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Mortality from cardiovascular diseases and sudden death in ferroalloy plants

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Objectives The aim of this study was to examine mortality from circulatory diseases and sudden death among workers in 12 Norwegian ferroalloy plants.

Methods The cohort comprised 14 730 men employed for the first time during 1933—1990 and for at least 6 months. Deaths observed during 1962—1990 were compared with expected figures calculated from national mortality rates. Internal comparisons of rates were performed by Poisson regression analysis.

Results The overall mortality from cardiovascular diseases was not increased [standardized mortality ratio (SMR) 1.01], but a significantly increased mortality from sudden death (SMR 1.55) and hypertensive disease (SMR 1.37) was observed. Among the ferromanganese/silicomanganese (FeMn/SiMn) furnace workers the sudden death mortality was significantly increased during the employment period (SMR 2.47). In an internal comparison of the sudden death rates, a significant increase of 0.05 in the rate ratio per workyear was observed in this group. The mortality from 3 hypertension-related diseases combined (cerebrovascular, hypertensive, and renal diseases) showed identical positive mortality trends among the ferrosilicon/silicon-metal (FeSi/Si-met) and the FeMn/SiMn furnace workers by increasing duration of work.

Conclusions Increased mortality from sudden death among the FeMn/SiMn furnace workers is not likely to be explained by smoking or alcohol consumption. Associations with work exposures (manganese and possibly carbon monoxide and heat) are suspected. The increasing mortality from hypertension-related diseases with increasing duration of work in both groups of furnace workers may be associated with common furnace work conditions (eg, heat, psychosocial stress, shift work, noise, carbon monoxide).

Key terms carbon monoxide, ferrosilicon, furnace, heat, hypertension, manganese.

Workers manufacturing ferroalloys have been exposed to agents that may increase the risk of cardiovascular diseases. Such agents are carbon monoxide, polycyclic aromatic hydrocarbons, and also heat, noise, shift work, and psychosocial stress (1, 2). An additional hazard is possible with exposure to manganese alloys, as animal studies have shown that the divalent manganese ion (Mn²⁺) may influence cardiac function (3, 4).

We have previously reported the main causes of death for a cohort of 14 730 male workers in the Norwegian ferroalloy industry (5). A significantly increased standardized mortality ratio (SMR) of 1.47 for sudden death was found for all men employed at least 3 years. Statistics Norway has formerly shown that workers in smelting plants have the highest mortality index for sudden death among all work categories in Norway (6). There has further been some concern within this industry about

a potential association between heat exposure and blood pressure elevation. However, no association between cardiovascular mortality and work in this industry has been reported.

Thus the aim of this study was to examine the associations between duration of work in specific departments and mortality from circulatory system diseases and sudden death within the same cohort (5).

Subjects and methods

Study setting

The study was conducted among employees in 12 Norwegian electrometallurgical ferroalloy plants. Nine of the plants started production before 1930. The remaining

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three were established in the period 1963—1974. Eight of the 12 plants had primarily produced ferrosilicon (FeSi) or silicon-metal (Si-met) or both. The remaining four had primarily produced ferromanganese (FeMn) and silicomanganese (SiMn).

The exposure variable

Only indirect exposure information from manual employment records was available in addition to sporadic measurements, mainly of dusts. Exposure classification was therefore based on the individual registered periods of work in the actual work areas at the department level (5).

In the 12 plants a total of 81 departments or specialized functions were identified. These were further divided into 16 main groups of departments. The 2 largest groups were the furnace workers in the FeSi/Si-met and FeMn/SiMn plants. As the other groups of workers were considerably smaller, we also defined 2 groups of blue-collar workers who were not furnace workers. They were the mechanics, electricians, transport workers, raw material workers, packers, and building and construction workers in each of the FeSi/Si-met and FeMn/SiMn types of plants. Individual information about type of plant, work area (department), and duration of work was there-by used as proxies for true exposure information.

