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NEUROLOGICAL AND NEUROPHYSIOLOGICAL EXAMINATIONS OF WORKERS OCCUPATIONALLY EXPOSED TO MANGANESE

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Abstract. The nervous system is the major target of the toxic effect of manganese (Mn) and its compounds. Nowadays, neurological diagnostics is directed towards early detection of symptoms and abortive forms, and the cases of serious damage of the nervous system are no longer reported.
The aim of the present study was to assess the effects of manganese on the functions of the nervous system in workers exposed to this metal in the ship and electrical industries.
The study covered a selected group of 75 male workers (mean age 39.17 yr ± 9.79; range 20–56 yr), including 62 welders and fitters, as well as 13 workers involved in the battery production. Their employment duration ranged between 1 and 41 yr (mean 17.5 yr ± 10.81). During the welding process the air Mn concentrations varied from 0.004 to 2.67 mg/m^3 (arithmetic mean, 0.399 mg/m^3; geometric mean, 0.154 mg/m^3; standard deviation, 0.586). Of the 62 workers, 30 worked in the area with exceeding MAC value of 0.3 mg/m^3. At the battery production workposts, Mn concentrations fell within 0.086–1.164 mg/m^3 (arithmetic mean, 0.338 mg/m^3, geometric mean, 0.261 mg/m^3; standard deviation, 0.292). The values of current Mn exposure in the study group fell within the range below 0.01 and 2.67 mg/m^3 (arithmetic mean, 0.4 mg/m; geometric mean, 0.15 mg/m^3). Of the 13 subjects, 6 worked at the Mn air concentration exceeding MAC values.
In the exposed group, the values of cumulated exposure index ranged from 0.008 to 35.52 (arithmetic mean, 8.045; geometric mean, 4.615; standard deviation, 6.562).
The control group consisted of 62 men non-occupationally exposed to Mn, matched by sex, age and work shift distribution.
Clinically, the increased emotional irritability, dysmnesia, concentration difficulties, sleepiness and limb paresthesia predominated among the disorders of the nervous system functions in workers chronically exposed to manganese. Neither in the central nor in the peripheral nervous system, the objective examinations revealed organic lesions that could provide grounds for diagnosing toxic encephalopathy or polyneuropathy. Generalized and paroxysmal changes were the most common recordings in the abnormal electroencephalography. Visual evoked potentials examinations showed abnormalities in the response evoked, which could be a signal of the optic neuron disorders and their significant relationship with cumulated exposure.
The results of the study demonstrate that Mn exposure within the range of <0.01–2.67 mg/m^3 (arithmetic mean, 0.4 mg/m^3; geometric mean, 0.15 mg/m^3) induces subclinical effects on the nervous system.

Key words:
Manganese, Occupational exposure, Nervous system, Electroencephalography, Visual evoked potentials

INTRODUCTION

Manganese (Mn) and its compounds affect primarily the nervous system. The noxious effect of this metal on the health of industrial workers has been reported for more than hundred years. In the literature, several hundred cases of serious occupational poisoning have been described. Generally, it has been recognized that chronic Mn poisoning assumes a particular form of Parkinson's

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syndrome. However, this applies only to exposures in extremely bad working conditions (e.g., in Moroccan Mines) [1]. Later observations of Mn poisoning revealed its multifocal process.

As pyramidal and cerebellar symptoms, as well as mental disorders in the form of psychoorganic syndrome of different intensity have been observed, their denomination as toxic encephalopathy seemed to be justified [2–4]. Among other manifestations, single reports on the retrobulbar damage of the optic nerve and polyneuropathic symptoms can be found in the literature [5]. Finally, the central nervous system has been considered to be a critical system [6]. Mn accumulates selectively in the globus pallidus of basal ganglia, where it can produce hyperintensities signals at brain magnetic resonance imaging (MRI) [7,8]. Nowadays, due to improved hygiene at work and decreased Mn concentrations at workposts, serious cases of poisoning by this metal are no longer reported, and the neurological diagnosis is directed towards detecting early symptoms of poisoning and abortive forms whose diagnosis was not feasible in the past.

The introduction of neurophysiological examinations into neurotoxicology has rendered it possible to study the nervous system thoroughly, and consequently to detect subclinical neurological pathologies in those occupationally exposed to manganese.

