

# Substantial decrease of blood lead in Swedish children, 1978-94, associated with petrol lead

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## Abstract

**Objectives**—To study the potential impact of environmental exposure to petrol lead, residential area, age, sex, and lead exposing hobby, on blood lead concentrations (BPb) in children.

**Methods**—In the south of Sweden, yearly from 1978-94, BPb was measured in 1230 boys and 1211 girls, aged between 3 and 19 (median 10; quartiles 9 and 12) years.

**Results**—For the samples of 1978, the geometric mean (GM) was 67 (range 30-250)  $\mu\text{g/l}$  in boys and 53 (18-161)  $\mu\text{g/l}$  in girls, whereas the corresponding GMs for 1994 were 27 (12-122) and 23 (12-97)  $\mu\text{g/l}$ . The sex difference was present only in children over eight. Moreover, residential area affected BPb; in particular, children living near a smelter area had raised BPbs. There was a clear ecological relation between BPb (adjusted GM) and annual lead quantity in petrol sold in Sweden, which was estimated to be 1637 tonnes in 1976 and 133 tonnes in 1993 ( $P < 0.001$ , ecological linear regression analysis, where a two year lag of petrol lead was applied). In the 171 boys and 165 girls who were sampled twice with an interval of one to four years, the decreases in BPb were estimated to be 6% (95% confidence interval 4%-8%) and 10% (8%-13%)/year, respectively.

**Conclusions**—The present report points out the considerable beneficial effect of the gradual banning of petrol lead on the lead exposure affecting the population and differential sex specific BPb patterns due to a pronounced age effect in girls, which may be caused by older girls' lower food intake per kg of body weight, lower lung ventilation, cleaner life style, and loss of blood lead through menstrual bleedings.

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Lead exposure from car exhausts is associated with increased blood lead concentrations (BPb), as is exposure from industrial emissions, house paint, and drinking water.<sup>1</sup> During the past decades, measures have been taken to reduce lead exposure.

In Sweden, as well as in many other countries, there has been a rapid reduction of the use of lead in petrol. We have reported a sig-

nificant decrease of BPb in Swedish children in 1978-84,<sup>2</sup> as well as in 1985-7.<sup>3,4</sup> In the present report we consider additional data from the period 1988-94, to analyse the total data set.

## Materials and methods

### CHILDREN STUDIED

At the end of May or the beginning of June each year, from 1978 to 1994, venous blood samples were obtained from independently sampled groups of children in schools and kindergartens in the urban and the surrounding rural areas of Landskrona (population: 37 438 in 1978; 36 336 in 1993) and Trelleborg (34 429 in 1978; 37 141 in 1993). Out of the children eligible for sampling, results on BPb were obtained for on average 63%, consisting of 2441 children (1230 boys and 1211 girls), aged 3-19 (median 10; quartiles 9 and 12) years. Furthermore, 171 boys and 165 girls were sampled unintentionally on two separate occasions, with an interval of one or two years, except for five boys and one girl with an interval of four years.

### EXPOSURE

Since 1944, there has been a secondary lead smelter located about 1 km from the town centre of Landskrona. In 1982, the lead emitted through the chimney was 2.5 tonnes. In the early 1970s, the emission was considerably higher. Also, there is a diffuse dusting from the smelter area. In 1984, another secondary smelter was built close to the first one. The maximum allowable lead emission for this smelter is 0.3 tonnes/year; the actual figure is probably higher. Systematic water spraying of the area was initiated in the first smelter in 1981, and in the second one in 1985. There are no homes within 0.5 km of the smelters. The area within 0.5-1 km of the smelter area is referred to as being near the smelters.

The other major lead emission in Landskrona is car exhausts. In 1970, the emission was about 10 tonnes, in 1984 about 2.5 tonnes, in 1990 about 1.7 tonnes, and in 1993 about 0.8 tonnes.

