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Psychological performance and long-term exposure to mercury vapors

by Leena Piikivi MD¹, Helena Hänninen PhD², Tuija Martelin MSocSc³, Pirjo Mantere MA²

PIIKIVI L, HÄNNINEN H, MARTELIN T, MANTERE P. Psychological performance and long-term exposure to mercury vapors. *Scand j work environ health* 10 (1984) 35–41. In a cross-sectional study the psychological test performances of a group of 36 male chlorine-alkali workers were compared with the level of exposure to mercury and to the corresponding results of referents. The mercury exposure had lasted for at least 10 years and had been controlled by regular health examinations and urine analyses. Several dose indicators were calculated. The more heavily exposed workers performed more poorly on the verbal intelligence test (Similarities) than the referents did. Impairments in the memory tests showed a statistically significant correlation with the actual exposure level, especially with the actual concentration of mercury in blood. The monitoring of mercury in blood can be useful in health surveillance programs. The level of mercury in the air was calculated from the dose indicators. The results support the recommended exposure limit of 25 µg/m³ for metallic mercury vapor in the air as a level avoiding adverse effects in exposed workers.

Key terms: blood mercury, chlorine-alkali plant, exposure limit, health surveillance, psychological tests, urinary mercury.

Minor symptoms of the central nervous system are some of the characteristics of early signs of chronic poisoning by mercury vapors. The symptoms include increased irritability, loss of memory, reduced self-confidence, and insomnia. Other symptoms are anorexia, weight loss, and slight tremor.

Psychological test methods, measurements of tremor, and electromyography have been used recently to detect the subclinical effects of exposure to mercury vapors. Impaired mental efficiency and increased neurotic reactions have been found among exposed workers (1, 3, 4). Deficiencies in short-term memory have been detected objectively among exposed workers, and patients suffering from mercury intoxication have had severe memory defects (15, 18). Performance decrements in psychomotor skills were found when groups of exposed subjects underwent tests for tremor, fingertapping, and eye-hand coordination (9, 12). Also the results of the electromyography showed minor but statistically significant disturbances.

In studies of psychomotor performances, the first effects were observed when the urinary mercury (U-Hg) level exceeded 240–500 µg/l (1,196–2,490

nmol/l). The best predictor of psychomotor performance proved to be the number of U-Hg peaks above 500 µg/l (2,490 nmol/l) within the past year. In studies applying psychological test methods, the exposure was either assessed from the number of times the U-Hg level exceeded 100 µg/l (499 nmol/l) within one year or was formulated according to an index of direct exposure in terms of the total number of hours of exposure to mercury vapors.

The purpose of the present study was to obtain data about the effects of long-term exposure to mercury vapors among a group of Finnish chlorine-alkali workers. We found that exposure to mercury affected the cognitive abilities and that the findings correlated with the intensity of exposure.

Subjects and methods

Subjects

The study group comprised 36 Finnish men employed at a chlorine-alkali plant, but with no history of mercury intoxication. Their mean age was 39.9 (SD 10.6) years. Thirteen of the men started work at the plant before 1957, 12 between 1957 and 1965, and 11 in 1966 or 1967. Their exposure had been monitored by regular health examinations and U-Hg analyses since 1957. The health examinations focused on the detection of central nervous system symptoms and tremor, which was tested by free-hand drawing of squares or the holding of a glass of water. Workers employed

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for at least 10 years were sent by their employer for a thorough health examination at the Institute of Occupational Health between 1972 and 1976.

One referent matched for age (within one year) was chosen for each exposed worker. The referents, selected by a research assistant working in the computer section of the Institute, were chosen from referents examined during two earlier Institute projects. The assistant did not know the referents' test scores. The referents were paper and cable industry workers with professional skills and educational requirements that corresponded with those of the mercury-exposed workers.

Collection of performance data

The examination of the study group included interviews for data collection about the workers' occupational and health histories, a psychological examination, surveys of the workers' clinical and neurological status, laboratory tests, and electroencephalograms. A subgroup also underwent electroneuromyography. The results of the neurophysiological examinations will be reported elsewhere.

