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BLOOD LEAD, INTELLIGENCE, READING ATTAINMENT, AND BEHAVIOUR IN ELEVEN YEAR OLD CHILDREN IN DUNEDIN, NEW ZEALAND

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Abstract—A study of blood lead levels and intelligence, reading, and behaviour problems was carried out using a sample of 579 Dunedin 11-yr-old children. The results suggested that when account was taken of social, environmental, and background factors, raised blood lead is associated with a small but statistically significant increase in children's general behaviour problems as reported by both parents and teachers. These results applied especially to the more specific problems of inattention and hyperactivity.

Keywords: Lead, intelligence, reading, behaviour problems, inattention, hyperactivity

INTRODUCTION

IN RECENT years there has been some evidence of a small but significant association between body lead burden, even at levels well below the accepted thresholds for frank poisoning, and cognitive deficits and behaviour problems in children. This has been disputed by some and the conflicting evidence has been reviewed by Rutter (1980, 1983), the Department of Health and Social Security (1980), the Royal Commission on Environmental Pollution (1983), Harvey (1984) and most recently by Smith (1985). Most reviews point out that differing conclusions from individual studies have been due to methodological differences. Such differences relate to sample ages and locations, methods of assessing lead burden and the material analysed (e.g. blood, teeth, hair), levels of lead considered "high", methods (if any) of accounting for the effect of extraneous or confounding social and environmental factors that co-vary with lead levels, methods of assessing cognitive development and behaviour and methods of statistical analysis of results. A number of studies have such serious methodological shortcomings that they cannot be used to support or reject hypotheses on the effects of lead on children (Harvey, 1984).

The Royal Commission on Environmental Pollution (1983) considered that the possibility of the observed associations between raised lead levels and cognitive deficits and behaviour problems in children being due to confounding social and environmental variables precluded any firm conclusion that raised lead levels are directly responsible

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for the children's cognitive deficits and behaviour problems. This view, however, is not universally accepted. For example, Rutter (1983) in his review stated that

> "Recent investigations have been able to demonstrate that the effects tend to be maintained (although substantially reduced) after control for possible confounding differences. However, in addition, they confirmed earlier findings in their indication that the effects on psychological functioning tend to be relatively small." (p. 347).

In a recent review, Harvey (1984) suggested that the most recent U.K. studies revealed greater consistencies than the earlier investigations because of the attempts made to control for the effect of the confounding social and environmental variables. All the studies were carried out on samples of children aged between 2 and 12 yrs and all used comparable measures. Harvey noted that at the lead levels studied, the effects found from the latest studies were small and when initial significant differences emerged, they became statistically insignificant when subjected to appropriate statistical analysis to take account of the confounding social and environmental variables.

In the most recent review, Smith (1985) concluded that . . .

> "body lead levels in children act as a marker for socially disadvantageous factors and that when these are controlled adequately adverse effects cannot be attributed to lead with any certainty, although they may exist. If there are any effects of lead at these levels, then they are small and may not be detectable with existing methods with any certainty." (p. 24).

This paper describes a study of the correlation between blood lead level and 11-yr-old children's intelligence, reading ability, and behaviour, controlling for the possible confounding effects of social, environmental, and background factors.

METHOD

Sample

The sample for the blood lead study comprised 579 of the 925 children assessed as part of the 11 yr follow up of the Dunedin Multidisciplinary Health and Development Study. This is a longitudinal study of a birth cohort of children born in Dunedin's only obstetric hospital between 1 April, 1972 and 31 March, 1973. The children were recalled for their first follow up when they were three years of age. At that time, 1139 eligible children were known to live in the province of Otago and 1037 (91%) were assessed. They were followed up at ages five ($N = 991$), seven ($N = 954$), nine ($N = 955$), and eleven ($N = 925$). The study sample is known to be over-representative of the higher socio-economic levels and under-representative of Maori and other Polynesian children in comparison with the country as a whole. A study of educational attainment test scores of children in the study sample compared with children of the same age attending Dunedin schools, but not in the study sample, showed no significant differences. This suggests that the study sample was representative of Dunedin children in educational attainment. The sample and the study have been described in detail elsewhere (e.g. McGee & Silva, 1982; Silva, 1984).