Fairly extensive surveys of lead contamination have been made in Landskrona. In 1980-1, extensive sampling of air was made in the urban area (five sampling spots, 1.0-1.8 km from the secondary smelter).<sup>5</sup> The average concentration was 0.17  $\mu\text{g}/\text{m}^3$  outdoors, and 0.15  $\mu\text{g}/\text{m}^3$  indoors. The concentrations were affected both by wind from the smelter and

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proximity to traffic. In 1977, in one of these urban area spots, the concentrations were higher than in 1980–1. In 1977, the concentration was  $0.42 \mu\text{g}/\text{m}^3$  in fine particles ( $<2 \mu\text{m}$ ), and  $0.12 \mu\text{g}/\text{m}^3$  in coarse fractions ( $2\text{--}10 \mu\text{m}$ ).<sup>6</sup> In 1988, the corresponding concentrations were much lower:  $0.04$  and  $0.02 \mu\text{g}/\text{m}^3$ , respectively.<sup>7</sup> In a sampling spot situated outside the inner rural area ( $2.2 \text{ km}$  from the smelter), the corresponding concentrations were  $0.15$  and  $0.04 \mu\text{g}/\text{m}^3$  in 1977, and  $0.03$  and  $0.02 \mu\text{g}/\text{m}^3$  in 1988.

In samples of deposited dust obtained in the period 1973–93 close to the smelter, the concentrations decreased dramatically between 1973 and 1983, but did not change thereafter.<sup>8</sup> In top soil obtained in 1992, the concentrations were 792, 158, 82, and  $39 \mu\text{g}/\text{g}$  in samples from the non-inhabited area close to the smelter ( $0.2 \text{ km}$ ), the inhabited area near the smelter ( $0.8 \text{ km}$ ), urban ( $1.0\text{--}1.8 \text{ km}$ ), and rural ( $3.0\text{--}4.5 \text{ km}$ ) areas, respectively.<sup>9</sup> In the same year, in road dust, the concentrations were 1270, 46–259, and  $225 \mu\text{g}/\text{g}$ , and in house dust, 185, 142, and  $114 \mu\text{g}/\text{g}$ , in the area near the smelter, urban, and rural areas, respectively.

In Trelleborg, there are no major industrial lead emissions. The emission from traffic should be about the same as that in Landskrona.

#### QUESTIONNAIRE

Each child was questioned about parents' occupation, family living conditions, and his or her own hobbies, in particular those involving lead exposures—for example, moulding tin soldiers or shooting air guns.<sup>10</sup>

#### PETROL LEAD

Yearly estimates of quantity of lead in petrol (tonnes) sold in Sweden were obtained from data on sale of petrol with known lead concentrations, provided by the National Swedish Environment Protection Agency and the Swedish Petroleum Institute.<sup>11</sup>

#### LEAD ANALYSES

All samples obtained in a particular year were analysed in a block. To avoid artificial differences in the results due to differences in systematic errors between methods, all samples were analysed by the same method as far as possible.<sup>2,3,10</sup> This method involved wet digestion, extraction, and flame atomic absorption spectrometry (AAS), and had a detection limit around  $10 \mu\text{g}/\text{l}$ . When the study started in 1978, the method had been used for many years at our laboratory. From the very beginning, four reagent blanks were included in each analytical series containing 12 unknown blood samples. The amount of lead in the reagent blanks varied between batches and corresponded to  $10\text{--}30 \mu\text{g}/\text{l}$  of blood, but was reproducible and without time trend. Also, the evacuated  $10 \text{ ml}$  tubes for blood sampling were checked regularly for lead contamination, which steadily corresponded to less than  $5 \mu\text{g}/\text{l}$  of blood.