The psychological examination consisted of a short interview and a brief test battery routinely used at the Institute in connection with the health examination of workers exposed to chemicals (6). This paper deals with the results of the six most regularly used tests.

The tests for cognitive performances included one verbal and one visual intelligence test from the Wechsler Adult Intelligence Scale (Similarities and Picture Completion) and three memory tests from the Wechsler Memory Scale (Digit Span, Logical Memory, Visual Reproduction) (2, 16, 17). Raw scores were applied in the data analyses and are reported in the tables. A modification (developed at the Institute) of the Santa Ana Dexterity Test was used for eye-hand coordination (Santa Ana with preferred hand, Santa Ana with nonpreferred hand, and Santa Ana with both hands). The scores refer to the number of pegs turned in two 30-s trials.

Data on exposure

The data on each subject's individual U-Hg levels were collected from the medical records kept by the occupational health care unit at the plant. Information about whether morning urine samples were used was not available, nor were the urine volumes known. Both the time of sampling and sample volumes are factors known to affect the wide variation in the individual excretion of mercury in the urine (13, 14).

The toxicologic laboratory of the Institute performed the analyses until 1970. One of the dithizone methods was used, corrected to the specific gravity of urine by 1.024. The standard deviation of the method in duplicate measurements is 7 % (8). Since 1968 a modification of the cold vapor atomic absorption

method of Hatch & Ott (7) has been used to analyze the U-Hg level and the blood mercury (B-Hg) level. The detection limit of this method is 5 $\mu\text{mol/l}$ for both urine and blood. The coefficients of variation calculated for this method from duplicate samples have been 8.6 % for U-Hg concentrations below 50 nmol/l, 4.1 % for U-Hg concentrations between 50 and 100 nmol/l, and 1.8 % for U-Hg concentrations above 100 nmol/l. Neutron activation analysis was used for interlaboratory comparisons.

The plant laboratory has performed the analyses since 1970 with the method of Hatch & Ott. Duplicate samples have been analyzed by the laboratory of the Institute for interlaboratory comparisons. In 1972 the correction 1.018 replaced 1.024 for the specific gravity of urine.

The monitoring of the amount of mercury in the air began in the 1960s. Because of job rotation — each exposed worker spent every third month doing "nonexposed" tasks — the U-Hg level was considered to be a more reliable indicator of exposure than the air content. At the group level 25 μg of mercury/ m^3 of air would correspond approximately to the U-Hg concentration of 50 $\mu\text{g/l}$ (249 nmol/l) suggested by a World Health Organization study group (19). When personal air monitoring was used, 50 $\mu\text{g}/\text{m}^3$ corresponded to a B-Hg concentration of 150–170 nmol/l at the group level (11). These ratios were used to estimate the levels of mercury in the air.

Dose indicators

The long-term dose indicators calculated to estimate exposure were (i) the number of three-month intervals in which the U-Hg level exceeded 1,500 nmol (300 μg)/l at least once, (ii) the number of three-month intervals in which the U-Hg level exceeded 500 nmol (100 μg)/l at least once, and (iii) the time-weighted average concentration of U-Hg.

The actual exposure indicators measured at the Institute were (i) the actual B-Hg level and (ii) the actual U-Hg level.

The dose indicators and other exposure variables are shown in table 1. The number of three-month peak intervals were concluded to be better indicators of exposure than the total number of peaks because a control urine sample was often — though not systematically — taken if the U-Hg level exceeded the recommended limit. The time-weighted average of the U-Hg concentrations was calculated as described elsewhere (5).

The actual B-Hg concentration of three workers exceeded the maximum level of 170 nmol/l recommended by the Institute. The mercury levels in the blood and urine of these workers were (i) 344 nmol/l (blood) and 509 nmol/l (urine), (ii) 224 nmol/l (blood) and 663 nmol/l (urine), and (iii) 264 nmol/l (blood) and 219 nmol/l (urine).

