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Occupational exposure to manganese[1]

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ABSTRACT The relationship between the degree of exposure and biological effects of manganese was studied in a group of 369 workers employed in the production of ferroalloys. Two other groups of workers, from an electrode plant and from an aluminium rolling mill, served as controls. Mean manganese concentrations at work places where ferroalloys were produced varied from 0·301 to 20·442 mg/m³. The exposure level of the two control groups was from 2 to 30 μg/m³ and from 0·05 to 0·07 μg/m³, in the electrode plant and rolling mill respectively. Sixty-two (16·8%) manganese alloy workers showed some signs of neurological impairment. These signs were noticeably less in the two control groups (5·8% and 0%) than in the occupationally exposed group. Subjective symptoms, which are nonspecific but may be symptoms of subclinical manganism, were not markedly different in the three groups. However, in the manganese alloy workers some of the subjective symptoms occurred more frequently in heavier smokers than in light smokers or nonsmokers. Heavier smokers engaged in manganese alloy production showed some of the subjective symptoms more often than heavier smokers from the control groups.

The problem of the effects of manganese on human health still leaves some open questions, one of which concerns the relationship between the degree of exposure and biological response.

For workers occupationally exposed to manganese the threshold limit value in the United States of America and Japan is as high as 5 mg/m³. Permitted exposure is considerably lower elsewhere. For instance, in Bulgaria the maximum permissible concentration (MAC) of manganese as MnO_2 is 0·02 mg/m³; in Poland and USSR 0·3 mg/m³ as MnO_2. The MAC value for manganese in Yugoslavia is 2 mg/m³.

To illustrate further the relationship between the degree of occupational exposure and biological effect of manganese we studied the symptoms and signs possibly associated with the most important effect of manganese, that on the central nervous system.

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Sample and method

The study was carried out in a group of 369 male workers employed in the production of ferroalloys. Two groups of workers served as controls: one from the electrode plant (190 workers) and the other from the aluminium rolling mill (204 workers).

Alloys are made from manganese ore by addition of coke and anthracite and by reduction in electric furnaces. Ferromanganese and silicomanganese are produced, depending on whether iron or silicon is used as the alloying component.

The raw material goes through the process of drying, grinding and sintering. It is then transported in electric trolleys to the furnaces. Every two or three hours the melted alloy is cast in pots and moulds.

During the grinding and mixing of the raw material a considerable amount of manganese dust is formed. The working atmosphere is also polluted with fumes containing manganese compounds, carbon monoxide, carbon dioxide and sulphur dioxide, all of which are produced during roasting of the raw material and casting of the molten alloy. Another atmospheric pollutant is coal dust. However, manganese dust and fumes are regarded as the main pollutants. The furnace and the manganese alloy emerging from the furnace give out a great deal of heat so that the ambient temperature, even in sum-

mer, can be considerably higher than the temperature outside the plant.

The electrode plant is situated within the same factory. The three types of electrodes manufactured are amorphous, Soderberger's and graphite electrodes. The workers in this plant are not exposed to manganese in the course of their work. The aluminium rolling mill is situated about 5 km away from the ferroalloy and electrode plants.

Table 1 shows the manganese concentrations to which ferroalloy, electrode and aluminium mill workers have been exposed.

Table 1 *Levels of manganese exposure*

Location	*Mean manganese concentration*
Ferroalloy plant (work places)	0·301-20·442 mg/m³
Electrode plant (work places)	2·00 -30·00 µg/m³
Aluminium rolling mill (outside air)	0·05 - 0·07 µg/m³

Table 2 shows the distribution of workers in the three groups with regard to age, height and weight, and smoking habit.

The number of subjects examined was 95% of the total number of workers called for examination. The remainder did not attend for examination mainly for objective reasons such as sick leave or annual leave. There was no difference in the rate of response between the compared groups.

A large number of workers (27%) in the ferroalloy plant had been exposed to manganese for up to four years. A minority (9·8%) had been exposed for over 20 years. The average exposure of the remaining 232 workers (63·2%) was about 11 years.

The study included collection of data concerning subjective symptoms which are possibly associated with exposure to manganese. A neurological examination was also included, in which particular attention was paid to tremor of fingers and hands at rest, difficulty in initiating voluntary movements, the cogwheel phenomenon, and pathological reflexes. Other neurological signs, if any, were also noted.