Due to decreasing BPbs over the years, the

detection limit and the precision of the method became unsatisfactory, as the coefficient of variation calculated on duplicate measurements increased from 6% to 13%. Simultaneously, there was an improvement of the electrothermal atomisation (ETA) AAS techniques. Therefore, an extensive testing of some ETA-AAS methods was carried out during 1990. A method described by Stoeppler and Brandt<sup>12</sup> for cadmium in blood was slightly modified, and was found to give results identical to those obtained by the flame AAS method. The ETA-AAS method was used as from 1991, and involved deproteinisation of blood ( $1 \text{ ml}$ ) by addition of nitric acid ( $1.4 \text{ M}$ ,  $2 \text{ ml}$ ). Each sample was prepared in triplicate, one of them with lead standard added before deproteinisation. Duplicates ( $20 \mu\text{l}$ ) of each sample preparation were made. A Varian Spectra AA-40 ( $283.3 \text{ nm}$ ) with autosampler, Zeeman background correction, and pyrolytically coated tubes were used. The temperature programme was: drying  $90^\circ\text{C}$ , ramp time  $5 \text{ s}$ ; ashing  $400^\circ\text{C}$ , ramp  $5 \text{ s}$ , hold  $10 \text{ s}$ ; atomisation  $2300^\circ\text{C}$ , ramp  $1 \text{ s}$ , hold  $2 \text{ s}$  (gas stop); clean out  $2400^\circ\text{C}$ , ramp  $2 \text{ s}$ . The detection limit, calculated as 3 SDs for reagent blanks, varied between 3 and  $5 \mu\text{g}/\text{l}$ , and the coefficient of variation for duplicate determinations between 4% and 7%. A subset of the samples from 1991 were analysed by both methods (fig 1); the obtained regression line is:

$$Y = 0.21 + 1.009 \times X \quad (r = 0.98).$$

The accuracy was tested twice each year in a calibration programme between Nordic laboratories with nine to 20 laboratories participating on each occasion. In samples with BPb of  $200 \mu\text{g}/\text{l}$  or less, our results averaged 97% (range 82%–116%,  $n = 59$ ) of the mean ( $121$ , range  $46\text{--}200 \mu\text{g}/\text{l}$ ). We also participated in the United Kingdom external quality assurance scheme, with good results. Concentrations of these samples were too high. After introduction of the ETA-AAS method, the accuracy was also checked by analysis of commercial reference samples of

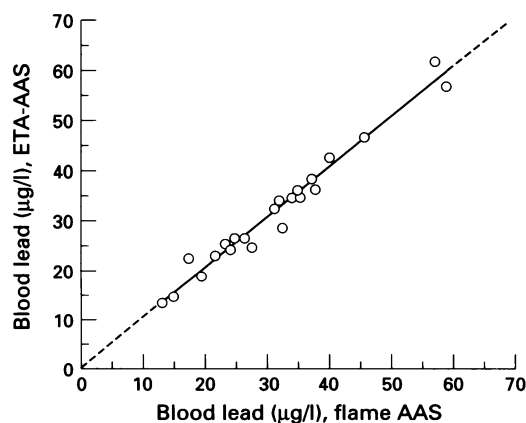


Figure 1 Comparison of different atomic absorption spectrophotometric (AAS) methods: electrothermal atomisation (ETA) and flame atomisation. Each point is the mean from duplicate samples.

lyophilised whole blood (from Nycomed AS, Oslo, Norway), with recommended mean concentrations in the range 35–51 µg/l. Our results averaged 98.5% (range 94%–104%) of these values. None of the accuracy controls showed any time trend.

#### STATISTICS

Individual BPbs were log transformed. The influence of sample year, residential area, age, sex, and potentially lead exposing hobby on BPb was examined by stratified analyses and analysis of variance (ANOVA) techniques.<sup>13</sup> An adjusted BPb value, expressed by the geometric mean (GM), was obtained by computing the corresponding least squares mean.<sup>14</sup>

The ecological relation between BPb (adjusted GM) and annual lead quantity in petrol sold in Sweden was investigated by weighted least squares regression,<sup>15</sup> with for each data point, the number of blood samples divided by the squared adjusted BPb value as weight, which is proportional to the approximate inverse variance of the GM.<sup>16</sup>

For the 336 children sampled twice, only the first blood sample was included in this type of analysis.

Estimates for the sex specific BPb decreases (%/year) were provided from individual BPb ratios in the children who were sampled twice. A confidence interval (CI) was obtained by a log normal approximation.