Data analyses

First the psychological performance levels of the exposed workers and the nonexposed referents were described by means and standard deviations. The significance of the differences between the two groups was tested by the paired t-test.

The association between the dose indicators was calculated by Pearson's product moment coefficients. The significance of the coefficients was tested by the t-test.

Further information was obtained from comparisons of the test performances of subgroups with their own referents' test scores. The subgroups were formed according to the amount of long-term and actual exposure, as indicated by the number of peak intervals above a U-Hg concentration of 1,500 nmol/l and the time-weighted average of the U-Hg levels, as well as by the actual B-Hg and U-Hg concentrations. The median values — ie, 550 nmol/l for the time-weighted average of the U-Hg levels, 75 nmol/l for the actual B-Hg level, and 280 nmol/l for the actual U-Hg level — were used as cutoff points

for the exposure variables. The significance of the differences in the psychological test performances was tested by the paired t-test.

Results

Relations between dose indicators

None of the long-term dose indicators correlated with the duration of exposure (table 2). The actual U-Hg and B-Hg concentrations correlated with each other on the group level, as was expected (8, 10). The actual B-Hg level correlated significantly both with the duration of exposure and with age. To determine the relationship between the duration of exposure and the dose indicators, the effect of age was canceled out by partial correlation. The analysis then showed that none of the dose indicators correlated with the duration of exposure. A possible explanation is of course the collinearity of attained age with years of exposure.

Table 1. Characteristics of the dose indicators for the exposed group (N = 36). (U-Hg = urinary mercury, B-Hg = blood mercury)

Variable	Mean	SD	Range
Duration of exposure (years)	16.9	8.0	10–37
Number of urine samples	31.5	10.8	10–51
Maximum U-Hg level in the 1960s (nmol/l)	1,737.2	778.7	638–3,709
Maximum U-Hg level in the 1970s (nmol/l)	1,079.2	384.7	474–1,795
Number of intervals with a U-Hg peak of >1,500 nmol/l ^a	1.7	1.7	0–7
Number of intervals with a U-Hg peak of >500 nmol/l ^b	10.3	4.3	1–16
Time-weighted average of the U-Hg levels (nmol/l)	598.7	158.5	36–1,072
Actual B-Hg level (nmol/l)	99.7	89.7	25–344
Actual U-Hg level (nmol/l)	290.6	145.6	35–663

^a Based on the number of three-month periods when the U-Hg concentration exceeded the threshold value of 1,500 nmol/l at least once.

^b Based on the number of three-month periods when the U-Hg concentration exceeded the threshold value of 500 nmol/l at least once.

Table 2. Intercorrelations of the dose indicators, exposure time, and age. — Only coefficients above 0.20 are shown. (U-Hg = urinary mercury, B-Hg = blood mercury)

	Intervals with a U-Hg peak of >1,500 nmol/l	Intervals with a U-Hg peak of >500 nmol/l	Time-weighted average for U-Hg	Actual B-Hg level	Actual U-Hg level	Duration of exposure	Age
Intervals with a U-Hg peak of >1,500 nmol/l	.	0.75**	0.81**	.	0.27	.	0.27
Intervals with a U-Hg peak of >500 nmol/l	0.75**	.	0.75**	.	0.41**	.	0.22
Time-weighted average for U-Hg	0.81**	0.75**	.	0.26	0.41**	0.29	0.45**
Actual B-Hg level	.	.	0.26	.	0.45**	0.43**	0.57**
Actual U-Hg level	0.27	0.41**	0.41**	0.45**	.	.	.
Duration of exposure	.	.	0.29	0.43**	.	.	0.79**
Age	0.27	0.22	0.45**	0.57**	.	0.79**	.

* $p < 0.05$, ** $p < 0.01$.

Table 3. Mean performance of the exposed workers and their referents (paired t-test).