The number of persons exposed to manganese bears witness to the significance of the problem in Poland. According to the 1994 data provided by the Nofer Institute of Occupational Medicine in Łódź, 3505 persons were at that time occupationally exposed to Mn concentrations exceeding the MAC values binding in Poland (0.3 mg/m^3).

The present study was undertaken with the objective to assess the effects of occupational chronic Mn exposure on the nervous system functions in workers employed in the ship and electrical industries. The assessment was based on the neurological and neurophysiological examinations (electroencephalography (EEG) and visual evoked potentials (VEP)). In particular, an attempt was made to explain whether there are differences in the efficiency of the nervous system functions between the exposed and control groups that could be considered as the effect of chronic Mn exposure; and whether the efficiency of the nervous system functions in workers occupationally exposed to Mn depends on the exposure magnitude.

MATERIALS AND METHODS

The study covered a selected group of 75 male workers (mean age 39.17 yr ± 9.79; range 20–56 yr) of the ship and electrical industries, including 62 welders and fitters, as well as 13 workers involved in the battery production (Table 1). The majority of the workers fell into the 30-49 age group as depicted in Table 1. Their employment duration varied from 1 to 41 yr (mean 17.5 yr ±10.81), and the workers employed for 10 yr made the largest group (Table 2).

Persons suspected of current or past diseases of the nervous system, especially of cranial and cerebral traumas, neuroinfections, brain tumor, cerebrovascular diseases, migraine, as well as persons inflicted by diabetes, hypertension, and ophthalmological diseases, and those suspected of alcoholism and drug abuse were excluded from the study.

The control group consisted of 62 men (mean age 40.0 yr ± 9.44, range 20–58 yr) non-exposed to chemical factors was matched by sex, age and work shift distribution (Table 1).

Table 1. The age characteristics of the study and control groups

Group	No. of subjects	Age (yr)				Number of subjects by age groups				ANOVA
		Min	Max	$\bar{X}$	SD	≤ 29	30–39	40–49	≥ 50	
Mn exposed workers	75 (100.0)	20	56	39.17	9.79	15 (20.0)	18 (24.0)	29 (38.6)	13 (17.4)	NS
Controls	62 (100.0)	20	58	40.0	9.44	10 (16.1)	20 (32.2)	24 (38.7)	8 (13.0)	

Table 2. The characteristics of the Mn exposed group by exposure duration in years

Group	No. of subjects	Exposure duration (yr)				Number of subjects by exposure duration				
		Min	Max	$\bar{X}$	SD	≤ 10	11–20	21–30	≥ 31	Total
Mn exposed workers	75	1	41	17.5	10.81	24 (32.0)	20 (26.7)	22 (29.3)	9 (12.0)	75 (100.0)

The choice of the control group was preceded, like in the study group, by a very careful selection of subjects with certain abnormalities in their health state.

Neurological and neurophysiological examinations

The neurological examinations performed under ambulatory conditions covered both subjective and objective status of the nervous system. Medical history was extended to include questions about symptoms possibly attributable to Mn exposure. In the objective examination, the condition of the cranial nerves and muscular system; the presence of limb tremor and its nature; the movement coordination and diadochokinese were assessed. The data obtained were documented in a form of neurological examination standardized for all study subjects, developed especially for this purpose.

Electroencephalographic recordings were taken on a 8-channel Beckman unit in the international system of 10–20 electrodes. The speed of paper transport was 30 mm/sec, gain 5 mm = 50 μV, time constant 0.3 sec. After EEG recording at rest, and checking the reaction retention, a 3-min hyperventilation was performed, followed by rhythmical flash activation. During the final trial lasting 30 min, a 10-sec flash series at the frequency of 1–30 Hz was applied. EEG recordings were assessed on the basis of the generally recognized criteria, including frequency, amplitude, morphology, localization, rhythms and their reaction to stimuli. The results were divided into two groups: normal and abnormal, according to the classification of Majkowski [9].

The EEG recordings with one of the basic rhythms of the brain bioelectric functions and those with about 5% of symmetric slow theta waves of 6–7 Hz in temporal-occipital leads were classified in the normal group.

Abnormal recordings were classified according to the nature of pathologies and their intensity. The following four subgroups were distinguished: generalized changes; focal changes; paroxysmal changes; and asymmetrical recordings.