#### Results

In the multivariate analyses, sample year, residential area, age, and sex had a significant impact on BPb, whereas potentially lead exposing hobby did not influence BPb. Table 1 shows the unadjusted and age and sex adjusted GMs for five residential areas. Children living near the smelter area in Landskrona had highest BPbs, whereas children from the rural district in Trelleborg had the lowest BPbs. Application of ANOVA models with sample year, age, sex, and a binary variable reflecting two residential areas, as independent variables, implied that chil-

dren from the area near the smelter in Landskrona had significantly higher BPb than those from the other urban area in Landskrona, and in both Landskrona and Trelleborg children from the urban area had significantly higher BPb than children from the rural area (all P values <0.01; NS interactions with sample year). Furthermore, note that BPb substantially decreased with calendar year in each area; the decrease in BPb during the observation period was 50%–60% (table 1).

Figure 2 shows yearly estimates for lead quantity in petrol sold in Sweden in 1976–93: in 1976 the amount was 1637 tonnes; in 1993 133 tonnes.

Figure 3 shows the relation between BPb (adjusted GM) and lead quantity in petrol sold in Sweden two years before. The data are stratified according to the residential areas that appear in table 1. Based on all data points the result of the ecological regression analyses is:

$$\text{BPb} = 16.7 + 0.027 \times \text{Petrol-Pb}$$

with the 95% CIs for the intercept and slope equal to 14.3–19.0 and 0.0240–0.030. The following area specific ecological regression slopes were obtained for the area near the smelter, urban, and rural areas in Landskrona, and urban and rural areas in Trelleborg, respectively: 0.031 (95% CI 0.027–0.034), 0.028 (0.022–0.033), 0.026 (0.022–0.030), 0.032 (0.027–0.037), and 0.024 (0.017–0.031). We also applied other lag times (one and three years); these, however, generally implied a somewhat worse fit (the mean squared error increased). Quadratic terms did not significantly contribute to the regressions. It should be pointed out that, during the first decade of the observation period, the BPb decrease seemed to be most pronounced for children that lived in the area near the smelter in Landskrona (table 1 and fig 3).

Based on data from 171 boys and 165 girls who were sampled twice, the sex specific BPb decreases were estimated at 6% (95% CI:

Table 1 Blood lead concentrations (BPb; µg/l) in Swedish children (1230 boys and 1211 girls), aged 3–19 (median = 10, quartiles = 9 and 12) in 1978–94 (children are classified into five residential areas)

Year	Landskrona									Trelleborg										
	Near smelter				Other urban area				Rural area			Urban area			Rural area					
	n	GM*	GM†	(range)	n	GM*	GM†	(range)	n	GM*	GM†	(range)	n	GM*	GM†	(range)	n	GM*	GM†	(range)
1978	142	67	70	(24–210)	156	59	62	(24–182)	215	56	58	(18–250)	0	—	—		0	—	—	
1979	0	—	—		0	—	—		0	—	—		146	58	59	(27–104)	12	39	42	(27–54)
1980	0	—	—		0	—	—		0	—	—		0	—	—		161	48	50	(20–134)
1981	0	—	—		0	—	—		0	—	—		47	59	59	(34–116)	62	49	48	(22–88)
1982	34	57	55	(25–94)	12	56	54	(34–90)	67	43	44	(15–100)	0	—	—		0	—	—	
1983	0	—	—		0	—	—		0	—	—		47	43	41	(20–73)	39	40	40	(19–81)
1984	41	41	42	(14–129)	47	39	39	(14–78)	82	38	37	(18–90)	0	—	—		0	—	—	
1985	0	—	—		0	—	—		0	—	—		38	35	34	(15–62)	21	43	41	(18–162)
1986	38	45	44	(24–78)	97	42	40	(19–84)	46	36	35	(14–80)	0	—	—		0	—	—	
1987	0	—	—		0	—	—		0	—	—		48	37	36	(14–91)	31	35	34	(16–115)
1988	31	38	37	(21–65)	55	32	33	(15–59)	64	31	32	(17–71)	0	—	—		0	—	—	
1989	0	—	—		0	—	—		0	—	—		30	34	34	(22–57)	37	34	33	(20–68)
1990	33	39	38	(23–73)	58	36	35	(19–68)	52	34	33	(11–63)	0	—	—		0	—	—	
1991	42	35	35	(14–59)	45	31	32	(15–58)	26	32	31	(19–64)	47	29	28	(15–58)	24	27	26	(16–42)
1992	8	36	36	(19–59)	12	33	32	(25–46)	23	27	27	(15–56)	0	—	—		0	—	—	
1993	0	—	—		0	—	—		0	—	—		55	23	23	(12–46)	35	23	22	(10–67)
1994	49	29	29	(13–97)	44	24	24	(12–49)	42	22	22	(12–123)	0	—	—		0	—	—	