Of the 925 children either fully or partially assessed within two months of their 11th birthdays, 803 attended the research unit. The remaining 122 children had intelligence and educational attainment tests in other parts of New Zealand or overseas. The 579 children who participated in the blood lead study were 72% of the sample assessed at the research unit as 11-yr-olds. Ninety per cent of the sample lived in the Dunedin metropolitan area. More detailed information on the socio-economic status of the sample included in the blood lead study compared with the remainder of the study sample and the New Zealand male workforce is given in the results section. Also shown is a comparison of those in the blood lead study and the remainder of the sample on some of the dependent variables in this study.

Measures

Blood lead. Approximately 30 ml of venous blood was collected from each child who freely agreed to participate, and this was used for a variety of investigations (Silva, 1985). Whole blood samples were analysed by one of the authors (PH), utilising the technique of graphite furnance atomic absorption spectrophotometry. The method of blood collection, division, storage, and analysis procedures are described in detail elsewhere (Hughes, 1984). Particular attention was paid to contamination control. The reliability of the method was checked by exchanging samples with a laboratory in Southampton. The correlation between independent assessments was 0.97 and the means were very similar. The method of analysis and quality assurance checks indicated that the Dunedin results can be compared with those from other studies which maintained similar quality control.

Intelligence, reading and behavioural measures. The children's intelligence was assessed by trained psychometrists who used the Wechsler Intelligence Scale for Children (WISC-R) (Wechsler, 1974), omitting the Comprehension and Picture Arrangement sub-tests due to time constraints. Reading was assessed with the Burt Word Reading Test (Scottish Council for Research in Education, 1976).

The children's behaviour was assessed by the Rutter Parent and Teacher Behaviour Questionnaires (Rutter, Tizard & Whitmore, 1970). The total scores of these questionnaires were used. In addition, two further measures of behaviour (inattention and hyperactivity) were derived from the parents' and teachers' reports. These additional measures were based on the items in the Rutter scales plus additional items included to assess inattention and hyperactivity. For inattention, from the teachers scale, the following items were used: fails to complete tasks, poor concentration, easily distracted, does not listen to instructions, difficulties organising work, needs help or attention, shifts from one activity to another, difficulty staying with play and acts before thinking. The hyperactivity scale was made up of the following items: has trouble sitting still, very restless, squirmy, fidgety, and calls out in class. The parents scales were based on similar items. These additional measures, their properties, and some of their correlates are described by McGee, Williams and Silva (1985).

Measures of social, environmental and background factors. The social, environmental and background factors were selected because they were known to be associated with the measures of intelligence, reading and behaviour. Socio-economic status (SES) was assessed with the Index of Socio-economic Status for New Zealand (Johnston, 1983). The mothers' cognitive ability was assessed using the SRA Verbal Test (Thurstone and Thurstone, 1973). Depression in the mother was assessed using a self report questionnaire as described by McGee, Williams, Kashani and Silva (1983).

A cumulative index of disadvantage was developed to include a number of elements known to correlate either singly or in combination with various cognitive and behavioural measures. Some aspects were assessed over several phases of the longitudinal study. The index included the following: frequent changes of residence, frequent changes of school, solo parenting, low SES, separation of the child from his or her parents, mother young at birth of first child, low maternal cognitive ability, a low score on a measure of family relations, marriage guidance sought by parents, and a high score on a check list of mental health symptoms. A high score on this index indicated that the child had experienced many disadvantages. The cumulative disadvantage index is described by Anderson, McGee, Williams and Silva (1985).

Finally, the mother's age and the child's sex and ordinal position in the family were used as additional factors to be included in the analyses.

The measures of intelligence and reading were used as additional variables for control in the analysis of the effect of blood lead on the behavioural measures. This was done because it was known that these two factors are important correlates of the behavioural measures. It was considered that these variables should be included in the analysis to ensure that any effects which lead might have on the behavioural measures would be independent of effects due to intelligence and reading ability.

RESULTS

Table 1 sets out the SES distributions for the blood lead study sample and the remainder of the Dunedin study sample. A Chi Square Test showed that the Dunedin blood lead study sample SES distribution differed significantly from that in the remainder of the Dunedin sample (X2 12.7; d.f. 5; $P < 0.05$). The table shows that

TABLE 1. A COMPARISON OF SOCIO-ECONOMIC LEVELS FOR THE BLOOD LEAD STUDY SAMPLE AND THE REMAINDER OF THE DUNEDIN STUDY SAMPLE

Socio-economic status	Dunedin blood lead study sample		Remainder of Dunedin study sample	
	N	%	*N*	%
1 (High)	84	16.7	32	11.6
2	92	18.3	60	21.8
3	137	27.3	85	31.0
4	148	29.5	62	22.5
5	28	5.6	26	9.5
6 (Low)	13	2.6	10	3.6
Not known	77	–	71	–
Total	579	100.0	346	100.0

the blood lead sample had more members of SES groups 1 and 4 but slightly fewer members of other levels.