Visual evoked potentials were recorded using a Dantec 2000 C Neuromatic unit with stimulation of each eye by the checkerboard reversal pattern. The responses were received from the active electrode placed at the cranial midline, 3 cm above the inion. A total of 200 evoked responses were averaged over 300 ms analysis time. Latency of N1, P100, N2, amplitude of N1 P100, P100 N2 and VEP configuration were evaluated. The examination was preceded by taking an ophthalmologic history and checking visual acuity.

Exposure assessment

Individual dosimetry method, as described in PN-1989-Z-04008-7, was used to assess occupational exposure to manganese present in the ambient air at workposts of welders and fitters employed in the ship industry and in the production of batteries. The welders and fitters welded by hand mainly low-alloy steel type ST-3 (MS-mild steel), using low-hydrogen coated electrodes EB-146 (manual metal arc welding), or solid wire type SPG 3S in CO_2 shielding (metal active gas welding) they also used acetylene-oxygen flame for cutting steel grades. The welders worked on ships and in production rooms, also in closed rooms (double bottom of ships).

The welding dust comprised mainly iron, manganese, silicon, fluorides, calcium, sodium (MMA method), and iron, manganese, silicon, and copper (MAG method).

The welding fumes comprised mainly carbon oxides (CO, CO_2) and nitrogen oxides (NO, NO_2).

Manganese dioxide, ammonium chloride, zinc oxide, and an electrolyte, containing ammonium chloride and zinc chloride, were used to manufacture the batteries.

Air was sampled constantly at the breathing zone of the subjects exposed during the effective working time (6–7 h).

Flame atomic absorption spectrophotometry was used to analyze Mn concentration in the samples. Manganese was determined using a Varian Spectr AA 250 atomic absorption spectrophotometer with wave length of 279.5 nm in the air-acetylene flame.

In the ambient air at workposts of welders and fitters, Mn concentrations varied from 0.004 to 2.667 mg/m^3 (arithmetic mean, 0.399 mg/m^3; geometric mean, 0.154 mg/m^3; standard deviation, 0.586). Of the 62 persons exposed, 30 worked in Mn concentrations exceeding MAC values.

In the ambient air at workposts of workers engaged in the production of batteries, Mn concentrations ranged between 0.086 and 1.164 mg/m^3 (arithmetic mean, 0.338 mg/m^3; geometric mean, 0.261 mg/m^3; standard deviation, 0.292). Of the 13 persons under study, 6 worked in Mn concentrations exceeding MAC values.

In the group of 75 workers exposed, air Mn concentrations ranged from 0.004 to 2.667 mg/m^3 (<0.01–2.67 mg/m^3) (arithmetic mean, 0.389 (0.4) mg/m^3; geometric mean, 0.154 (0.15) mg/m^3; standard deviation, 0.5454).

The cumulated exposure index (CEI) (a product of total Mn exposure index and exposure duration in yr) was calculated for each worker exposed. In the whole group of workers, CEI values varied from 0.008 to 35.52 (arithmetic mean, 8.045; geometric mean, 4.615; standard deviation, 6.562) (Table 3).

As depicted in Table 3, the workers exposed to current Mn concentrations of 0.301–0.600 mg/m^3 predominated in the study group, and according to CEI those falling within the range of 8.1–16.0 were in the majority.

Statistical analysis

Statistical analysis of the results involving the chi-square test, one-way analysis of variance and r-Pearson correlation coefficient was performed by Maria Szymczak, MSc of the Institute of Sociology, University of Łódź.

RESULTS

The most frequent complaints reported by the workers in question were: increased emotional irritability (49.3%), headache (29.3%), sleepiness (14.7%), vertigo (12.0%), dysmnesia (12,0%), mood swings (12.0%), concentration difficulties (12.0%), anxiety and fear (9.3%), pains (13.3%) and limb paresthesia (13.3%) (Table 4).

Headaches reported by workers were not characterized by any specific features. Their location, duration and time varied. In a large group of workers, headache occurred at work and subsided after leaving the production premises. However, in many cases, headache persisted even at rest and assumed the form of vasomotor pains. Headaches were often accompanied by vertigo, frequently intensified with the changed position of the body, but in general, they were not so acute as to lead to difficulties in walking or collapse.