Other groups of employees not included in the 4 main groups were office workers, technicians, engineers, research workers, laboratory workers, workers in the parts and accessories departments, ferrochromium furnace workers, ferrovandium furnace workers, calcium carbide furnace workers, and electrode paste production workers. These groups of furnace workers and the electrode paste production workers were analyzed separately.

Study population

Men employed for the first time during 1 January 1933 to 31 December 1990 and at least 6 months in 1 of the 12

ferroalloy plants were eligible for the cohort. Altogether 4% (629 persons) of the primary cohort was excluded due to unknown vital status or death before the start of the observation period. The cohort then comprised 14 730 identified men. The variables recorded were name, date of birth, the 5-digit personal identification number, an identification number of the plant, up to 10 employment periods, and smoking habits (from medical records).

Information on individual causes of death and death dates were supplied by linking the cohort to Statistics Norway (the national registry for causes of death). Only the underlying cause of death was supplied and not contributory causes. The causes of death had been coded by Statistics Norway according to the Norwegian version of the International Classification of Diseases (ICD) in use at the time when the deaths occurred. The 7th to 9th editions of the ICD were used. The observation period was restricted to 1 January 1962 to 31 December 1990 due to lack of computerized detailed national cause-specific mortality rates before 1962.

The total cohort was observed for 288 886 person-years (table 1). The number of person-years of observation within each of the 4 main subgroups ranged from 45 314 to 72 692, and the number of workers from 2517 to 3695. The distributions by year of birth were almost identical in the 4 subgroups. The distribution by duration of work within the groups showed the shortest median and 95th percentile values for the 2 groups of furnace workers. A total of 3382 men had only worked in other departments and were not included in the 4 main subgroups.

Data analysis

The causes of death used in the analyses are presented together with the corresponding ICD codes, in table 2. The analyses of mortality from hypertension-related diseases comprise deaths from hypertensive disease, cerebrovascular disease and renal diseases (except those of the lower genitourinary tract).

Table 1. Some characteristics of the total cohort and four main subgroups. (FeSi/Si-met = ferrosilicon/silicon-metal, FeMn/SiMn = ferromanganese/silicomanganese)

Group of workers	Cohort		Year of birth			Duration of work (years)		
	N	Person-years	Median	5th percentile value	95th percentile value	Median	5th percentile value	95th percentile value
Total cohort	14 730	288 886	1934	1903	1963	5.4	0.7	35.8
Four main groups								
FeSi/Si-met furnace workers	2 517	45 314	1935	1904	1963	4.5	0.6	25.9
Nonfurnace workers ^a in FeSi/Si-met plants	3 695	72 692	1932	1903	1962	5.5	0.7	35.2
FeMn/SiMn furnace workers	3 086	60 741	1934	1905	1963	4.2	0.6	28.0
Nonfurnace workers ^a in FeMn/SiMn plants	3 119	62 863	1934	1905	1964	4.9	0.5	35.8

^a Comprise six main groups of blue-collar workers (mechanics, electricians, transport workers, raw material workers, packers and building and construction workers).

Table 2. Codes of the International Classification of Diseases (ICD) from the 7th to the 9th versions used in classifying the causes of death.

Cause of death	ICD-7 ^a	ICD-8 ^b	ICD-9 ^c
All circulatory diseases	400—468	390—458	390—459
Ischemic heart disease	420—422	410—414	410—414
Cerebrovascular disease	330—334	430—438	430—438
Hypertensive disease	440—447	400—404	401—405
Renal diseases	590—603	580—593	580—593
Sudden death	795	795	798

^a 1962—1968.

^b 1969—1985.

^c 1986—1990.