\*Geometric mean of BPb data, unadjusted; †Geometric mean of BPb data, adjusted for age and sex.

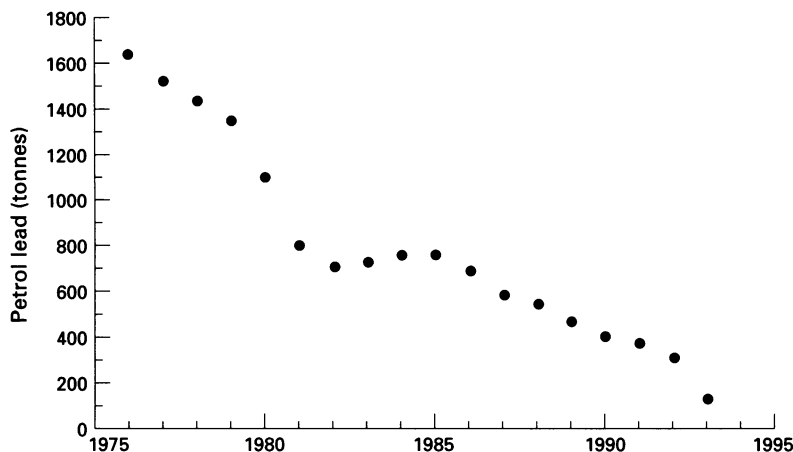


Figure 2 Yearly estimates for lead quantity in petrol (tonnes) sold in Sweden in 1976-93.

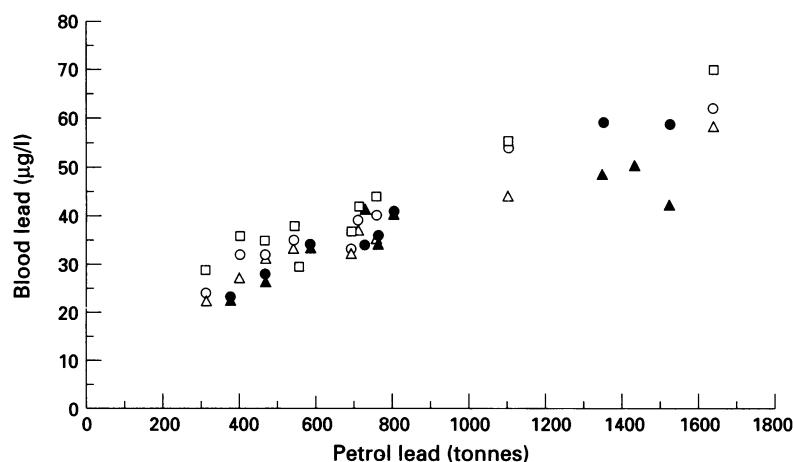


Figure 3 Relation between blood lead concentrations (BPb; geometric means adjusted for age and sex) found in Swedish children, on the one hand, and lead in petrol sold in Sweden two years before, on the other. BPb data are stratified for five different residence areas of the children: area near the smelters in Landskrona (open squares); other urban area in Landskrona (open circles); rural area in Landskrona (open triangles); urban area in Trelleborg (filled circles); rural area in Trelleborg (filled triangles).

4%–8%) and 10% (8%–13%)/year, respectively (table 2). Stratified analyses showed no evidence of the sex specific BPb decreases being modified by calendar time period or residential area.