Data on smoking habit were also recorded in the interview, as it had been observed that exposure to manganese combined with smoking might produce a synergistic effect on the respiratory system (Šarić and Lučić-Palaić, 1975). Our intention was to find out whether the same is true for neurological symptoms and signs. Smokers were classified into categories according to the criteria used by Brinkman and Coates (1963).

The interview and the examination were performed in April within an epidemiological study which was conducted primarily to determine the prevalence of respiratory symptoms.

Statistical significance of results was determined by Student's *t* test.

Results

The prevalence of recorded subjective symptoms did not differ greatly in the three groups (Table 3). In the ferroalloy group there were significantly more workers in a bad mood than in the two other groups. On the other hand, in the group with the lowest exposure to manganese, sleepiness, irritability, fatigue, tremor, and tired stiff legs were also frequently noted. The prevalence of these symptoms was similar to that in the ferroalloy group. The prevalence of symptoms was lowest in the electrode group.

Tables 4-6 show the prevalence of some of the symptoms according to the degree of exposure to manganese and smoking habit.

Moderate and heavy smokers in the ferroalloy group had a significantly higher rate of fatigue and irritability than light smokers. Symptoms of cramps in arms and legs were significantly more frequent in moderate and heavy smokers than in light smokers and in nonsmokers. In the electrode group the symptoms were almost equally frequent in nonsmokers and in smokers, with the exception of fatigue

Table 2 *General characteristics of workers*

	Ferroalloy plant	*Electrode plant*	*Aluminium rolling mill*
Number of workers	369	190	204
Mean age (years)	37·8 (S.D. 8·8)	35·8 (S.D. 9·4)	36·8 (S.D. 8·7)
Mean height (cm)	173·3 (S.D. 6·6)	172·8 (S.D. 7·1)	173·6 (S.D. 6·3)
Mean weight (kg)	76·6 (S.D. 10·4)	75·2 (S.D. 11·3)	75·2 (S.D. 10·4)
Nonsmokers	169 (45·9%)	102 (53·7%)	81 (39·7%)
Past smokers	57 (15·4%)	19 (10·0%)	29 (14·0%)
Current smokers	143 (38·8%)	69 (36·3%)	94 (46·1%)
Light	51 (13·8%)	35 (18·4%)	41 (20·1%)
Moderate	73 (19·8%)	25 (13·2%)	42 (20·6%)
Heavy	19 (5·1%)	9 (4·7%)	11 (5·4%)

Table 3 *Prevalence of subjective symptoms*

Symptoms	*(a) Ferroalloy plant (N = 369)*		*(b) Electrode plant (N = 190)*		*(c) Aluminium rolling mill (N = 204)*		*Significance of difference*	
	No.	*%*	*No.*	*%*	*No.*	*%*	*Working groups*	*P*
Fatigue	152	41·2	55	28·9	76	37·3	a - b	$P < 0.01$
Bad mood	68	19·0	18	9·5	22	10·8	a - b	$P < 0.01$
							a - c	$P < 0.01$
Sleepiness	77	20·9	29	15·3	54	26·5	b - c	$P < 0.01$
Irritability	161	43·6	63	33·2	89	43·6	a - b	$P < 0.01$
							b - c	$P < 0.05$
Hypersalivation	38	10·3	17	8·9	20	9·8		
Tiredness, stiffness, heaviness in legs	105	31·2	51	26·8	77	37·7	b - c	$P < 0.05$
Tremor of hands	89	24·1	21	11·1	52	25·5	a - b	$P < 0.01$
							b - c	$P < 0.01$
Recurring cramps in arms and legs	45	12·2	17	8·9	16	7·8		

Table 4 *Prevalence of symptoms in ferroalloy plant workers by smoking habit*

Symptoms	*(1) Moderate & heavy smokers (N = 92)*		*(2) Light smokers (N = 51)*		*(3) Nonsmokers (N = 169)*		*Significance of difference*	
	No.	*%*	*No.*	*%*	*No.*	*%*	*Smoking groups*	*P*
Fatigue	48	52·2	19	37·3	61	36·1	1 - 3	$P < 0.05$
Bad mood	24	26·1	4	7·8	26	15·4		
Irritability	47	51·1	13	25·5	66	39·1	1 - 2	$P < 0.01$
							1 - 3	$P < 0.01$
Recurring cramps in arms and legs	20	21·7	1	2·0	19	11·2	1 - 3	$P < 0.05$
							2 - 3	$P < 0.01$