Table 3. Mortality from circulatory system diseases, renal diseases, and sudden death in the total cohort. (O = observed number of deaths, E = expected number of deaths, SMR = standardized mortality ratio, 95% CI = 95% confidence interval)

Cause of death	O	E	SMR	95% CI ^a
All circulatory diseases	1518	1499.60	1.01	0.96—1.06
Ischemic heart disease	999	1015.50	0.98	0.92—1.05
Cerebrovascular disease	295	278.23	1.06	0.95—1.19
Hypertensive disease	51	37.09	1.37	1.02—1.81
Renal diseases	26	30.52	0.85	0.56—1.25
Sudden death	172	111.15	1.55	1.33—1.80

Standardized mortality ratios for specific causes of death were calculated by comparing the observed numbers of deaths with the expected numbers. The expected numbers were calculated from 5-year age-specific rates for each year from 1962 through 1990 for the Norwegian male population. For all the standardized mortality ratios (SMR) a 95% confidence interval (95% CI) was calculated as presented elsewhere (5). The Epicure program package (7) was used to create event-time tables stratified by both fixed and time-dependent variables. Analyses of mortality in the time-related categories of employment status (active and inactive person-time) were performed (8). The active person-time comprises all person-time from the start of follow-up until the end of last employment (including periods off work before that point of time) added by 0.1 year, and inactive person-time is the remaining person-time of observation (5). If a man had worked as both a furnace and a nonfurnace worker he was included in both groups with the actual periods. A distinction between short- and long-term workers was made at 3 years' duration of work.

Internal comparisons of the rates were performed with the Poisson regression analysis with the Epicure program package (7). Confidence intervals (95%) for rate ratios (RR) and P-values for likelihood ratio tests and trend analysis were calculated by the program. The P-value for the trend analysis was calculated as the P-value for the likelihood ratio test when the variable was withdrawn from the final model after the categories of

the variable had been scored by their mean values. Rural-urban location was included in the regressions due to previous findings (5). As only 18.5% of the dead could be categorized as ever- or never-smokers, analyses of cardiovascular mortality by smoking habits were not performed.

Results

Mortality from ischemic heart disease and sudden death

The mortality from all diseases of the circulatory system was not increased in the total cohort (1518 deaths, SMR 1.01) (table 3). The SMR for ischemic heart disease was 0.98 (999 deaths). A significantly increased mortality from sudden death was found (SMR 1.55, 172 deaths). The sudden deaths were evenly distributed over the observation period. For ischemic heart disease and sudden death combined the SMR was 1.04 (95% CI 0.98—1.10).

Table 4 shows a significantly increased mortality from ischemic heart disease among short-term FeSi/Si-met furnace workers (SMR 1.35, 70 deaths), an excess of sudden deaths among the short-term furnace and nonfurnace workers in the FeSi/Si-met plants (SMR 2.36 and 2.45, respectively), and an increased mortality from sudden death among the long-term furnace workers both in the FeSi/Si-met plants (SMR 1.70) and in the FeMn/SiMn plants (SMR 2.16).

Further analyses of mortality from sudden death in 4 categories of duration of FeMn/SiMn furnace work (<3, 3—9, 10—19, ≥20 years) showed SMR values of 1.22 (95% CI 0.56—2.32), 1.61 (95% CI 0.77—2.96), 2.68 (95% CI 1.43—4.58), and 2.39 (95% CI 1.09—4.54), respectively (not shown). A Poisson regression analysis of mortality from sudden death adjusted for age, calendar time, duration of follow-up, and rural-urban location showed a significant increase in rate ratio of 0.050 per workyear ($P = 0.01$) for the FeMn/SiMn furnace workers and a nonsignificantly increasing rate ratio of 0.019 ($P = 0.35$) per workyear for the nonfurnace workers in the same plants. Similar analyses for both groups of workers in the FeSi/Si-met plants showed nonsignificantly decreasing rate ratios by increasing duration of work.

Table 5 shows that the mortality from sudden death during active person-time was significantly increased for the FeMn/SiMn furnace workers (SMR 2.47, 12 deaths) but not for any of the 3 other groups. Of the 12 sudden deaths in the active person-time category 6 occurred during 1962—1969, 3 during 1970—1979, and the 3 last deaths during 1980—1984.

