

Blood lead levels and erythrocyte δ -amino-levulinic acid dehydratase activity of selected population groups in Helsinki

by CLAES HENRIK NORDMAN, M.D., and SVEN HERNBERG, M.D.¹

NORDMAN, C. H. and HERNBERG, S. Blood lead levels and erythrocyte δ -amino-levulinic acid dehydratase activity of selected population groups in Helsinki. *Scand. j. work environ. & health* 1 (1975) 219–232. The levels of lead in the blood of the adult general population in Helsinki were determined during the period May 1972–June 1973. The possibility of occupational exposure to lead was scrupulously excluded. As control groups rural population groups were sampled in the commune of Pertunmaa and the communes of Haapajärvi and Pyhäjärvi. The concentrations of air-suspended particulate lead were studied during 1 year in Helsinki and Pertunmaa; the population groups were sampled from the geographical vicinity of the sampling sites. Care was taken to ensure the accuracy and precision of the analytical methods, the blood lead (Pb-B) assay in particular, by continuously checking the methods at experienced laboratories. The annual mean concentration of lead in air in Helsinki ranged from 0.43 to 1.32 $\mu\text{g}/\text{m}^3$. The corresponding mean at the rural sampling site (Pertunmaa) was 0.025 $\mu\text{g}/\text{m}^3$. From an international standpoint, the Pb-B levels were low. The highest mean Pb-B value in groups of the general population occurred in the rural male group (12.3 $\mu\text{g}/100$ ml); and the lowest, in the female respondents of the Pertunmaa survey (7.9 $\mu\text{g}/100$ ml). A group comprising 86 male streetsweepers from Helsinki displayed a Pb-B mean value of 13.3 $\mu\text{g}/100$ ml, and 28 traffic-directing policemen displayed a mean of 13.5 $\mu\text{g}/100$ ml, a finding indicating a slight increase in lead absorption. No effect on the Pb-B levels of traffic alone was detectable within the general population; thus no statistically significant differences were found between downtown and rural or suburban Pb-B levels. The observation that the Pohjois-Haaga suburbanites disclosed higher Pb-B levels than did other suburbanites indicates that factors other than traffic should be borne in mind in the assessment of the effect of traffic on lead absorption. The δ -amino-levulinic acid dehydratase (ALAD) assay proved useful and reliable in the discrimination between separate groups whose Pb-B levels differed to a small but measurable extent. The negative correlation between Pb-B and ALAD activity was found to prevail at a statistically significant level still at Pb-B levels of 10 $\mu\text{g}/100$ ml or lower.

Key words: lead, blood, air, erythrocyte δ -aminolevulinic acid dehydratase, population groups, Helsinki, Finland.

It is known that traffic increases the lead content of air (9, 13, 15, 33, 42, 43). Furthermore, the isotopic composition of lead aerosols in air indicates that the decomposition products of lead alkyl are the main source of the lead in urban air (10).

In close accord with this, several studies have disclosed that exposure to exhaust gases increases blood lead (Pb-B) levels (13, 23, 24, 29, 33, 43, 46). However, it is still necessary to determine the concentrations of lead in the air which will increase the lead absorption to a measurable extent.

The U.S. Environmental Protection Agency, after a review of studies on the subject, has declared that lead levels of around 2 $\mu\text{g}/\text{m}^3$ of air induce a measurable increase in Pb-B levels among adults (14).

¹ Department of Epidemiology and Biometry, Institute of Occupational Health, Helsinki, Finland.

Reprint requests to: Dr. C. H. Nordman, Institute of Occupational Health, Haartmaninkatu 1, FIN-00290 Helsinki 29, Finland.

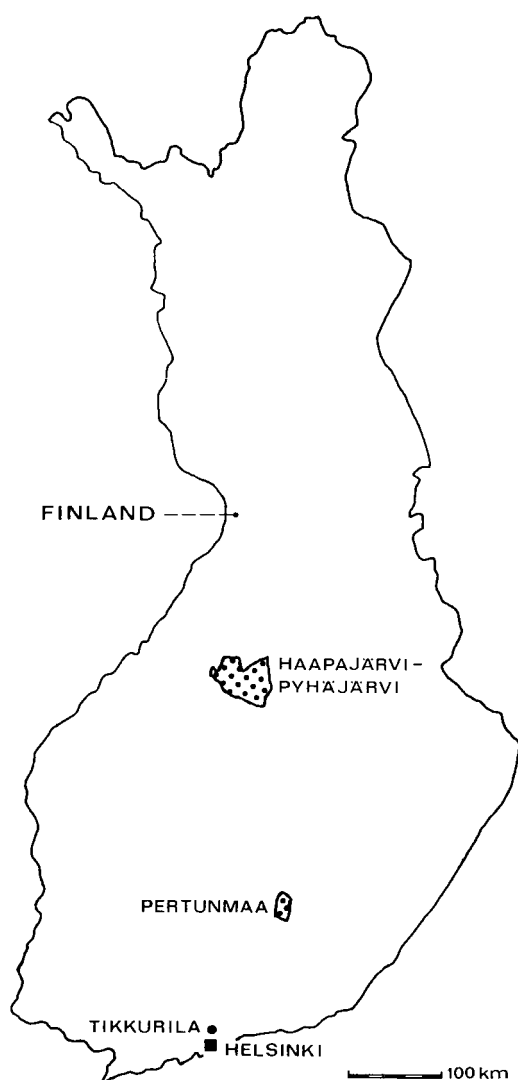


Fig. 1. Location of the rural communes surveyed.