Table 5 *Prevalence of symptoms in electrode plant workers by smoking habit*

Symptoms	*(1) Moderate & heavy smokers (N = 34)*		*(2) Light smokers (N = 35)*		*(3) Nonsmokers (N = 69)*		*Significance of difference*	
	No.	*%*	*No.*	*%*	*No.*	*%*	*Smoking groups*	*P*
Fatigue	11	32·4	5	14·3	33	32·4	2 - 3	$P < 0.05$
Bad mood	6	17·6	1	2·9	9	8·8	1 - 2	$P < 0.05$
Irritability	13	38·2	8	22·9	37	36·3		
Recurring cramps in arms and legs	2	5·9	1	2·9	12	11·8		

Table 6 *Prevalence of symptoms in aluminium rolling mill workers by smoking habit*

Symptoms	*(1) Moderate & heavy smokers (N = 53)*		*(2) Light smokers (N = 41)*		*(3) Nonsmokers (N = 81)*		*Significance of difference*	
	No.	*%*	*No.*	*%*	*No.*	*%*	*Smoking groups*	*P*
Fatigue	21	39·6	12	29·3	28	34·6		
Bad mood	7	13·2	1	2·4	10	11·5	1 - 2	$P < 0.05$
							2 - 3	$P < 0.05$
Irritability	27	50·9	14	34·1	32	39·5		
Recurring cramps in arms and legs	6	11·3	1	2·4	3	3·7		

which was more frequent in nonsmokers than in light smokers. In the group from the aluminium rolling mill there was no statistically significant difference in the prevalence of symptoms by smoking habit, with only one exception: bad mood was more frequent in moderate and heavy smokers but also in non-smokers than in light smokers.

If moderate and heavy smokers in all the three groups of workers (ferroalloy plant, electrode plant, aluminium rolling mill) are compared it appears that the rate of fatigue and cramps in arms and legs was significantly higher in the ferroalloy group than in the electrode group ($P < 0.01$). Bad mood was more frequent in moderate and heavy smokers from the ferroalloy group than in those from the aluminium rolling mill ($P < 0.05$).

Light smokers from the ferroalloy group had a higher rate of fatigue than light smokers from the electrode group ($P < 0.05$).

Table 7 shows the comparative prevalence of neurological findings in the groups of workers. Such signs were noted only in workers engaged in the production of manganese alloys and of electrodes, and were more frequent in the manganese alloy group. There was no apparent correlation with smoking habit.

Table 8 shows the prevalence of neurological findings in the manganese alloy group in relation to the level of manganese exposure.

The prevalence of neurological signs seems to be highest in the most exposed group but the difference is not statistically significant. On the other hand in the least exposed group the number of neurological signs was also rather numerous.

Discussion

Epidemiological and clinical studies show three phases in the development of manganism: a sub-clinical stage with a general vague symptomatology, the initial period in which the psychic or neurological symptoms are predominantly acute psychomotor disturbances, dysarthria, disturbances of the gait and sialorrhea; and the fully developed stage which can be associated with acute psychosis of the manic or depressive type but usually presents as parkinsonism with associated neurological disorders (Ansola *et al.*, 1944).

This study did not reveal any advanced forms of disease in workers engaged in the production of manganese alloys. However, a certain number of neurological findings which might be connected with manganese effects were recorded. Of 369 workers, 62 (16·8%) displayed one or more neurological signs, in

Table 7 *Prevalence of neurological signs*

Signs	*Ferroalloy plant*		*Electrode plant*		*Aluminium rolling mill*	
	Nonsmokers (N = 169)	*Smokers* (N = 200)*	*Nonsmokers (N = 102)*	*Smokers* (N = 88)*	*Nonsmokers (N = 81)*	*Smokers* (N = 123)*
Cogwheel phenomenon	—	1	—	—	—	—
Tremor at rest	24 (14·2%)	23 (11·5%)	2	8 (9·1%)	—	—
Difficulty in initiating voluntary movements	—	1	—	—	—	—
Pathological reflexes	4	4	—	1	—	—
Cogwheel phenomenon and tremor at rest	—	1	—	—	—	—
Cogwheel phenomenon and pathological reflexes	—	1	—	—	—	—
Pathological reflexes and tremor at rest	1	2	—	—	—	—