Table 6 presents the analyses of mortality from ischemic heart disease and sudden death combined in the

Table 4. Mortality from some circulatory diseases, renal diseases, and sudden death within the four main groups of workers, categorized by duration of work. (O = observed number of death, E = expected number of death, SMR = standardized mortality ratio, 95% CI = 95% confidence interval, FeSi/Si-met = ferrosilicon/silicon-metal, FeMn/SiMn = ferromanganese/silicomanganese)

Cause of death	Duration of work in department							
	< 3 years				≥ 3 years			
	O	E	SMR	95% CI	O	E	SMR	95% CI
Ischemic heart disease								
FeSi/Si-met furnace workers (N = 2517)	70	51.93	1.35	1.05—1.70	121	110.74	1.09	0.91—1.31
Nonfurnace workers in FeSi/Si-met plants (N = 3695)	65	70.80	0.92	0.71—1.17	193	208.94	0.92	0.80—1.06
FeMn/SiMn furnace workers (N = 3086)	69	63.80	1.08	0.84—1.37	124	138.71	0.89	0.75—1.07
Nonfurnace workers in FeMn/SiMn plants (N = 3119)	66	59.39	1.11	0.86—1.41	130	140.16	0.93	0.78—1.10
Cerebrovascular disease								
FeSi/Si-met furnace workers (N = 2517)	10	12.43	0.80	0.39—1.48	34	30.55	1.11	0.77—1.56
Nonfurnace workers in FeSi/Si-met plants (N = 3695)	27	19.30	1.40	0.92—2.04	40	60.08	0.67	0.48—0.91
FeMn/SiMn furnace workers (N = 3086)	19	15.67	1.21	0.73—1.89	52	37.50	1.39	1.04—1.82
Nonfurnace workers in FeMn/SiMn plants (N = 3119)	16	14.80	1.08	0.62—1.76	31	37.44	0.83	0.56—1.18
Hypertensive disease								
FeSi/Si-met furnace workers (N = 2517)	3	1.85	1.63	0.34—4.75	6	4.06	1.48	0.54—3.21
Nonfurnace workers in FeSi/Si-met plants (N = 3695)	0	2.57	0.00	0.00—1.44	8	7.72	1.04	0.45—2.04
FeMn/SiMn furnace workers (N = 3086)	3	2.25	1.33	0.27—3.90	8	5.07	1.58	0.68—3.11
Nonfurnace workers in FeMn/SiMn plants (N = 3119)	3	2.10	1.43	0.29—4.17	11	5.06	2.18	1.09—3.89
Renal diseases								
FeSi/Si-met furnace workers (N = 2517)	2	1.58	1.27	0.15—4.58	4	3.25	1.23	0.34—3.16
Nonfurnace workers in FeSi/Si-met plants (N = 3695)	2	2.15	0.93	0.11—3.36	3	6.23	0.48	0.10—1.41
FeMn/SiMn furnace workers (N = 3086)	2	1.99	1.00	0.12—3.63	5	4.10	1.22	0.40—2.85
Nonfurnace workers in FeMn/SiMn plants (N = 3119)	3	1.88	1.60	0.33—4.67	1	4.26	0.23	0.01—1.31
Sudden death								
FeSi/Si-met furnace workers (N = 2517)	14	5.94	2.36	1.29—3.95	20	11.76	1.70	1.04—2.63
Nonfurnace workers in FeSi/Si-met plants (N = 3695)	20	8.15	2.45	1.50—3.79	25	22.10	1.13	0.73—1.67
FeMn/SiMn furnace workers (N = 3086)	9	7.36	1.22	0.56—2.32	32	14.81	2.16	1.48—3.05
Nonfurnace workers in FeMn/SiMn plants (N = 3119)	7	6.80	1.03	0.41—2.12	21	15.16	1.39	0.86—2.12

Table 5. Mortality from sudden death among all the employees and within the four main groups of workers in time-related categories of employment status (active and inactive person-time). (O = observed number of deaths, E = expected number of deaths, SMR = standardized mortality ratio, 95% CI = 95% confidence interval, FeSi/Si-met = ferrosilicon/silicon-metal, FeMn/SiMn = ferromanganese/silicomanganese)