Test	Exposed workers			Referents			t	p
	N	Mean	SD	N	Mean	SD		
Similarities	36	16.3	4.7	36	18.5	4.4	−1.97	<0.10
Picture Completion	36	14.1	3.0	36	15.1	2.7	−1.52	.
Digit Span	36	9.7	1.2	36	10.2	1.7	−1.24	.
Logical Memory	35	10.1	3.4	35	10.9	3.4	−1.31	.
Visual Reproduction	36	9.7	2.8	36	10.3	2.4	−1.08	.
Santa Ana right ^a	36	45.5	5.0	36	47.3	6.1	−1.28	.
Santa Ana left ^a	35	41.4	4.4	35	43.0	6.7	−1.50	.
Santa Ana coordination ^a	35	27.4	5.5	35	30.3	6.6	−2.06	<0.05

^a Santa Ana Dexterity Test performed with the preferred hand (Santa Ana right), with nonpreferred hand (Santa Ana left) or with both hands (Santa Ana coordination).

Table 4. Comparison of the exposed subgroups and their referents according to the occurrence of three-month intervals with peak urinary mercury (U-Hg) levels above 1,500 nmol/l.

Test	Subgroup with U-Hg peaks of > 1,500 nmol/l					Subgroup without U-Hg peaks of > 1,500 nmol/l				
	Difference in performances			t	p	Difference in performances			t	p
	N	Mean	SD			N	Mean	SD		
Similarities	23	−3.2	6.5	−2.38	<0.05	13	−0.4	7.0	−0.20	.
Picture Completion	23	−0.9	3.6	−1.17	.	13	−1.2	4.7	−0.95	.
Digit Span	23	−1.0	2.3	−1.99	<0.10	13	0.4	2.1	0.67	.
Logical Memory	22	−2.1	4.1	−2.35	<0.05	13	1.2	2.1	2.13	<0.10
Visual Reproduction	23	−0.7	3.8	−0.84	.	13	−0.5	2.8	−0.70	.
Santa Ana right ^a	23	−0.7	9.2	−0.36	.	13	−3.8	7.3	−1.90	.
Santa Ana left ^a	23	−1.7	8.1	−1.02	.	12	−3.2	6.5	−2.40	<0.05
Santa Ana coordination ^a	23	−2.2	9.1	−1.15	.	12	−4.3	6.6	−2.20	<0.05

^a Santa Ana Dexterity Test performed with the preferred hand (Santa Ana right), nonpreferred hand (Santa Ana left) or with both hands (Santa Ana coordination).

Table 5. Comparison of the exposed subgroups and their referents according to the time-weighted average (TWA) of the urinary mercury (U-Hg) concentration.

Test	Subgroup with a U-Hg TWA of > 550 nmol/l					Subgroup with a U-Hg TWA of ≤ 550 nmol/l				
	Difference in performances			t	p	Difference in performances			t	p
	N	Mean	SD			N	Mean	SD		
Similarities	20	−3.8	6.4	−2.60	<0.01	16	−0.3	6.7	−0.15	.
Picture Completion	20	−0.5	3.7	−0.55	.	16	−1.7	4.3	−1.58	.
Digit Span	20	−1.0	2.5	−1.70	<0.10	16	0.1	1.9	0.26	.
Logical Memory	19	−1.5	4.3	−1.51	.	16	−0.1	3.3	−0.15	.
Visual Reproduction	20	−0.5	3.9	−0.52	.	16	−0.8	2.7	−1.18	.
Santa Ana right ^a	20	−1.2	9.6	−0.56	.	16	−2.6	7.4	−1.42	.
Santa Ana left ^a	20	−1.6	7.8	−0.91	.	15	−2.3	7.4	−1.21	.
Santa Ana coordination ^a	20	−0.8	9.4	−0.40	.	15	−5.7	6.4	−3.40	<0.01

^a Santa Ana Dexterity Test performed with the preferred hand (Santa Ana right), with the nonpreferred hand (Santa Ana left) or with both hands (Santa Ana coordination).

Comparison between the exposed workers and the referents

Table 3 gives the mean performance scores, their standard deviations, and the tests for statistical difference between the exposed and reference groups. The performances of the exposed group were slightly inferior to the referents' performances on all of the tests, but only the difference in the two-hand task of the Santa Ana Dexterity Test was statistically significant.