Comparison of the blood lead study sample and the remainder of the Dunedin study sample on some measures

The results from the Full Scale WISC(R) IQ, the scores on the reading test, and from the Rutter Behaviour Questionnaires for the two groups are set out in Table 2. With one exception (Teachers' Rutter Behaviour Questionnaire), there were no significant differences between the children in the blood lead study sample and those from the sample assessed at age 11 who were not included.

Blood lead results

For the 579 Dunedin children, the range of blood lead levels was from 4 to 50 μg/dl with a mean of *11.1* and a standard deviation of 4.91. Only two children had levels above 30 μg/dl; one was 31 μg/dl and the other was 50 μg/dl. The mean blood lead level for 311 boys was 11.4 μg/dl (standard deviation 4.57 μg/dl) and for 268 girls

TABLE 2. A COMPARISON OF THE BLOOD LEAD STUDY SAMPLE AND THE REMAINDER OF THE DUNEDIN STUDY SAMPLE FOR THE COGNITIVE AND BEHAVIOUR MEASURES

Measure	Dunedin blood lead *study sample*			Remainder of Dunedin study sample			Student's *t*-test	Significance
	N	*Mean*	*SD*	*N*	*Mean*	*SD*		
WISC(R) Full Scale IQ	579	108.9	15.12	338	107.0	16.75	1.77	NS
Reading Score	579	72.9	19.52	340	71.6	21.43	0.89	NS
Parents' Rutter Questionnaire	572	7.0	5.28	323	7.4	5.82	1.21	NS
Teachers' Rutter Questionnaire	578	3.6	4.85	328	4.3	5.28	2.08	< 0.05

was 10.4 μg/dl (standard deviation 4.6 μg/dl). The sex difference was statistically significant ($P < 0.01$). The distribution was positively skewed with a small hump in the distribution between 20 and 31 μg/dl.

Direct correlations between log blood lead and the intelligence, reading and behaviour measures

Because of the distribution of the blood lead data, a logarithmic transformation was undertaken and used in all further analyses. Table 3 sets out the correlations between the Dunedin blood lead levels and the intelligence, reading, and behaviour measures.

TABLE 3. CORRELATIONS BETWEEN LOG BLOOD LEAD LEVELS AND THE COGNITIVE AND BEHAVIOUR MEASURES SCORES

Measure	*N*	r	Significance
Verbal IQ	574	−0.06	NS
Performance IQ	574	−0.03	NS
Full Scale IQ	574	−0.05	NS
Reading	574	−0.09	< 0.05
Parents' Rutter Behaviour Scale	567	0.14	< 0.001
Teachers' Rutter Behaviour Scale	573	0.14	< 0.001
Parents' Inattention Scale	535	0.11	< 0.01
Parents' Hyperactivity Scale	535	0.14	< 0.001
Parents' Inattention Scale	535	0.19	< 0.001
Parents' Hyperactivity Scale	535	0.14	< 0.001

The correlations between blood lead and the WISC(R) IQ's were not significant so they were not subject to further analysis. The correlation between blood lead and the reading score was low but significant ($P < 0.05$). All the correlations between blood lead and the behaviour measures were significant and in every case but one, the levels of significance were less than 0.001.

Regression analyses

Taking all subjects for whom all the relevant information was available (N = 535), a series of standard regression analyses was carried out with the social, environmental, and background factors as predictors of the reading and behaviour measures. Logarithmic transformations were carried out on the ordinal position and family disadvantage scores. Because lead has been shown to have a relationship with low SES (e.g. Smith, 1985), a dummy variable was created in which the lower two SES levels were coded as 1 and the other SES levels as 0. After calculation of the multiple correlation, the measure of blood lead was entered into the regression equation in order to assess whether the blood lead measure significantly increased the multiple correlation. In effect, this method of analysis serves to estimate the effect of blood lead on the dependent variables, after controlling for the possible confounding effect of the social, environmental, and background measures.