Group of workers	Active person-time				Inactive person-time			
	O	E	SMR	95% CI	O	E	SMR	95% CI
Total cohort	33	30.12	1.10	0.75—1.54	139	81.01	1.72	1.45—2.03
Four main subgroups								
FeSi/Si-met furnace workers	4	3.85	1.04	0.28—2.66	30	13.85	2.17	1.46—3.09
Nonfurnace workers in FeSi/Si-met plants	6	8.37	0.72	0.26—1.56	39	21.87	1.78	1.27—2.44
FeMn/SiMn furnace workers	12	4.85	2.47	1.28—4.32	29	17.33	1.67	1.12—2.40
Nonfurnace workers in FeMn/SiMn plants	7	5.69	1.23	0.49—2.54	21	16.27	1.29	0.80—1.97

2 categories of employment status. The mortality was not increased for the workers in the active person-time category in any of the 4 groups. However, for the FeMn/SiMn furnace workers, the proportion of sudden deaths to all deaths from ischemic heart disease or sudden death was significantly elevated in the active person-time category (38.7%) when compared with the proportion in the

inactive person-time category (14.3%). The proportion of sudden deaths among the nonfurnace workers in the FeMn/SiMn plants was also (borderline) significantly elevated for the active person-time category (23.3%) when compared with the proportion for the inactive person-time category (10.8%). For the 2 groups of workers in the FeSi/Si-met plants no difference between active

Table 6. Mortality from ischemic heart disease and sudden death combined for active and inactive person-time within the four main groups of workers. (SMR = standardized mortality ratio, 95% CI = 95% confidence interval, FeSi/Si-met = ferrosilicon/silicon-metal, FeMn/SiMn = ferromanganese/silicomanganese)

Group of workers	Active person-time			Inactive person-time			P-value ^b
	SMR	95% CI	Proportion of sudden deaths ^a	SMR	95% CI	Proportion of sudden deaths ^a	
FeSi/Si-met furnace workers	0.93	0.62—1.33	4/29 (13.8%)	1.31	1.14—1.51	30/196 (15.3%)	0.83
Nonfurnace workers in FeSi/Si-met plants	0.63	0.45—0.85	6/43 (14.0%)	1.08	0.95—1.22	39/260 (15.0%)	0.86
FeMn/SiMn furnace workers	0.81	0.55—1.16	12/31 (38.7%)	1.09	0.95—1.25	29/203 (14.3%)	0.001
Nonfurnace workers in FeMn/SiMn plants	0.65	0.44—0.93	7/30 (23.3%)	1.11	0.96—1.27	21/194 (10.8%)	0.05

^a Proportion of sudden deaths among all deaths from ischemic heart disease and sudden death combined.

^b P-value for a difference between the proportions of sudden death calculated for the active and inactive person-time categories.

and inactive person-time was found regarding the proportions of sudden deaths.

Analyses of mortality in the groups of ferrochromium furnace workers (N = 522), calcium carbide furnace workers (N = 257), ferrovanadium furnace workers (N=66), and electrode paste production workers (N = 342) did not show significantly elevated mortality from any of the studied causes of death (not shown).

Mortality from hypertension-related diseases

In the total cohort the mortality from hypertensive disease was slightly increased (SMR 1.37, 51 deaths), while the mortality rates for cerebrovascular and renal diseases were as expected (table 3). Among the long-term workers an increased mortality from cerebrovascular disease was found for the FeMn/SiMn furnace workers (SMR 1.39, 52 deaths), as was an increase in hypertensive disease among the nonfurnace workers in the FeMn/SiMn plants (SMR 2.18, 11 deaths) (table 4). Stratified analyses of mortality from these 3 hypertension-related causes of death combined indicated increasing mortality by duration of work in both groups of furnace workers (not shown). These associations were further investigated with Poisson regression analyses (table 7). For the com-

bined group of FeSi/Si-met and FeMn/SiMn furnace workers a significantly increasing rate ratio of 0.020 per workyear (P = 0.05) was observed. The corresponding result for the 2 groups of nonfurnace workers was a significantly decreasing rate ratio of 0.022 per workyear (P = 0.01).