The difference between the sex specific BPb patterns was also found in data analyses that included all children. For example, the unadjusted GM for the samples from 1978 was 67 (range: 30–250) µg/l in boys and 53 (18–161) µg/l in girls, whereas the corresponding GMs for 1994 are 27 (12–122) and 23 (12–97) µg/l; relevant adjustments did not change these GMs noticeably. Nevertheless, table 3 indicates similar sex specific concentrations for ages up to eight years; by contrast

Table 2 Characteristics of the 171 boys and 165 girls who were sampled twice, and the corresponding sex specific estimates for decrease in blood lead concentration (BPb; µg/l)

	First sample		Second sample		BPb decrease %ly (95% CI)
	BPb	Age (y)	BPb	Age (y)	
	GM (range)	median (5-95%)	GM (range)	median (5-95%)	
Boys	39 (14-116)	8 (8-9)	34 (12-124)	10 (9-11)	6 (4-8)
Girls	39 (15-162)	8 (8-9)	32 (11-92)	10 (9-11)	10 (8-13)

the estimates for older children reflect progressively higher BPbs in boys compared with girls. This tendency was not modified by residential area. (Table 3 shows that BPb in boys did not decrease with age as a consequence of the presence of a considerable birth cohort effect; see discussion.)

**Discussion**

Generally, the BPbs in the children studied were similar to concentrations in other areas of Sweden,<sup>17-21</sup> but low compared with those reported in many other countries<sup>22-24</sup> (also reported by Kaniewski A J, Grabecki J, Schütz A, Skerfving S, "Lead and cadmium exposure around lead-emitting industries in Poland and Sweden" personal communication).

Remarkably similar decreases of BPb have been reported, during shorter observation periods, in adults from another part of Sweden,<sup>25</sup> and in subjects from the United States,<sup>26 27</sup> New Zealand,<sup>23</sup> South Africa,<sup>28</sup> the United Kingdom,<sup>29</sup> Greece,<sup>30</sup> Belgium,<sup>31</sup> and Germany.<sup>32</sup>

Preanalytical (purity of reagents, glassware, and sample tubes) and analytical (change of method from flame-AAS to ETA-AAS in 1990) factors have been kept under strict control, and have not shown any time trend.

House paint that contained lead, which may have a substantial impact on children's BPbs,<sup>33</sup> drinking water contaminated with lead, and lead glazed pottery are uncommon in Sweden. During the past few years, there has been a shift from lead soldered cans to welded ones. The effect of cans upon lead intake is probably not large.<sup>17</sup>

There was a dramatic decrease in petrol lead in the period 1978-94. The decrease was gradual, starting in the sixties; in 1994 there was no lead in petrol (although a total ban is effective as from 1995). Health aspects have been the reason for the reduction in lead exposure. Moreover, the incompatibility between lead and catalytic converters, introduced to reduce other air pollutants, has played an important part.

Our data show a clear relation between BPb decrease in children and petrol lead reduction. Similar data have been published from other studies with shorter observation periods.<sup>19 22 26-28 30 34 35</sup> In view of the fact that lead emission might be expected to cause a long lasting contamination of the environment, including foods, the rate of decrease of the BPb is particularly remarkable. Further, the decrease should be dampened by the skeletal lead pool, which has a slow turnover.<sup>36</sup>

Interestingly, studies of the isotope ratios in blood in United States citizens<sup>37 38</sup> and Italians<sup>39</sup> have indicated that 50-100 µg/l originated from petrol lead, which is comparable with the concentrations from 1978 in our children. The comparison may not be valid, however, as Sweden has a rather low density of traffic and as there is lead exposure from other sources than petrol (although, as already said, these are low in Sweden). The

Table 3 Blood lead concentrations (BPb;  $\mu\text{g/l}$ ) in Swedish boys and girls, stratified by calendar year and age