The regression analyses are summarised in Table 4 which sets out the simple correlations between the social, environmental, and background measures and the measures of lead, reading and behaviour and the multiple correlations.

Blood lead correlated at a low level with all the social, environmental, and background measures. The multiple correlation was 0.13, indicating a weak relationship between blood lead and the social, environmental, and background measures.

The simple correlations between the social, environmental, and background variables and the reading and behaviour measures varied from zero to 0.42. The multiple correlation of the social, environmental, and background measures with the reading score was moderately high (0.65), while the multiple correlations of these variables plus the intelligence and reading measures with the behaviour measures were lower, ranging from 0.30 to 0.49.

The contribution of blood lead

The lead measure improved the prediction of the reading measure by a trivial amount which was not statistically significant.

The predictions of all but one of the behaviour measures were significantly improved by the addition of the lead measure, but the reductions in the residual mean squares were very small. The effect of a 10-fold increase in lead was to increase the behavioural scores by around 0.1 points.

DISCUSSION

The sample used in this study was drawn from one urban area of New Zealand, was socio-economically advantaged, and under-representative of Maori and other Polynesian children. The children were older than those used in most other studies of blood lead. It was also noted that the children in the Dunedin study sample who took part in the blood lead study differed slightly from those who did participate. Those who did not participate gained a higher score on the Teacher's Rutter Behaviour Scale and slightly lower SES levels. These sample characteristics may well have masked associations between blood lead levels, intelligence, reading, and behavioural problems as some studies have found stronger direct associations between high blood lead and development in lower SES levels (e.g. Harvey, Hamlin, Kumar & Delves, 1984).

The mean blood lead level of 11.1 μg/dl from the Dunedin sample was very similar to that reported for the British outer city population level (11.0 μg/dl) and a little lower than the inner city population level (12.8 μg/dl). One point six per cent of the Dunedin sample had blood lead levels greater than 25 μg/dl in comparison with 1.9% for the British outer city populations and 3.1% for the inner city populations (Royal Commission on Environmental Pollution, 1983). The Dunedin children had a lower mean blood lead level than that reported from a sample of London 6–12-yr-old children who lived near a lead smelter (Yule, Landsdown, Millar & Urbanowicz, 1981). The

TABLE 4. CORRELATIONS AND SUMMARY OF REGRESSION ANALYSES ($N = 535$)

Social, environmental, and background factors	Independent Varible	Dependent Variables						
Simple correlations	Blood* Lead	Reading	Parent Rutter Questionnaire	Teacher Rutter Questionnaire	Parent Inattention	Parent Hyperactivity	Teacher Inattention	Teacher Hyperactivity
SES (low)	0.01	−0.10	0.07	0.01	0.01	0.06	0.05	0.04
Mother's cognitive ability	−0.07	0.34	−0.16	−0.09	−0.12	−0.13	−0.15	−0.05
Mother's depression score	0.05	−0.12	0.35	0.08	0.30	0.12	0.11	0.04
Disadvantage index*	0.04	−0.21	0.31	0.15	0.24	0.19	0.20	0.09
Mother's age	−0.03	0.13	−0.16	0.01	−0.12	−0.04	−0.03	0.02
Child's sex	0.09	−0.09	0.03	0.13	0.11	0.11	0.22	0.24
Ordinal position in Family*	0.01	0.03	−0.08	0.01	−0.06	0.06	0.01	0.03
Intelligence	–	–	−0.27	−0.20	−0.33	−0.21	−0.32	−0.10
Reading	–	–	−0.22	−0.25	−0.36	−0.26	−0.42	−0.22
Residual standard deviation	0.43	14.82	4.79	4.62	3.05	2.71	3.69	2.44
Residual standard deviation with addition of lead	–	14.80	4.75	4.59	3.05	2.70	3.66	2.43
Partial regression coefficient for lead	–	−0.05	0.12†	0.11†	0.05	0.10†	0.12†	0.09†
Standard error of regression coefficient	–	0.033	0.039	0.042	0.038	0.041	0.038	0.042

*A log transformation was carried out on these variables.
†Statistically significant ($P < 0.05$).

distribution of results (i.e. lognormal) was very similar for both samples. The Dunedin lead levels were a little lower than those from the NHANES II study (Annest, 1983) which included nearly 10,000 Americans whose blood was taken between 1976 and 1980. They recorded a mean blood lead level of 13.9 μg/dl. Altogether, 1.9% of the total NHANES II study sample had blood lead levels greater than 30 μg/dl while there were only two such "high" levels in the Dunedin sample (0.3%). The Dunedin mean results, however, were a little higher than the last year's results (1980) from the NHANES II study, when they recorded a mean of 10.0 μg/dl. In summary, the results from the Dunedin study showed that this sample tended to have slightly lower mean lead levels than those reported from the United Kingdom and considerably fewer children in the higher lead level groups.