In other Poisson regression analyses of mortality from the 3 hypertension-related causes of death, we included all the 4 main groups of workers in the analyses. The groups were then defined exclusively, and each worker was defined as a nonfurnace worker only if he had never been a furnace worker. This procedure reduced the number of nonfurnace workers to 3354 (9.2%) in the FeSi/Si-met plants and to 2390 (23.4%) in the FeMn/SiMn plants. With adjustments for age, calendar time, length of follow-up, rural or urban location, group of workers, and duration of work within each work category, we found (in different analyses) an increased rate ratio for furnace work of ≥ 10 years compared with nonfurnace work of ≥ 10 years in both of the 2 types of plants. For the FeSi/Si-met plants this rate ratio became 2.11 (95% CI 1.21—3.70), and for the FeMn/SiMn plants it was 1.89 (95% CI 1.13—3.15). When the categories for ≥ 10 years' duration of work were compared between

Table 7. Mortality from cerebrovascular disease, hypertensive disease, and renal diseases combined and the rate ratios (RR) from the internal comparisons of duration of work categories with the slopes and P-values for mortality trends among the four main groups of workers. (O = observed number of deaths, 95% CI = 95% confidence interval, FeSi/Si-met = ferrosilicon/silicon-metal, FeMn/SiMn = ferromanganese/silicomanganese)

Group of workers	Duration of work in department								Slope ^a	P-value ^b
	< 3 years		3—9 years			≥ 10 years				
	O	RR ^c	O	RR	95% CI	O	RR	95% CI		
FeSi/Si-met furnace workers	15	1.00	19	1.40	0.69—2.82	25	1.63	0.84—3.17	0.019	0.23
Nonfurnace workers in FeSi/Si-met ^d plants	29	1.00	26	0.83	0.48—1.44	25	0.48	0.28—0.84	-0.036	0.005
FeMn/SiMn furnace workers	24	1.00	21	0.97	0.54—1.75	44	1.48	0.88—2.46	0.019	0.14
Nonfurnace workers in FeMn/SiMn plants	22	1.00	14	0.85	0.43—1.67	29	0.87	0.49—1.53	-0.006	0.62
Both groups of furnace workers	39	1.00	40	1.12	0.71—1.75	69	1.54	1.02—2.30	0.020	0.05
Both groups of nonfurnace workers ^d	51	1.00	40	0.82	0.54—1.25	54	0.62	0.42—0.92	-0.022	0.01

^a Proportional change in risk per workyear.

^b P-value for trend in RR.

^c RR values adjusted for age (< 60, 60—69, ≥ 70 years), calendar time (1962—1976, 1977—1990), duration of follow-up (< 3, 3—9, ≥ 10 years), and rural-urban location.

the 2 groups of furnace workers (FeMn/SiMn versus FeSi/Si-met) the rate ratio became 1.18 (95% CI 0.72—1.93).

Discussion

The main findings from this study were the increased mortality from sudden death among the FeMn/SiMn furnace workers and the association between mortality from hypertension-related diseases and the duration of furnace work, both for the FeSi/Si-met and the FeMn/SiMn workers. Previous studies of cause-specific mortality within the ferroalloy industry have only concerned workers in 2 ferrochromium producing plants (9, 10).

The main risk factors for coronary heart disease and sudden cardiac death are very similar (11—14). The precipitating factors for sudden cardiac death — possibly as the first manifestation of coronary heart disease — are less clear (13). In this study the sudden deaths were not only likely to include cardiac deaths, but also other natural causes of sudden death (pulmonary embolism, cerebrovascular disease, etc). However, it has been assumed that all sudden deaths without other explanation are attributable to coronary heart disease (11). Therefore, deaths from ischemic heart disease and sudden deaths were combined in some of the analyses.