The state of increased emotional irritability with symptoms of impatience and lack of self-control was reported by 37 workers. Dysmnesia, usually temporary, applied

Table 3. The characteristics of the Mn exposed group by the values of current exposure and cumulated exposure index

Group	No. of subjects	Current Mn exposure in mg/m^3					
		– 0.075	0.076 –0.150	0.151 –0.300	0.301 –0.600	0.601 –	Range (0.004-2.667) < 0.01–2.67 Arithmetic mean (0.3887) 0.4 Geometric mean (0.1539) 0.15 SD (0.5454) 0.54
Mn exposed workers	75 (100.0)	22 (29.3)	9 (12.0)	8 (10.7)	26 (34.7)	10 (13.3)	
		Cumulated exposure index (mg/m^3 • years)					
		– 2.0	2.1–4.0	4.1–8.0	8.1 – 16.0	16.1 –	Range 0.008–35.52 Arithmetic mean 8.045 Geometric mean 4.615 SD 6.562
	75 (100.0)	17 (22.7)	12 (16.0)	12 (16.0)	28 (37.3)	6 (7.0)	

Percentages within each column in parantheses.

Table 4. The frequency of subjective symptoms in the nervous system in the study and control groups

Subjective symptoms	Group		
	Mn exposed workers	Controls	Significance
Number subjects %	75 100.0	62 100.0	
Headaches	22 29.3	14 22.6	NS
Vertigo	9 12.0	3 4.8	NS
Increased emotional irritability	37 49.3	16 25.8	0.01
Dysmnesia	9 12.0	2 3.2	0.10
Concentration difficulties	9 12.0	2 3.2	0.10
Sleeplessness	6 8.0	3 4.8	NS
Sleepiness	11 14.7	2 3.2	0.05
Mood swings	9 12.0	4 6.5	NS
Anxiety and fear	7 9.3	3 4.8	NS
Myospasm	3 4.0	2 3.2	NS
Muscular fatigue	4 5.3	1 1.6	NS
Extremity pains	10 13.3	4 6.5	NS
Paresthesia	10 13.3	0	0.01

Chi-square test.

mostly to recent events and co-existed with concentration difficulties. Sleepiness during the day was associated with fatigue and nervous exhaustion. As clarified in interviews, this type of sleep disorders, known as symptomatic hypersomnia, was not related to shift work. Only 9 workers reported mood swings characterized by a rapid change from a cheerful to a depressive mood. Any regular sequence of the particular mood occurrence could be identified, and the respondents themselves did not regard this symptom as a morbid one.

Complaints for limb pains and paresthesia were reported by 13.3% of workers. Paresthesia, characterized by formication and numbness, was usually located in distal segments of lower extremities, and frequently intensified at night. The symptom frequency in Mn exposed workers and in the control group was compared by means of the chi-square test of independence. The comparison indicated that the occurrence of increased emotional irritability, dysmnesia, concentration difficulties, sleepiness during the day and paresthesia was significantly more frequent in the study than in the control group.

The comparison of the relationship between the occurrence frequency of the afore-said symptoms and the values of current Mn exposure and the cumulated exposure index did not show any statistical significance*.

In the study group, the subjective neurological examination did not reveal focal symptoms of organic lesions in the central and peripheral nervous systems that could be

* As it has not been possible to include full statistical calculations, no data are given, but they are available from the author.

Table 5. The frequency of EEG changes in the study and control groups

Group	No. of subjects	Normal EEG	Abnormal EEG					Significance level
			Generalized	Focal	Paroxysmal	Asymmetrical	Total	
Mn exposed workers	75 (100.0)	54 (72.0)	8 (10.7)	5 (6.7)	7 (9.3)	1 (1.3)	21 (28.0)	NS
Controls	62 (100.0)	51 (82.3)	6 (9.7)	3 (4.8)	2 (3.2)	0	11 (17.3)	

Chi-square test.
Percentages within each column in parentheses.

attributable to occupational exposure. Neither clinical neurological examination provided grounds for diagnosing toxic encephalopathy or polyneuropathy.