The existence of an association between Pb-B levels and lead concentrations has been supported by a controlled 18-week chamber exposure study at about $3 \mu\text{g}/\text{m}^3$, which resulted in a rise of Pb-B levels (12). In contrast, Tepper and Levin (42) did not find any relationship between annual air lead concentrations, ranging from 0.14 to $4.55 \mu\text{g}/\text{m}^3$, and Pb-B levels.

Although it is impossible to draw any definite conclusions yet, measures to lower the content of lead in gasoline have been adopted by a number of governments (8). However, little is known about the Pb-B

levels of Scandinavian populations, and even less about the probable hazards that arise from the probable alternatives replacing lead (5). The commendable decisions made with a view to the reduction of lead pollution are largely based upon results obtained in American population studies. However, the U.S.A. differs from Europe, and from Scandinavia in particular, in many relevant respects, such as the previous use of lead pigments, traffic density, and the degree of industrialization. By reason of the lack of data from Scandinavia, it was decided to study the Pb-B levels in Helsinki, and the relationship between them, and to compare urban and rural conditions.

In 1972 Helsinki had about 510,000 residents, i.e., 2,900 inhabitants per square kilometer (Central Statistical Office of Finland). At the time the total number of automobiles registered in Helsinki, according to the owner's domicile, was 110,000, of which 100,000 were gasoline-powered (From: Automobiles and Highways in Finland 1973, Finnish Road Association). However, the inhabitants of adjacent communes bordering on Helsinki are to a large extent commuters working in the city. When these communes are taken into account, the totals rise to 730,000 people and 140,000 gasoline-powered automobiles, respectively.

Finland has no statute pertaining to the maximum content of lead in gasoline. According to the national refinery, the addition of lead to gasoline has never exceeded 0.7 g/l (personal communication, Neste Oy).

MATERIAL AND METHODS

Selection of population groups

The population groups under survey were selected from regions surrounding the air sampling sites. Two main population groups were formed in Helsinki: a downtown group derived from employees of the main post office, who both worked and resided within the downtown area, and a suburban group comprising employees, store clerks, and clerical staff working and residing within the suburban districts concerned.

In addition studies were made of two

target groups with special exposure patterns; these comprised 97 streetsweepers, all of whom had their working place in downtown districts, and 28 of a total of 61 traffic-directing policemen working at the time in Helsinki.

To obtain control groups for the Helsinki series, two rural population groups were selected. One was made up of 33 men and 33 women from the Pertunmaa commune. The other was formed of 93 female post office employees from Haapajärvi and Pyhäjärvi communes (fig. 1). The rural communes of Haapajärvi and Pyhäjärvi are both situated about 400 kilometers north of Helsinki, with about 8,000 inhabitants and less than 1,500 automobiles each. The number of inhabitants per square kilometer is 5.9 for Pyhäjärvi and 9.9 for Haapajärvi (Central Statistical Office of Finland). The corresponding data for Pertunmaa are 7.4 inhabitants per square kilometer and 562 automobiles (Central Statistical Office of Finland).

Distributions by age and sex of the different groups are indicated in table 1; and smoking habits, in table 2.

Aerometric sampling

The sampling of air-suspended particulate lead was effected at four fixed sampling sites. The downtown sampling site (no 1) was situated about 300 m from the main post office, close to the city railroad station (fig. 2). Sampling site 2 was situated in a mixed commercial, industrial, and residential area; sampling site 3, in the suburb

of Pohjois-Haaga; and sampling site 4, in the suburb of Otaniemi.

The sampling equipment for air-suspended particulate matter comprised a holder with a membrane filter (Millipore AAWP 03700) with a pore diameter of 0.8 μ m, and a pump supplying an air flow of about 10 l/min (Neuberger V H 15). For measurement of the terminal air flow, each sampling device was fitted with a gasometer (Nordgas, Stockholm). Air lead was collected on the filters as dust in sampling cycles of 2 weeks. The sampling devices were placed at a height of 2.5–3.5 m.

The sampling continued at all sampling sites for 1 year. Although air sampling at some sampling sites was effected for more than 1 year, the results reported here relate only to the period from November 1971 through October 1972; the reliability of the analytical techniques was not regarded as satisfactory before that. Atmospheric lead sampling was carried out in Pertunmaa and Helsinki.

Collection of biological data

Two factors influenced the choice of the time for collecting the biological samples. First it was assumed that the street-sweepers' springcleaning of the streets was finished by the end of April, a time which implied a maximum exposure to street dust. Secondly the possibility of seasonal variation had to be excluded. The street-sweepers were thus examined concomitantly with the downtown group, half of the suburban group, and the Pertunmaa

Table 1. Distribution of different urban and rural population groups by age and sex.