In the search for dose-effect relationships between long-term mercury exposure and psychological performance, the differences between the mean performances of the exposed workers and the referents' were tested for the subgroup of 23 workers with one or more U-Hg peak intervals above 1,500 nmol/l and for the subgroup of 20 workers whose time-weighted

average of the U-Hg levels was above 550 nmol/l. According to the results presented in tables 4 and 5 the workers with higher exposure did worse than their referents on the verbal concept formation test (Similarities). A similar trend was found for two of the memory tests, though only one of the four differences reached statistical significance. The subgroup exposed to lower mercury concentrations did not differ from its reference group with respect to the cognitive performances, but the performance of the exposed was significantly inferior on the eye-hand coordination tests.

The analysis was continued in a comparison of the test performances of the subgroups selected according to the actual B-Hg and U-Hg with the scores of their referents. The results are summarized in tables 6 and 7. Compared with their referents, the sub-

Table 6. Comparison of the exposed subgroups and their referents according to the actual exposure level indicated by the blood mercury (B-Hg) concentration.

Test	Subgroup with a B-Hg of > 75 nmol/l					Subgroup with a B-Hg of ≤ 75 nmol/l				
	Difference in performances			t	p	Difference in performances			t	p
	N	Mean	SD			N	Mean	SD		
Similarities	16	-5.3	5.8	-3.68	<0.01	20	0.3	6.4	0.21	.
Picture Completion	16	-1.3	3.9	-1.34	.	20	-0.8	4.0	-0.83	.
Digit Span	16	-1.4	2.0	-2.71	<0.01	20	0.3	2.3	0.49	.
Logical Memory	15	-1.1	2.2	-1.89	<0.10	20	-0.7	4.8	-0.65	.
Visual Reproduction	16	-1.6	2.9	-2.14	<0.05	20	0.1	3.6	0.19	.
Santa Ana right ^a	16	-0.4	10.0	-0.15	.	20	-3.0	7.3	-1.84	<0.10
Santa Ana left ^a	16	-0.3	7.3	-0.14	.	19	-3.3	7.7	-1.87	<0.10
Santa Ana coordination ^a	16	-3.2	9.2	-1.39	.	19	-2.6	7.7	-1.50	.

^a Santa Ana Dexterity Test performed with the preferred hand (Santa Ana right), with the nonpreferred hand (Santa Ana left) or with both hands (Santa Ana coordination).

Table 7. Comparison of the exposed subgroups and their referents according to the actual exposure level indicated by the urinary mercury (U-Hg) concentration.

Test	Subgroup with U-Hg > 280 nmol/l					Subgroup with U-Hg ≤ 280 nmol/l				
	Difference in performances			t	p	Difference in performances			t	p
	N	Mean	SD			N	Mean	SD		
Similarities	18	-5.9	6.3	-3.98	<0.001	18	1.5	4.9	1.30	.
Picture Completion	18	-1.4	4.1	-1.48	.	18	-0.6	3.8	-0.62	.
Digit Span	18	-0.9	2.2	-1.68	.	18	-0.1	2.3	-0.10	.
Logical Memory	17	-1.7	3.7	-1.89	<0.10	18	-0.1	3.9	-0.06	.
Visual Reproduction	18	-1.2	3.8	-1.37	.	18	0.0	2.9	0.00	.
Santa Ana right ^a	18	-0.9	8.5	-0.47	.	18	-2.7	8.8	-1.31	.
Santa Ana left ^a	18	-0.8	6.3	-0.52	.	17	-4.8	7.9	-2.49	<0.05
Santa Ana coordination ^a	18	-1.6	7.7	-0.89	.	17	-4.2	8.9	-1.97	<0.10

^a Santa Ana Dexterity Test performed with the preferred hand (Santa Ana right), with the nonpreferred hand (Santa Ana left) or with both hands (Santa Ana coordination).

groups with a higher actual exposure level showed statistically significant deficits on the verbal concept formation test (Similarities), and also on the memory tests. For these tests there was no significant difference between the subgroup with lower actual B-Hg and U-Hg levels and their referents. The results of the eye-hand coordination test were the opposite of those expected, ie, only the subgroups with a lower actual exposure level had statistically significant disturbances.