Year Age (y)	BPb in boys			BPb in girls			BPb ratio between boys and girls (95% CI) <sup>†</sup>
	n	GM*	(range)	n	GM*	(range)	
1978-82							
≤8	30	57	(22-116)	48	56	(28-89)	1.02 (0.88-1.18)
9-11	105	54	(20-102)	97	51	(15-104)	1.07 (0.98-1.17)
12+	381	63	(20-250)	393	50	(18-161)	1.27 (1.21-1.33)
1983-90							
≤8	139	38	(14-84)	120	38	(16-162)	1.00 (0.92-1.08)
9-11	338	39	(11-129)	303	35	(14-77)	1.13 (1.07-1.19)
12+	21	41	(16-81)	14	33	(19-53)	1.22 (0.96-1.55)
1991-94							
≤8	52	29	(12-64)	65	28	(13-58)	1.05 (0.92-1.21)
9-11	164	28	(13-122)	169	26	(10-97)	1.07 (0.99-1.16)
12+	0	—	—	2	18	(12-28)	—

\*Geometric mean, unadjusted; <sup>†</sup>95% confidence interval for the ratio of the means of the sex specific BPb distributions, obtained by a log normal approximation.

ecological regressions for BPbs on petrol lead indicate intercepts of 12 to 20  $\mu\text{g/l}$  (depending on residential area), thus reflecting other exposures. The response of BPb to the petrol lead decrease is substantial. This is probably partly due to the fact that the relation between BPb and lead uptake is non-linear, being steep at low exposures.<sup>1</sup> Indeed, this might result in lower intercepts than indicated from the present data. A related issue is the seemingly delayed effect of reduced petrol lead emission on BPb. We obtained a better linear ecological regression fit when a two year lag, rather than a one year or three year lag was applied. Such a lag might be caused by a long lasting contamination of the environment or a slow excretion of lead from the skeleton<sup>36</sup> (which implies an endogenous lead exposure). One cannot, however, infer that petrol lead emissions persist for about two years based on the present data alone (to realise this, consider the simple situation where both petrol lead emission and BPb show a linear decrease with calendar year; in that case, any lag period would give a close fit). A follow up of the time trend will clarify these issues, as there was no emission of lead from petrol in 1994. Thus, the shape of the BPb curve after the end of petrol lead exposure will be of particular interest.

Yearly estimates for lead quantity in petrol sold in Sweden (fig 2) were considered in the ecological analysis. Of course, the time trend of these estimates may not correctly reflect the time trend of petrol lead emission in the residential areas under study. In fact, the estimates of petrol lead emission in Landskrona from 1984, 1990, and 1993 show a weaker decreasing trend compared with the total estimates from Sweden. On the other hand, regional estimates from the south of Sweden between 1985 and 1993 proportionally follow the time trend in fig 2.

A considerable effect of birth cohort was present in our study, because year of birth correlated highly with cumulative lead exposure. Unfortunately, due to this effect it was not feasible to examine the pure effect of age on BPb. This is, indeed, an interesting aspect to study, as is the impact of sex on BPb. Our data did, however, indicate that the sex specific BPbs are similar up to eight years of age, and from nine years up to early teens the age effect (on decreasing BPb) is more pro-

nounced in girls than in boys. This interrelation between age and sex with regard to BPb is in accordance with other studies.<sup>20 26 27 40 41</sup> The different sex specific age patterns may follow the differences in biological variables and lifestyle of older girls and boys: older girls are likely to have lower food intake per kg of body weight, lower lung ventilation<sup>42</sup> and a cleaner life style. Also, menstrual blood losses may cause loss of lead in the older girls.

The children living near the smelter had slightly higher BPb than those from other urban areas in Landskrona, who in turn had somewhat higher concentrations than the children from the surroundings (significant differences were found). This indicates that lead emissions from both the smelter and traffic had an influence on BPb (also in Trelleborg the children from the urban area had significantly higher BPb than those from the rural area). Residential area did not significantly modify the sex specific BPb decreases. The lack of such modification may well be due to a widespread lead contamination of the society caused by petrol, affecting children in both urban and rural areas, probably through contamination of foods that are widely consumed. Nevertheless, it should be pointed out that we obtained somewhat less pronounced slopes for the ecological regressions when data from children in rural areas were compared with those from urban areas. Moreover, from our data it seems that during the first decade of the study period, the BPb decrease was most notable in the area near the smelter in Landskrona; this may reflect an effect of reduced industrial lead emission on BPb. Due to the limited number of data points, such an effect (modified by calendar time) could not be statistically confirmed.

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