Age	Downtown			Suburban			Street-sweepers			Traffic policemen	Pertunmaa			Haapajärvi-Pyhäjärvi
	Males	Females	All	Males	Females	All	Males	Females	All	Males	Males	Females	All	Females
15–24	32	7	39	18	3	21	3	—	3	6	8	5	13	12
25–34	61	13	74	9	18	27	8	1	9	17	3	3	6	18
35–44	25	6	31	6	27	33	17	1	18	2	5	4	9	26
45–54	16	7	23	3	21	24	32	6	38	3	7	8	15	23
55–64	8	5	13	—	12	12	25	3	28	—	6	8	14	12
65 or more	—	—	—	—	—	—	—	—	—	—	4	5	9	2
Total	142	38	180	36	80	117	85	11	96	28	33	33	66	93

Table 2. Smoking habits of different urban and rural population groups.

Group	Cigarettes daily			Pipe or cigars	Nonsmokers
	> 20	10—20	< 10		
Downtown					
Males	17	42	13	6	69
Females	1	9	7	—	22
All	18	51	20	6	91
Suburban					
Males	4	9	6	2	16
Females	1	13	12	1	56
All	5	22	18	3	72
Streetsweepers					
Males	12	20	8	2	44
Females	—	1	—	—	10
All	12	21	8	2	54
Policemen					
Males	2	5	3	—	18
Haapajärvi-Pyhäjärvi					
Females	—	3	18	—	72
Pertunmaa					
Males	1	5	4	—	23
Females	—	—	3	—	30
All	1	5	7	—	53

group from the end of May through the end of June 1972, and the Haapajärvi-Pyhäjärvi group in August 1972. For practical reasons examination of the other half of the suburban group had to be postponed until June 1973. The policemen were examined as early as in November 1971, however.

All of the blood and dietary samples collected for the determination of lead content were stored in lead-free polyethene flasks or bottles which had been carefully washed with 10 % nitric acid and repeatedly rinsed with demineralized, distilled water.

Blood samples were drawn from a cubital vein into lead-free flasks. Only stainless steel syringes with polypropylene hubs were used. The skin was cleaned with a 0.2 % benzethone chloride solution containing 2.9 % butanol and, as the solvent, 68.9 % isopropanol. An amount of 20 ml of blood was drawn from each person for Pb-B analysis; duplicate samples were drawn from every fifth person for storage and future analysis. The Pb-B flasks were stored deep-frozen until analysis. Samples for the determination of erythrocyte δ -aminolevulinic acid dehydratase (ALAD) were drawn into heparinized test tubes of

10-ml capacity. Otherwise the test tubes were prepared analogously with the Pb-B flasks. For determination of the hematocrit value and the hemoglobin concentration, 2.5 ml of blood was drawn into a test tube containing 4 mg of ethylenediamine tetraacetate (EDTA).

Analytical methods

All of the Pb-B samples, except for those of the 29 policemen, were intermixed and analyzed in series made up by proportional amounts from each group, for the avoidance of systematic errors.

Pb-B determinations were performed from duplicate samples; thus the reported results of each analysis denotes the average of two parallel measurements. The duplicate samples were analyzed in different runs. The method employed throughout was that of atomic absorption spectrophotometry (Perkin—Elmer 303), described by Hessel (22). A series of 26 duplicate samples analyzed unbeknown to the laboratory personnel showed a method error of 1.7 $\mu\text{g}/100\text{ ml}$; the method error reported by the laboratory for the same period was 1.1 $\mu\text{g}/100\text{ ml}$. The method was

continuously checked by the introduction of spiked samples.

During the period from July, 1972, to June, 1973, the monthly determinations of three spiked pig blood samples, to which 30 μg of lead (PbCl_2) per 100 ml of blood had been added (a total of 36 samples), resulted in a mean value of 34.0 $\mu\text{g}/100$ ml, a standard deviation of 1.7, and a range of 20.5–37.7 $\mu\text{g}/100$ ml. During the same period, a series of 12 human blood samples, to which had been added the same amount (30 μg Pb/100 ml) of lead, were analyzed monthly without the knowledge of the laboratory staff. These gave a mean of 46.7, a standard deviation of 3.6, and a range of 42.3–52.5 $\mu\text{g}/100$ ml. Unspiked

duplicates were currently analyzed. The mean estimated value of the added amount of lead was 31.4 $\mu\text{g}/100$ ml. New spiked samples were prepared once a month.

The accuracy of the Pb-B method was further controlled within the compass of an inter-Scandinavian comparison program. Spiked and unspiked blood samples were distributed to the eight Scandinavian laboratories involved. The results of the interlaboratory comparison are presented in tables 3 and 4.