In Norway, the rules for deciding the underlying cause of death have been much the same during the observation period even if the code numbers have varied through the 7th to the 9th ICD editions. Sudden death (*mors subita*) has only been used if no other relevant disease was known. This usage was also found in a previous Norwegian study (14) in which sudden death was the underlying cause of death for 50 men (10.3 per 100 000 observation years, age-adjusted), while this diagnosis was mentioned on the death certificate also for another 314 men. Hypertension as the underlying cause of death comprises mainly conditions in which hypertension is mentioned on the death certificate together with strictly defined cardiac or renal disease. In the earlier mentioned Norwegian study (14) 18 men (3.6 per 100 000 observation years, age-adjusted) had hypertension as the underlying cause of death, while hypertension was also mentioned for another 108 men.

In this study, the positive association between duration of work at the FeMn/SiMn furnaces and sudden death is of particular interest as the mortality from ischemic heart disease and sudden death combined was not increased or positively associated with duration of work. There was also an excess of sudden deaths for the active person-time category (SMR 2.47), for which the mortality from coronary heart disease and sudden death combined was not elevated (SMR 0.81). This finding

strongly indicates an association with work exposures. One would expect low SMR values for the active person-time category (8) due to “the healthy worker effect” (ie, an inappropriate comparison group for active person-time analyses).

Smoking, alcohol abuse, and elevated blood pressure are risk factors for sudden death (11—16). In this study, the influence of these factors could however not be evaluated. But it seems unlikely that the consumption of tobacco and alcohol was higher during the employment period than after employment or that these habits should be positively correlated with duration of furnace work. A potential effect on sudden death mortality from hypertension is more difficult to rule out. But it seems unlikely that elevated blood pressure would increase only sudden death mortality and not mortality from ischemic heart disease.

Work exposures to carbon monoxide, heat, and manganese could theoretically increase the mortality from sudden death. Deaths at work due to acute carbon monoxide exposure or heat stroke would be less likely misclassified as sudden deaths if they were suspected of being accidental, which, according to Norwegian legislation, would probably lead to an autopsy, which in turn could provide the real cause of such deaths. A detrimental effect of chronic exposure to carbon monoxide at a low level among persons with subclinical ischemic heart disease cannot however be ruled out. The level of individual exposure to carbon monoxide among FeMn/SiMn furnace workers is unknown, but it has probably not been high, as carbon monoxide has been continuously monitored through stationary sampling in the furnace houses with flashlights or alarms at concentrations of 30 or 50 ppm during most of the observation period.

The possibility that manganese exposure is associated with an increased risk of sudden death is speculative, but should be pursued. In animals the divalent, free manganese ion (Mn^{++}) can severely depress cardiac inotropy and chronotropy when present in high concentrations (3). Cardiotoxic effects are also reported to be the ultimate limiting factor when Mn^{++} is administered intravenously to humans (3). The effects of long-lasting exposures are however less clear. A Mn^{++} , intragastric rat-feeding study over 14 days (0.25 mmol/kg daily) resulted in increased myocardial contractility (4). Work exposure to manganese was estimated from 339 personal samples of total dust and total manganese during 1979—1991 in the largest of the FeMn/SiMn plants; the results showed decreasing values during this period (figure 1). This result is compatible with the observation that no sudden death occurred in the active person-time category among the FeMn/SiMn furnace workers after 1984. Because of a lack of data, we were unable to demonstrate a higher manganese exposure for furnace than for nonfurnace