Discussion

Our results support the previously reported findings of disturbances in cognitive abilities and memory among workers exposed to mercury vapors (3, 15, 18). The verbal concept formation test (Similarities) proved to be the most sensitive component of the test battery used for this study. Comparison of the exposed and reference groups revealed indications of effects. The association was more evident when the subgroup with heavier exposure, as measured both by long-term indicators and by the actual mercury level, was compared with the referents. Although the relation was less evident, differences in memory performances were also associated with mercury exposure.

Several problems should be mentioned, the first being the small number of exposed workers. Selection during employment could not be controlled in this study. Selection can explain some of the unexpected results, such as the lack of association between the length of employment and the number of the peak intervals in table 2.

Another problem is the data on exposure. Thirteen of the exposed workers may have been exposed to high levels before the urine analyses started in 1957, but they did not have more "peaks" in their urine than their fellow workers whose duration of exposure was shorter. Furthermore the retrospectively gathered data on exposure contained inaccuracies and probably became less reliable as the interval of time increased.

The composition of the reference group was also problematic. The referents were chosen from groups of workers whose occupational requirements and level of education equaled those of the exposed group. However, the group of exposed workers contained foremen whose occupational requirements must have been higher than those of the referents. Nevertheless we considered the skilled workers a suitable reference group even though we could not control all the background parameters.

Despite these problems, we were able to corroborate earlier findings of statistically significant disturbances on the verbal intelligence test (Similarities). We also detected the expected negative correlations between performance on the memory test and heavier exposure. Thus our results can hardly be due to

chance alone, though the problem of mass significance cannot be excluded with certainty.

The results of the eye-hand coordination tests were unexpected. One possible explanation for the statistically significant disturbances detected for the subgroup with the lower exposure level but not for the subgroup with the higher exposure level is confounding selection among the workers with long-term exposure. The selective effect of the tremor tests (square drawing and holding of a glass of water) used in the health examinations may have succeeded in removing workers with higher U-Hg levels and psychomotor decrements due to mercury exposure. It has also been suggested that decrements in psychomotor skills are reversible to a certain degree (12).

It is noteworthy that statistically significant memory disturbances correlated better with the actual B-Hg level than with the U-Hg concentration. However, it would be hasty to conclude that the moderately low level of actual exposure alone could produce the effect seen on the tests of verbal intelligence and memory. In this respect the trend for an increase in the number of peak U-Hg intervals above 1,500 nmol/l was the same.

Some conclusions can be drawn about the value of B-Hg monitoring. The actual B-Hg level did not correlate with the long-term dose indicators estimated from the U-Hg concentrations. We found that workers with a relatively high B-Hg level could have an acceptable U-Hg level. The urine monitoring used perhaps failed to exclude workers whose minor symptoms were not reflected in their U-Hg concentrations, which remained at or returned to acceptable levels. Monitoring the B-Hg level can be useful in health surveillance programs to prevent the impairment of cognitive functions.

Conclusions about the biological significance of the impairments (eg, the question of permanent or reversible damage) cannot be based on a single cross-sectional study with only a small number of exposed workers. The decrements in cognitive abilities found in this study were slight; most of the performances of the exposed workers were still within the range of normal variation. The consequences that these kinds of effects may have in the everyday life of the exposed workers are still an unsettled matter. Nevertheless they indicate early adverse effects on the central nervous system, and as such they should, in our opinion, be prevented.

Our results suggested some dose-response relationship. Disturbances on the tests of verbal intelligence and memory were more frequent among the subgroup whose B-Hg level was above 75 nmol/l and whose U-Hg was above 280 nmol/l. The corresponding air level, estimated as described, was about 22–28 $\mu\text{g}/\text{m}^3$. Our results support the recent hygienic standard of 25 $\mu\text{g}/\text{m}^3$ recommended for air by the World Health Organization (19) in cases of long-term exposure to mercury.

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