*Present and past smokers.
The difference between the number of symptoms of tremor at rest in ferroalloy and electrode plant workers is statistically significant ($P < 0.01$)

Table 8 *Ferroalloy workers with neurological signs by level of exposure to magnanese*

Signs	*Mean manganese concentrations at working places (mg/m³)*		
	0·301-4·933 (N = 268)	*9·480-11·062 (N = 17)*	*16·347-20·442 (N = 18)*
Cogwheel phenomenon	1	—	—
Difficulty in initiating voluntary movements	2	—	—
Pathological reflexes	6	1	1
Tremor at rest	42	2	2
Pathological reflexes and tremor at rest	3	—	—
Cogwheel phenomenon and tremor at rest	—	—	1
Cogwheel phenomenon and pathological reflexes	—	—	1
Total	54 (20·1%)	3 (17·6%)	5 (27·8%)

In 66 workers with a mean manganese exposure of 0·469-1·056 mg/m³ no neurological signs were found.

most cases (47), tremor. Tremor, which usually appears during rest and increases with movement, is frequently observed, particularly in the tongue, arms and legs (Peñalver, 1955). In the group of workers exposed to manganese, neurological signs were more frequent than in those employed in the adjoining electrode plant who were not occupationally exposed to manganese. Pathological reflexes in the electrode group were found in only one worker. Tremor at rest was also statistically significantly more frequent in workers occupationally exposed to manganese.

In one worker from the manganese alloy group a subsequent detailed clinical examination showed a picture of manganism (initial period with extrapyramidal symptoms). This worker had been exposed for over 20 years to manganese concentrations estimated to be approximately 5-16 mg/m^3.

Statistical analysis of results concerning other workers did not show a correlation between the measured mean manganese concentration at their places of work and the incidence of the disorders. This might be partly due to the fact that the manganese concentrations in air to which the workers are exposed are not constant. In addition, some of the workers change their work place from time to time, thus altering their exposure level. On the other hand it is known that there are marked differences in individual susceptibility to manganese. Only a small percentage of those who are exposed to manganese dusts develop chronic manganese poisoning. This may be due to variations in the excretory capacity of the liver and kidney which may lead to accumulation of toxic levels of manganese.

Horiguchi *et al.* (1966) reported neurological signs in a percentage of workers engaged in manganese refining and in the manufacture of dry cells and welding rods. In four refinery workers who were exposed to manganese concentrations of 2·3-17·1 mg/m^3, symptoms and signs of central nervous system impairment were observed. Eleven of 47 workers in the manganese refining industry were thought to have some neurological signs. Four of 32 workers manufacturing electric welding rods, with an exposure to manganese ranging between 3·1 and 8·1 mg/m^3, and seven out of 55 workers manufacturing dry cells, exposed to manganese concentrations of 1·9 to 21·1 mg/m^3, were also thought to have some degree of neurological abnormality.

The symptoms which we recorded are not specific. They were found in a relatively high percentage of our workers, even in the control group with a minimal exposure to manganese. However, in the ferroalloy group some of the symptoms which may well be those of the subclinical phase of manganism were more prevalent in moderate and heavy smokers than in light smokers or in nonsmokers. Smokers from the ferroalloy production group showed some of the subjective symptoms more often than the smokers from the other two groups.

Conclusion

This study has shown that in the production of ferroalloys where manganese exposure ranges from a rather low to a rather high level, a certain number of workers had neurological disturbances, in most cases tremor at rest only. No advanced form of manganism was found. The prevalence of neurological signs did not correlate well with the mean manganese concentrations at places of work.

The prevalence of symptoms which are not specific but may be connected with the subclinical phase of manganism did not differ between the exposed and the control groups. However, some of these vague symptoms were more frequent in heavier smokers compared with other occupationally exposed workers or heavier smokers among controls.

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