A series of duplicate samples were also analyzed twice a year in the laboratory of the American Smelting and Refining Company (ASARCO), Utah, U.S.A. These are accounted for in table 5. The samples

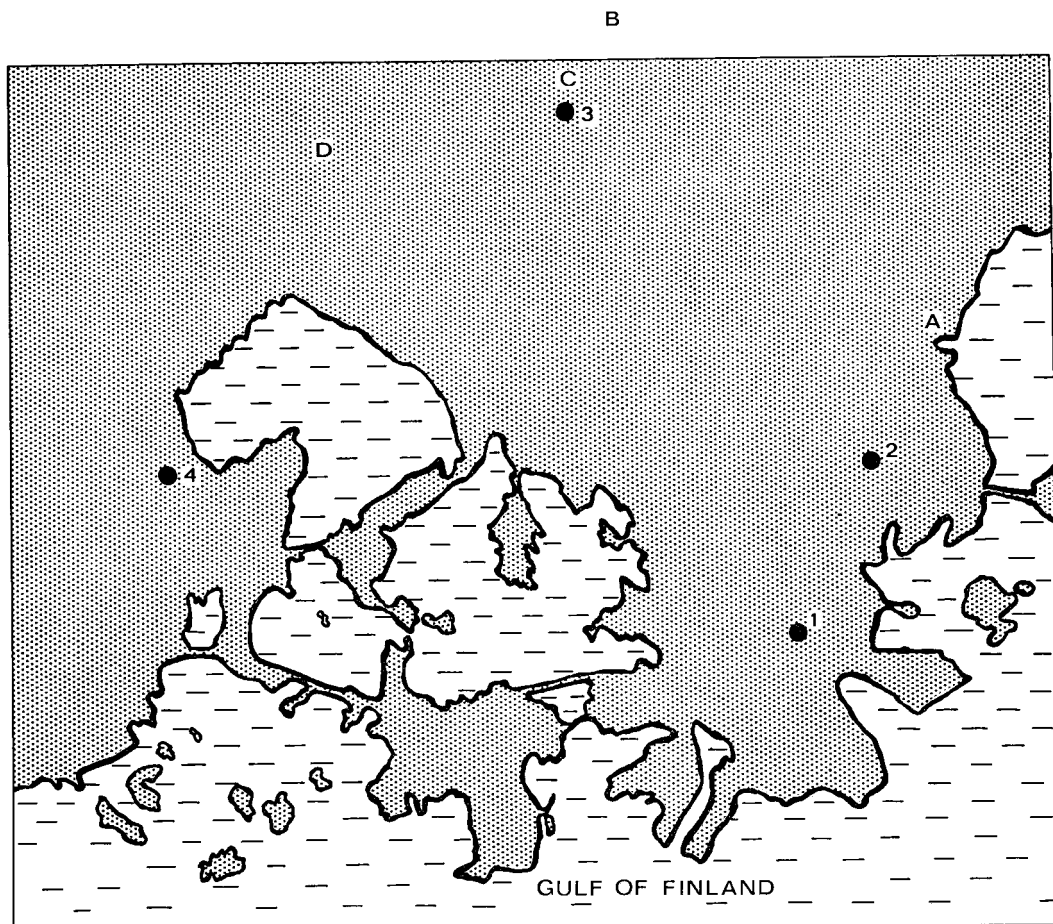


Fig. 2. Air sampling sites in Helsinki. Sampling site no. 1 = downtown, no. 2 = mixed traffic-industrial-residential, no. 3 = suburb of Pohjois-Haaga, no. 4 = suburb of Otaniemi. A = Helsinki main incinerator, B = Tikkurila lead emitters at a distance of about 10 km from sampling site no. 3, C = Haaga no. 3 power station, D = lead pigment plant.

of both the accuracy control programs were first analyzed at the Institute of Occupational Health, and the results were passed to the reference laboratories con-

cerned before reports of their results had been received.

Erythrocyte ALAD activity was measured by a modified version of the method of Bonsignore and his colleagues (6, 37). Briefly, the modification involves the use of the more stable sodium phosphate buffer and a pH of 6.8, instead of a carbonate buffer and a pH of 7.0. The activity is expressed as micromols porphobilinogen (PBG) formed during 1 h of incubation at 37°C per liter of packed red blood cells (RBC). The RBC volume was estimated from the hematocrit value measured previously. The ALAD assay showed a method error from duplicate measurements of 18.4 μ mol PBG per liter RBC. All of the ALAD assays were made within 5 h of sampling.

The hematocrit value was measured

Table 3. Comparative inter-Scandinavian check of blood lead determination. Values expressed as μ g/100 ml.

Time of check	Mean of 8 laboratories	Range of 8 laboratories	Present value
Spring 1972	14	10—18	17
	14	9—17	17
	51	44—61	61
	85	80—95	95
	85	81—93	93
Spring 1973	87	80—94	94
	7	5—13	12
	8	5—17	12
	26	24—41	31
	40	38—51	44
	76	74—104	82

Table 4. Inter-Scandinavian accuracy check of blood lead determination. Values expressed as μ g/100 ml.

Time of check	Lead added	Calculated values		
		Mean of 8 laboratories	Range of 8 laboratories	Present value
Spring 1972	38.4	38	31—44	44
	77	72	67—78	78
	77	72	65—76	76
	77	74	67—79	77
Spring 1973	19	21	18—30	19
	32	34	29—40	32
	68	72	66—93	70

Table 5. American accuracy check of blood lead determination in 1972. Values expressed as μ g/100 ml.