The characteristics of the EEG recordings is summarized in Table 5. In the study group, 54 (72.0%) normal and 21 (28.0%) abnormal recordings were yielded. Normal EEG recordings were characterized by the presence of alpha and beta rhythms, as well as by the alpha rhythm blockade. The alpha rhythm frequency in those exposed was 9–11 Hz. The alpha wave amplitude varied, and it accounted most frequently for about 40–60 μV. Beta activity of the frequency between 14 and 30 Hz and amplitude below 25 μV was another background rhythm. Recordings with 5% of symmetric slow free theta waves, frequency of 6–7 Hz in parietal leads, frequency of 4–6 Hz in anterior-temporal leads or deep structures and amplitude below 40 μV were classified as normal EEG recordings.

In abnormal EEG recordings, those with generalized changes (10.7%) predominated. They were characterized by irregular background activity, decreased alpha waves and increased, usually scattered, slow theta waves of varied frequency and amplitude, appearing sometimes in shorter or longer episodes. More serious pathological disturbances involved paroxysmal changes observed in 7 (9.3%) workers. Paroxysmal changes assumed the form of slow dysrhythmic theta wave discharges, usually at the unchanged background activity. Focal changes in frontal-temporal leads were recorded in 5 (6.7%) persons. In one subject, asymmetric recording with left-sided laterization associated with the asymmetry of dominant alpha rhythm was observed.

The comparison of the frequency of abnormal EEG recordings did not reveal any significant differences between the study and control groups.

The results of visual potentials evoked by using the reversal method regarding the values of mean latencies of N1, P100, N2 and amplitudes of N1 P100, P100 N2 are given in Table 6. The comparison of the latency values for the main components in the study and control groups revealed a significant difference in N1 component latency time after stimulation of both eyes.

The mean values of VEP amplitude, except for N1 P100 after the right eye stimulation, were lower in the study group. A statistically significant difference was revealed for P100 N2 following the left eye stimulation.

The comparison of the interocular latency and amplitude of VEP components did not demonstrate significant differences.

The statistical analysis, involving r-Pearson correlation coefficient, helped to investigate the relationship between the values of individual VEP components and the current, as well as cumulated Mn exposures.

Statistically significant relationship was found between latency of P100 and N2 components after stimulation of the right eye and both eyes, respectively, and N1 P100 amplitude after stimulation of both eyes and cumulated Mn exposure. The comparison of the afore-said VEP parameters with the values of current Mn exposure did not reveal any significant relationship (Table 7).

The individual assessment of the VEP results in 75 Mn exposed workers showed abnormalities in 16 (21.3%) cases. In 12 persons, prolonged latency of the study components, and P100 component in particular (144 ms) and interocular asymmetry in the latency of this component were observed. In 3 cases with abnormal VEP, asymmetry in interocular P100 latency, exceeding 6 ms, and decreased amplitude in single tests were found. In one

Table 6. VEP latency and amplitude in the study and control groups

Group	No. of subjects		VEP latency (ms)						VEP amplitude (mV)			
			Stimulation of the right eye			Stimulation of the left eye			Stimulation of the right eye		Stimulation of the left eye	
			N1	P100	N2	N1	P100	N2	N1 P100	P100 N2	N1 P100	P100 N2
Mn exposed workers	75	$\bar{X}$	70.76	99.04	129.46	71.26	99.53	130.36	7.62	7.15	6.93	7.48
		SD	5.05	7.32	15.65	5.51	8.46	15.86	3.10	3.05	2.80	2.78
Controls	62	$\bar{X}$	74.56	100.37	126.89	73.60	99.37	126.98	6.98	7.78	7.01	8.28
		SD	8.05	8.90	10.34	5.07	6.12	9.24	1.90	2.63	1.97	2.46
Analysis of variance significance level			0.01	NS	NS	0.05	NS	NS	NS	NS	NS	0.10

Table 7. The comparison of VEP parameters in the study group with the values of current and cumulated Mn exposures

Study parameters VEP		Current Mn exposure			Cumulated Mn exposure	
		No. of examinations	Correlation coefficients r-Pearson	Significance level	Correlation coefficients r-Pearson	Significance level
Latency N 1	RE	65	0.095	NS	0.13	NS
Latency P 100	RE	65	-0.055	NS	-0.23	$p < 0.05$
Latency N 2	RE	65	-0.017	NS	-0.37	$p < 0.01$
Latency N 1	LE	65	0.03	NS	0.15	NS
Latency P 100	LE	65	0.03	NS	-0.17	NS
Latency N 2	LE	65	0.06	NS	-0.37	$p < 0.01$
Amplitude N 1 P 100	RE	65	0.15	NS	-0.25	$p < 0.05$
Amplitude P 100 N 2	RE	65	0.12	NS	-0.18	NS
Amplitude N 1 P 100	LE	65	0.05	NS	-0.28	$p < 0.01$
Amplitude P 100 N 2	LE	65	0.09	NS	-0.18	NS

RE – rigt ege; LE – left eye.

case, abnormal VEP configuration at normal values of the components in question was noted.