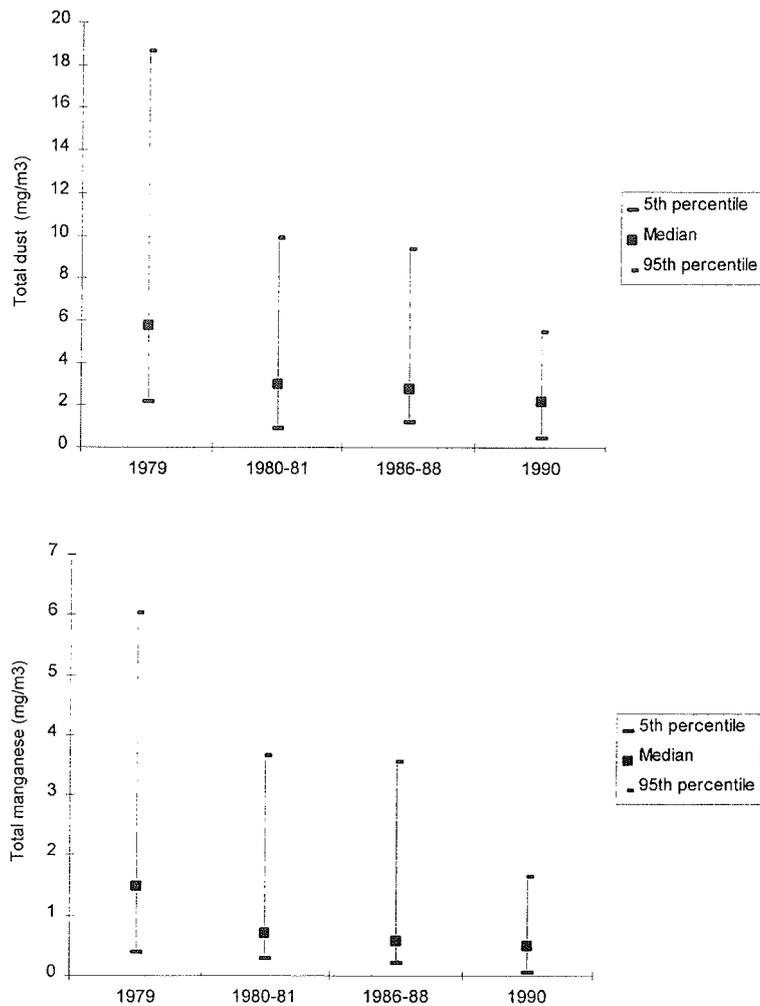


Figure 1. Personal measurements of total dust (mg/m³) and total manganese (mg/m³) exposure among the furnace workers during 1979—1990 in the largest of the FeMn/SiMn plants.

workers in the FeMn/SiMn plants. But we believe that such a difference exists. This assumption is also in agreement with the findings of an Italian study (17).

In regard to the hypertension-related causes of death, we included renal diseases since preliminary analyses indicated that the death diagnoses of hypertensive disease and renal disease might be inaccurately distinguished among employees in rural plants. The identical increase in the rate ratio per workyear in the FeSi/Si-met and FeMn/SiMn groups of furnace workers and the similar rate ratios when these groups were compared suggest that common exposures related to furnace work, rather than exposures to specific metals, may increase the mortality from hypertension-related diseases.

From studies in iron foundries and steel works associations have been reported between elevated blood pressure and exposure to heat or carbon monoxide (18—20). However, in a Norwegian study among workers in 1 of the FeSi/Si-met plants, no difference in blood pressure between heat- and nonheat-exposed workers was revealed (21). Psychological stress and shift work have been associated with cardiovascular diseases (2). Both

groups of furnace workers were shift workers, but so were some of the nonfurnace workers. Exposure to noise has been shown to increase blood pressure (22). It was not possible to evaluate, however, the influence of noise exposure on our results, but more than one-half of the noise measurements from one plant exceeded 85 dB(A).

As for most historical cohort mortality studies, several weak points may have distorted our results. The lack of real exposure data, the uncertain death diagnoses, and the use of national rates in the analyses for SMR probably attenuated any true exposure-response relationships.

The lack of data concerning possible confounding factors (eg, smoking, alcohol consumption, and employment or exposure data before and after employment in this industry) may both strengthen and attenuate real exposure-response associations. The internal comparisons are independent of external rates, but may be distorted if unequal distributions of confounding factors occur within a group (eg, FeMn/SiMn furnace workers). However, it seems unlikely that confounding factors are positively associated with the duration of work.

In summary, excess sudden deaths among FeMn/SiMn furnace workers have been observed. Associations with work exposures (manganese and possibly carbon monoxide and heat) are suspected. The increasing mortality from hypertension-related diseases with increasing duration of furnace work both in FeSi/Si-met and FeMn/SiMn plants may be related to common furnace work conditions (eg, heat, psychosocial stress, shift work, noise, carbon monoxide).

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