at an ecological level, with these associations being far weaker at an individual level. However, it should also be noted that small effect sizes can translate into large numbers of cases when describing population-level outcomes [35].

It is important to note that the present study describes lead levels that were assessed over 20 years ago. Since that time, there have been marked changes in childhood lead levels [12, 36]. The likely effects of declining lead levels in a number of countries will be to make the contribution of population lead levels to crime weaker than suggested by the present analysis. For all of these reasons, it seems unlikely that childhood lead exposures will play a significant role in crime in contemporary populations of children who have lower exposure to lead than was the case in the 1980s. Similarly, because of the weak individual associations between lead and crime, it is implausible to suggest that changes in crime in the United States and in other western countries are substantially explained by declining population exposure to lead. It should be noted however, that in developing nations environmental lead levels are often much higher than in western nations [37], suggesting that the neurotoxic and behavioural outcomes, including criminal behaviour, associated with lead will be an ongoing problem in developing regions.

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