Sample no.	ASARCO ^a value	Present value	Sample no.	ASARCO ^a value	Present value
1	21	12	14	43	53
2	12	10	15	57	47
3	19	19	16	43	56
4	70	86	17	8	9
5	54	73	18	7	7
6	66	74	19	8	8
7	57	64	20	10	8
8	64	77	21	15	15
9	76	79	22	12	13
10	64	71	23	6	9
11	54	63	24	11	12
12	49	60	25	7	8
13	57	72	26	10	10

^aAmerican Smelting and Refining Company, Utah, U.S.A.

with an Adams Autocrit Centrifuge (CT 2900). Duplicate blood samples were spun for 4 min at 15,000 g.

Blood hemoglobin was determined by the standard method, after conversion to cyanmethemoglobin.

The air-suspended particulate matter obtained on the membrane filters was analyzed for lead directly by X-ray fluorescence spectrometry (Philips PW 1410). A lithium-fluoride crystal (LiF 200), and a wolfram anode tube were employed. The X-ray generator was set at 60 kV and 30mA. Lead was determined from the alpha-line, 2-theta angle = 33.91. Measurement was effected three times, each one extending over a 20-s period. The background was determined at a 2-theta angle of 34.50 (16, 38). The method was checked by parallel determination with atomic absorption spectrophotometry. The comparison is accounted for in table 6.

RESULTS

Lead in air

Monthly and annual mean values for lead in urban and rural air are listed in table 7. The highest annual mean value of 1.32 $\mu\text{g}/\text{m}^3$ was measured at the Helsinki down-

town sampling site; it was about 50 times the rural yearly mean value of 0.025 $\mu\text{g}/\text{m}^3$. The monthly means at this urban sampling site ranged from 0.68 to 2.20 $\mu\text{g}/\text{m}^3$, while the rural monthly mean never exceeded 0.06 $\mu\text{g}/\text{m}^3$. The suburban sampling site no. 3 displayed a higher yearly mean than did sampling site 2. The

Table 6. Comparison between X-ray fluorescence spectrometry and atomic absorption spectrophotometry. Values expressed as micrograms per sample.

May—July 1973			August 1973		
Sample no.	X-ray	AAS	Sample no.	X-ray	AAS
1	261	143	18	520	666
2	26	23	19	165	205
3	2	3	20	62	61
4	460	449	21	32	37
5	1,170	819	22	7	6
6	1,246	774	23	22	19
7	1,035	552	24	37	33
8	105	93	25	24	20
9	1,255	1,172	26	202	198
10	581	633			
11	50	55			
12	103	132			
13	86	87			
14	47	52			
15	10	22			
16	25	34			
17	55	73			

Table 7. Monthly and yearly mean values of air-suspended particulate lead in Helsinki. Values expressed as $\mu\text{g}/\text{m}^3$. Numbers of sampling sites refer to area as follows: 1 = downtown, 2 = mixed industrial-traffic-residential, 3 and 4 = suburban.

Period of sampling	Helsinki sampling site no.				Pertunmaa
	1	2	3	4	
1971					
November	— ^a	—	1.10	0.46	0.02
December	2.20	1.30	1.40	0.76	0.02
1972					
January	1.70	1.30	1.20	0.62	0.06
February	1.80	0.97	1.50	0.33	0.06
March	1.20	—	1.20	—	0.03
April	1.80	0.38	0.67	—	0.01
May	0.74	0.83	0.80	—	—
June	0.87	0.92	0.91	—	0.02
July	0.68	0.59	0.67	0.16	0.01
August	1.10	0.90	1.02	0.18	0.02
September	1.40	0.85	1.18	0.47	0.02
October	1.55	1.00	1.13	0.52	—
Annual mean	1.32	0.90	1.05	0.43	0.025

^a Stroke denotes emission of sample.

Table 8. Blood lead levels of different urban and rural population groups. Values expressed as $\mu\text{g}/100$ ml of blood. (N = number, M = mean, SD = standard deviation).

	Males						Females					
	Police-men	Street-sweep-ers	Helsinki Down-town	Sub-urban	Pertun-maa	Pyhä-järvi	Police-men	Street-sweep-ers	Helsinki Down-town	Sub-urban	Pertun-maa	Pyhä-järvi
N	28	86	142	37	33	—	—	11	37	81	33	93
M	13.5	13.3	11.4	10.6	12.3	—	—	10.4	8.5	9.7	7.9	8.6
SD	2.8	4.1	3.3	2.8	3.3	—	—	3.0	2.0	2.6	1.9	2.5
min	9	7	5	6	5	—	—	5	6	6	5	4
max	20	29	23	18	19	—	—	15	14	20	12	20

Otaniemi sampling site had a yearly average of $0.43 \mu\text{g}/\text{m}^3$. Seasonal fluctuations were observable in the monthly means, with a tendency towards lower values during the summer months and achievement of the highest values in the autumn and winter months.