DISCUSSION

In the clinical picture of the nervous system disorders observed in workers of the ship industry and in those employed in the battery production, occupationally exposed to manganese in the range < 0.01–2.67 mg/m^3 (arithmetic mean, 0.4 mg/m^3; geometric mean, 0.15 mg/m^3), the increased emotional irritability, dysmnesia and concentration difficulties, sleepiness during the day and limb paresthesia predominated. In the majority of symptoms, there was no relationship with either current or cumulated Mn exposure. Therefore, the presence of the association with the enzymatic constitution, namely an individual sensitivity to manganese, known from the clinical practice, is most likely. Unquestionable individual predisposition has been underlined by many researchers who observed that the extent of neurological manifestations was not the same in all persons exposed to manganese [10].

In the study group, the nervous system disorders did not differ from those described by other authors [11–13] and recognized by Mergler and Baldwin [10] as the first phase of Mn poisoning.

The objective neurological examination did not reveal organic lesions in the central, or peripheral nervous system that could provide the ground for diagnosing toxic encephalopathy or polyneuropathy.

Ferraz et al. [14] exploring the group of 50 agriculture workers occupationally exposed to fungicides, containing Mn compounds, noticed neurological symptoms, which suggested a possible occurrence of encephalopathy, but the changes did not differ considerably from disorders observed in non-exposed workers.

A lot of research has been devoted to EEG examinations in Mn exposed persons. The findings indicate the presence of bioelectric disorders of cerebral functions. Particularly frequent and intense abnormalities in EEG recordings have been described in cases of acute Mn poisoning [15].

In the study group, there were 28% of abnormal EEG recordings. In the majority of electroencephalograms (10.7%), generalized changes were found, whereas paroxysmal changes at the unchanged background activity were rather small and less frequent (9.3%).

Abnormal EEG recordings were more frequent in the study group, and the frequency exceeded the so-called "population standard", but did not differ significantly from that in the control group.

Similar observations were made by Wennberg et al. [16] who registered 23% of abnormal EEG recordings in the group of 30 workers employed in the steel cast and exposed to Mn in concentrations of 0.19–1.39 mg/m^3.

The examination of cerebral evoked potentials in neurotoxicology is not so common, however, a growing interest in this method has recently been observed both in experimental and clinical investigations.

The VEP examination was included in our study in view of the findings reported earlier in the literature on retrobulbar damage of the optic nerve in the cases of Mn poisoning.

The study indicated abnormalities in the visual evoked potentials. The changes were observed in both VEP latency and amplitude of some components and revealed the statistically significant relationship with cumulated Mn exposure. The results suggest the presence of the optic nerve disorders without clinical symptoms.

CONCLUSIONS

The neurological examinations performed in our study showed that:

1. Occupational exposure to manganese present in the ambient air at the workposts of welders and fitters employed in the ship industry and in the production of batteries, in the concentration range of <0.01–2.67 mg/m^3 (arithmetic mean, 0.4 mg/m^3; geometric mean, 0.15 mg/m^3) does not induce organic lesions in the nervous system that could provide grounds for diagnosing encephalopathy and polyneuropathy, however, it is responsible for the subclinical effects in the nervous system.
2. Disorders of the nervous functions occur in the form of the subjective syndrome consisted of the increased emotional irritability, dysmnesia and concentration difficulties, sleepiness during the day, and limb paresthesia. The occurrence of these symptoms was significantly more frequent in the study group than in controls, however, no significant relationship between Mn current and cumulated exposure was observed. It is most likely that this observation is related to an individual sensitivity to the effect of manganese.
3. Disorders, revealed in neurophysiological examinations (EEG), are probably multietiologic; the influence of brain anoxia may not be excluded. Results of the VEP examinations indicate the statistically significant relationship with cumulated Mn exposure.

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