The small but significant sex difference in blood lead levels between boys and girls was expected on the basis of the NHANES II study (Annest, 1983). The reason for this is unclear and requires further investigation. It may be that boys are more exposed to lead during their different daily activities. Alternatively, there may be important differences between the sexes in the metabolic handling of lead.

The direct correlations between blood lead and the intelligence measures were not significant in this sample, so these measures were not subjected to further analysis. Thus, this study did not support the findings of those who have found a significant association between raised lead levels and low intelligence (Needleman, Gunnoe, Leviton, Reed, Pevesie, Maher & Barrett, 1970; Yule *et al.*, 1981) but supported those who reported no significant association (e.g. McBride, Black & English, 1982; Smith, Delves, Landsdown, Clayton & Graham, 1983; Harvey *et al.*, 1984).

All the remaining direct correlations were significant, so the measures were subjected to further analysis. As pointed out by numerous reviewers (e.g. Harvey, 1984; Smith, 1985) in studies of the effect of lead on development and behaviour it is essential to control for the confounding effect of extraneous factors. This is because high lead levels are often associated with social and environmental disadvantage. Thus, if the disadvantage is not controlled, it is possible that any significant associations found would reflect the disadvantage rather than the lead.

It was interesting to find no significant correlation between blood lead levels and socio-economic status. Many other studies (e.g. NHANES II study, Annest, 1983) have found that the more socio-economically disadvantaged tend to have higher lead levels. The lack of a significant association between lead levels and SES in Dunedin may reflect the higher SES of the Dunedin sample or other differences related to SES. Future studies of lead in this country should attempt to elucidate the nature of other environmental correlates that co-vary with lead. At present the only research on this question in New Zealand is being carried out in Auckland (Kjellstrom, Borg, Reeves, Edgar, Pybus, Ohms, Sewell & Hodgson, 1978; Kjellstrom, 1984; Reeves, Kjellstrom, Dallow & Mullins, 1982). It is expected that the New Zealand results will differ from those overseas as many of the overseas studies have been carried out in very large cities in areas characterised by low socio-economic status and its associated crowding, poor housing, and sometimes, high road traffic concentrations.

When the social, environmental, and background factors were controlled, the addition of the blood lead measure did not result in a significant increase in the multiple correlation with the reading score. This suggests that the original small direct correlation between the blood lead measure and reading score was partly a reflection of the confounding effect of the social, environmental and background measures. This has not been an uncommon finding as emphasised by Smith (1985), who stated:

> "when social variables which have been shown to correlate significantly with outcome variables are controlled, more of the variance is explained, and differences which can be attributed to lead are no longer statistically significant, although they remain in the same direction." (p. 32)

An interesting finding from this study was that despite controlling for the possible confounding effects of SES, maternal cognitive ability, maternal depression, a variety of other disadvantageous factors, the mother's age, and the child's sex, ordinal position in the family, intelligence quotient and reading score, in five out of six analyses the lead measure was found to have a statistically significant but very small effect on the behaviour measure. The inclusion of lead in the analysis resulted in an increase of the variance explained in the dependent variables of between 0.8 and 1.5%. The only behaviour measure not to show a significant effect was the parents' inattention measure.

It is concluded that even where social, environmental, and background factors are taken into account, raised blood lead is associated with a very small but statistically significant increase in children's behavioural problems, both general problems reported by parents and teachers, problems of inattention reported by teachers, and hyperactivity reported by both parents and teachers. These findings are at variance with other recent findings as reviewed by Harvey (1984) and Smith (1985), but support the views of Rutter (1983). The results suggest that there is good reason to be cautious before dismissing lead as a significant factor in children's behavioural problems. The effect of lead may be statistically significant in large samples but is too small to have any meaning in individual cases. Further research is needed with other samples, of other ages, in other settings and countries, and with other measures before a firm conclusion can be reached on the effect of lead on child development.

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