Lead in blood

Table 8 lists the mean Pb-B values of the different population groups together with the standard deviations of the means and the ranges. The most conspicuous feature of the results is that no subgroup displayed a mean Pb-B value exceeding $13.5 \mu\text{g}/100$ ml. The highest mean values were found in the groups of policemen and male streetsweepers, i.e., 13.5 and $13.3 \mu\text{g}/100$ ml of blood, respectively. Both are higher than the means of the other urban male groups. When the male streetsweepers were tested for significance against the male downtown group, they yielded a t -value of 3.64 , corresponding to a p -value of <0.001 . The level of significance was similar when tested against the suburban males ($t = 4.23$, $p < 0.001$). No statistically significant differences were found between downtown and suburban or rural males. The rural males had higher Pb-B values than the suburban males ($t = 2.31$, $p < 0.05$). Throughout, the Pb-B values of the females were lower than those of the males. The highest mean was exhibited by the 11 female streetsweepers; however, this group was small and has consequently been omitted from the statistical calculations. Surprisingly the suburban females exhibited a mean value that

Table 9. Lead in blood of suburbanites of Pohjois-Haaga as compared to other suburbanites.

	Males		Females	
	Poh-jois-Haaga	Other suburb-anites	Poh-jois-Haaga	Other suburb-anites
N	8	28	27	53
M	13.1	10.0	10.9	9.2
SD	3.2	2.3	3.4	1.9
t	2.56		2.41	
p	<0.05		<0.05	

exceeded those of the other female groups. This diversity was statistically significant when tested against the downtown group ($t = 2.74$, $p < 0.01$), the Pertunmaa group ($t = 4.10$, $p < 0.001$), and the Haapajärvi—Pyhäjärvi group ($t = 2.84$, $p < 0.01$). Only insignificant differences were apparent between downtown and rural females. For elucidation of whether any dependence existed between the finding of unexpectedly high lead concentrations in air at suburban sampling site no. 3 and the higher Pb-B values of the suburban females, a subdivision was made of the suburban group. Comparisons were drawn between the population living within 1 kilometer of sampling site no. 3 (Pohjois-Haaga) and all of the other suburbanites (table 9). This comparison revealed that the mean Pb-B value was higher for the Pohjois-Haaga group than for the others and applied both to males and to females. The arbitrarily composed group of "other suburban" females did not differ from downtown or Haapajärvi—Pyhäjärvi fe-

Table 10. Erythrocyte δ -aminolevulinic acid dehydratase activity for different urban and rural population groups. Values expressed as $\mu\text{mol/PBG/h/l RBC}$.

	Males				Females			
	Street-sweepers	Down-town	Sub-urban	All	Street-sweepers	Down-town	Sub-urban	All
N	85	145	37	267	11	38	82	131
M	811	1,075	1,020	983	746	1,203	1,138	1,124
SD	215	193	203	234	218	175	222	239
min	335	464	552	335	449	913	770	449
max	1,294	1,552	1,384	1,552	1,052	1,608	2,116	2,116

Table 11. Significance testing of differences between erythrocyte δ -aminolevulinic acid dehydratase activity levels of Helsinki target groups.

Groups tested	Males		Females	
	t	p	t	p
Streetsweepers vs. downtown	- 9.37	< 0.001	- 6.37	< 0.001
Streetsweepers vs. suburban	- 5.13	< 0.001	- 5.59	< 0.001
Downtown vs. suburban	1.51	> 0.1	1.72	$\approx$ 0.08

males but still had a higher mean than the Pertunmaa females. The Pb-B values among Pohjois-Haaga males and females were of the same order of magnitude as the Pb-B values of the streetsweepers.

Erythrocyte ALAD activity

The ALAD values are listed in table 10. For methodological reasons, the ALAD values of the policemen were omitted; these had been analyzed before the current modification of the ALAD assay was taken into use. The streetsweepers had significantly lower ALAD values than the downtown and the suburban group, whereas only minimal differences existed between the downtown and the suburban groups.

The results of significance testing between the groups are indicated in table 11. The males also had lower ALAD values than the females ($t = 5.55$, $p < 0.001$). In this series the relationship between ALAD and Pb-B yielded a correlation coefficient of $r = -0.37$ ($p < 0.001$, $N = 419$, range 4–29 $\mu\text{g Pb/100 ml}$). Interestingly this negative correlation was still statistically

Table 12. Correlations between erythrocyte δ -aminolevulinic acid dehydratase (ALAD) activity and blood lead (Pb-B) concentration after adjustment of the upper Pb-B limit at varying levels. $\bar{y}$ = mean values of ALAD activity, expressed as $\mu\text{mol PBG/h/l RBC}$; $\bar{x}$ = Pb-B mean values, expressed as $\mu\text{g/100 ml}$.

Pb-B	N	$\bar{y}$	$\bar{x}$	r	p
> 15	357	1,050	10.3	- 0.32	< 0.001
> 14	335	1,056	10.0	- 0.32	< 0.001
> 13	306	1,064	9.6	- 0.32	< 0.001
> 12	281	1,078	9.3	- 0.27	< 0.001
> 11	241	1,097	8.9	- 0.20	< 0.01
> 10	197	1,104	8.4	- 0.23	< 0.001
> 9	145	1,135	7.8	- 0.13	< 0.05

significant when all of the Pb-B values over 10 $\mu\text{g/100 ml}$ were omitted from the calculations ($r = -0.23$, $p < 0.001$, $N = 197$) (table 12).

No influence of age on the Pb-B levels or the ALAD activity was detectable among any of the groups in question. This also applied to cigarette smoking with the exception of the streetsweeper group, in which a difference of Pb-B mean values was found between cigarette smokers and

Table 13. Effect of cigarette smoking on the blood lead (Pb-B) concentration and erythrocyte δ -aminolevulinic acid dehydratase (ALAD) activity of Helsinki streetsweepers. (Pb-B values expressed as $\mu\text{g}/100\text{ ml}$; ALAD as PBG/h/l RBC)

Values		≤ 45 years of age		> 45 years of age	
		smokers	nonsmokers	smokers	nonsmokers
Pb-B	N	13	15	29	28
	M	12.9	12.5	14.9	12.2
	SD	2.8	4.3	5.2	2.9
	t	0.30		2.37	
	p	> 0.1		< 0.05	
ALAD	N	13	15	29	28
	M	814	846	751	852
	SD	177	254	216	204
	t	- 0.39		- 1.82	
	p	> 0.1		$= 0.08$	

nonsmokers over 45 years of age (table 13). The difference was statistically significant at the 5 % level ($t = 2.37$). The ALAD values showed a slightly smaller difference between smokers and nonsmokers in the older group. No such differences were found in the younger group, 44 years of age or less.

DISCUSSION

The most striking result obtained is the low level of Pb-B found in all the groups. As a whole the mean values for the urban and the rural population groups are about the lowest reported Pb-B values for general populations. It is, however, difficult to achieve a satisfactory degree of comparability to other studies in the absence of intermixing.

When this study was begun, the Pb-B assay was known to be vulnerable to systematic errors. As interpretation of the results would be completely dependent on the validity of the Pb-B assay, great care was taken to ensure its accuracy and precision throughout the work. The precision appeared to be on a high level. The method error of duplicate measurements reported by the laboratories ($1.1\ \mu\text{g}/100\text{ ml}$), somewhat lower than that noted for a set of 26 duplicate samples analyzed unbeknown to the laboratory personnel ($1.7\ \mu\text{g}/100\text{ ml}$), is consistent with the findings of Berlin and his colleagues (2), who suggested that laboratories tended to

reject outlying results when reporting. All of the Pb-B values reported here were mean values of two parallel determinations; if the discrepancy between duplicate measurements exceeded $5\ \mu\text{g}/100\text{ ml}$, the analyses were repeated. This procedure probably accounts for the previously described differences.

In regard to accuracy, it is observable from the inter-Scandinavian comparison (table 3) that at the time our method showed somewhat higher Pb-B values than did most of the other laboratories and our values were systematically higher than the mean values of the eight participating laboratories. The agreement between results obtained by the ASARCO laboratories and those of the Institute of Occupational Health was, especially at low Pb-B levels, much closer than is usually found in interlaboratory comparisons (1, 2, 26) (table 5). It can be concluded that, if anything, the values reported by the Institute of Occupational Health were systematically a little higher than the mean values of the reference laboratories.

The absence of differences between rural and urban Pb-B levels also arouses interest. No differences were apparent between the downtown and the two rural population groups. The Pohjois-Haaga group exhibited unexpectedly high Pb-B values. The mean values of the lead in the air (Pb-A) of Pohjois-Haaga were also surprisingly high, approximating the downtown levels. In all probability these are attributable to at least four lead-emitting sources apart from traffic. De-

pendent upon the wind direction, these sources may have been: the main Helsinki incinerator, at a distance of about 5 kilometers east of Pohjois-Haaga; the Tikkurila lead plants, situated about 10 kilometers northeast of Pohjois-Haaga; a lead pigment plant at a distance of 1.5 kilometers west of Pohjois-Haaga; and the Haaga no. 3 power station in Pohjois-Haaga. Mattson and Jaakkola (34) have suggested that in particular the main Helsinki incinerator, but also the lead smelteries in Tikkurila (fig. 1), may significantly contribute to the Helsinki Pb-A, and especially to that of Pohjois-Haaga.

The Pb-B values of the Pohjois-Haaga females seem to indicate a measurable effect of Pb-A amounting to about $1 \mu\text{g}/\text{m}^3$, whereas the downtown group did not exhibit any effect of this kind. Nonetheless, it must be emphasized that the use of a few fixed sampling devices is an inadequate method for assessing the exposure of an entire population group. Furthermore, in population studies it is difficult to cope with interindividual variations of dietary lead intake that mask the influence of low lead concentrations in ambient air.

The finding that the streetsweepers had higher Pb-B values is consistent with earlier reports (29, 32).

Cigarette smoking was not found to exert any effect upon Pb-B within the groups of the general population. Only in the streetsweeper group over 45 years of age did the smokers show higher Pb-B values than nonsmokers. No such difference was discernible in the younger age group. The literature is controversial on this point. Some investigators have reported higher Pb-B levels for smokers than for nonsmokers (23, 33, 42), while others have been unable to detect such an effect (13, 30, 35). It seems probable that in itself the inhalation of tobacco smoke does not have a measurable effect on Pb-B levels. The differences reported are probably attributable to the ingestion of particles from contaminated fingers. The occurrence of the difference in the older groups alone presumably arose from hygienic differences between the age groups, decreased mucociliary activity and changes in the phagocytic capacity of macrophages in the older smokers, and a longer period of lead accumulation.

The sensitivity of the ALAD test has been established by many investigators (6, 7, 17, 18, 19, 21, 36, 44). Moreover, it has repeatedly been shown that the specificity is high (20) and the accuracy and precision are good (1, 4). It has been suggested that the ALAD assay, by virtue of these characteristics, would be suitable for population surveys (1, 3, 4, 21). Despite the exceptionally low Pb-B levels found in the present study, the ALAD assay appeared to be sufficiently sensitive for discrimination between most groups in which the Pb-B levels differed at a statistically significant level. The ALAD test failed to reflect only the differences found between the downtown and the suburban females and the differences between the two suburban groups. When the study was initiated, no experience had been gained with ALAD from population studies, but during its course some researchers reported on their experience with population studies in which the ALAD test was employed. Secchi and his colleagues, for instance, successfully applied the ALAD test in studies on varying population groups subjected to different degrees of environmental lead exposure (39, 40, 41). The Pb-B levels of those population groups from Milan, or the rural neighborhoods of Milan, however, were higher than the commonly reported levels for general populations. Also Lob and his coworkers were able to discriminate between a rural and an urban group of schoolboys by employment of the ALAD assay. The mean Pb-B values of the two groups were 18.9 for the rural and $22.2 \mu\text{g}/100 \text{ ml}$ for the urban group (31). In contrast Kennedy and his colleagues (25) did not discover any relationship between ALAD activities and Pb-B values below $25 \mu\text{g}/100 \text{ ml}$. Vallotton and his colleagues (45) could not establish a significant correlation between Pb-B levels and ALAD activities in people unexposed to lead by profession; neither did Coulston's team find any inhibition of ALAD in their 18-week chamber exposure study at $3.2 \mu\text{g Pb}/\text{m}^3$ of air, although a distinct elevation of the Pb-B levels occurred. However, in an identically designed study at $10.9 \mu\text{g Pb}/\text{m}^3$ of air, a distinct inhibition of the ALAD activity was noted (11, 12). These seeming discrepancies are probably attributable to methodological aspects. Close correlation

between Pb-B and ALAD necessarily calls for extremely high precision and sensitivity in both methods. These aspects become even more important when the range of variation is very narrow, as is the case in studies of the general population. The validity aspects of Pb-B have already been discussed and will not be repeated here. In regard to the ALAD assay the most important feature is standardization of the pH value, which presupposes a stable buffer. Furthermore, all of the researchers referred to earlier used a pH of 7.0, which according to Nikkanen and his co-workers (37) is less sensitive than the 6.8 employed here; however, the highest correlation coefficient was found by Nikkanen and his colleagues at a pH of 6.4. With a view to the comparability between laboratories, it thus seems reasonable to recommend the standardized ALAD assay suggested by Berlin and Schaller (3) for future population studies; the method employs a pH of 6.4 and has been specially developed to suit low-level exposure to environmental lead.

An important feature of the results was that the negative correlation between Pb-B and ALAD was statistically highly significant ($p < 0.001$), even at Pb-B levels of 10 $\mu\text{g}/100\text{ ml}$ or below. This finding has a bearing upon the question of whether or not a threshold exists for the inhibitory effect of Pb-B on ALAD activity. Both the conception of a threshold and that of a nonthreshold have their advocates. However, whether a threshold is obtained or not seems to be a question of the sensitivity and precision of the methods applied.

In the comparison of environmental exposure, the Pb-B technique applied is currently the most straightforward method, although it calls for advanced equipment and skilled personnel. On the other hand, the ALAD assay is less expensive, less exacting, and has a higher interlaboratory comparability than the Pb-B method (1, 2, 4). The only important drawback of the ALAD method is the lack of stability, which means that the analyses should be performed within 5 h of sampling (37). According to experience gained in this study, ALAD assay appears to be a useful epidemiologic tool for the comparison of environmental lead exposure in various populations.

CONCLUSIONS

From an international standpoint the Pb-B levels of all the groups studied were low. No differences were observable between Pb-B levels of downtown and rural residents despite the fact that the Pb-A concentrations in Helsinki were 50 times as great. The Pohjois-Haaga Pb-B levels were slightly higher than the downtown levels, although similarity was found in the Pb-A concentrations. The difference may have originated from the following: (a) chance, (b) higher exposure to dustborne lead for the Pohjois-Haaga population, or (c) different emitting sources producing particles with different characteristics (chemical composition, shape, solubility) which may affect the rate of absorption (27, 28). Nonetheless, Helsinki traffic alone does not increase the Pb-B levels of the general population to an extent that is significant in practice. The exposure of the traffic policemen and the streetsweepers to exhaust gas and dust is followed by a measurable increase in Pb-B levels.

The ALAD assay proved useful for discriminating between separate groups whose Pb-B levels differed to a small but measurable extent. The negative correlation between Pb-B and ALAD appeared, furthermore, to prevail at extremely low Pb-B levels.

Age per se was not found to have any relationship to Pb-B level.

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