Incidence of leukaemia and brain tumours in some "electrical occupations"

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Abstract

A 19 year follow up study was conducted to explore the association between occupations expected to be exposed to electromagnetic fields and the occurrence of leukaemia and brain tumours. Incidence of cancer between 1961-79 was calculated and the standardised morbidity ratio (SMR) with a 95% confidence interval (95% CI) was related to that of all Swedish working men. For all the selected "electrical occupations" the SMRs for total leukaemia and brain tumours were near unity. Increased risks were noted for all leukaemia among electrical/electronic engineers and technicians, (SMR 1.3; 95% CI 1.0-1.7) as well as in the sub-groups of telegraph/telephone (2.1; 1.1-3.6) and machine (2.6; 1.0-5.8) industries. Risk for chronic lymphoid leukaemia was increased in the same occupational category (1.7; 1.1-2.5) and in the sub-group of machine industry (4.8; 1.0-14.0), as well as for all linesmen (2.0; 1.0-3.5) and power linesmen (2.8; 1.1-5.7). Risk for acute myeloid leukaemia was increased among all miners (2.2; 1.0-4.1) and miners working in iron/ore mines (5.7; 2.1-12.4). Increased risk for all brain tumours (2.9; 1.2-5.9) and glioblastomas (3.4; 1.1-8.0) appeared among assemblers and repairmen in radio and TV industry. Raised risk for all brain tumours was seen for all welders (1.3; 1.0-1.7) and welders in iron/steel works (3.2; 1.0-7.4) and risk for glioblastomas was also increased for all welders (1.5; 1.1-2.1). No major changes in relative risk estimates were noted after the exclusion of persons who were over 65 at the time of diagnosis. Although a homogeneous pattern of increased risks of leukaemia or

brain tumour was not noted, the hypothesis that magnetic fields might play a part in the origin of cancer cannot be rejected.

A substantial number of epidemiological studies have suggested an increased risk of cancer, particularly leukaemia and brain tumours, in various categories of "electrical occupations". Most of the leukaemia studies have been proportionate mortality ratio (PMR) or standard morbidity ratio (SMR) type studies based on job titles as they appear in censuses or registries based on routinely collected information. A possible relation between exposure to low frequency electric and magnetic fields and the incidence or mortality of leukaemia or brain tumours has been discussed. Several reviews have indicated the difficulties in finding a homogeneous pattern in the results presented. Furthermore, the lack of knowledge about which characteristics of the magnetic fields might be relevant and the lack of measurement of the fields, as well as of potential confounders, have been mentioned in the reviews.¹⁻⁵ Recently the question of an association between electromagnetic fields and adverse health effects was discussed in an editorial.⁶ The evidence of an association with cancer is inconclusive and results reported so far are contradictory.⁷

We have previously reported the cancer incidence in power linesmen and power station operators based on the Swedish census of 1960 and the cancer registry for the period 1961-79.⁸ We now report incidence of leukaemia and brain tumours in some other occupations, presumably exposed to electromagnetic fields, as well as incidence in occupational sub-cohorts in industries.

Material and methods

Every person living in Sweden is given an individual identification number at birth, or at the time of immigration, which is used as an identification code in most official registries. This makes it possible to link the census to medical registries. Thus, a cancer environment registry (CER) has been created through a record linkage between the cancer registry for the period 1961-79 and the census of 1960. The CER provides information about the number of

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specific cancer cases at different sites according to age, sex, occupation, industry, area of residence, and social state. The population by the same variables is given in the 1960 census.

The present study was based on Swedish working men aged 20–64 and working in an electrically related occupation according to the job title in the census. Eleven occupations were selected according to previous reports of increased risks for leukaemia or brain tumours. Also, five experienced occupational hygienists have estimated the magnetic field exposure, according to Swedish conditions, in the selected occupational categories. By using the industry code provided by the census, occupational sub-cohorts of more than 500 persons have been defined in 14 specific industries. Altogether, occupation and industry amounted to more than 30 combinations.

Cases of all leukaemia (International Classification of Diseases ICD code 204–209 7th revision) as well as sub-groups of acute myeloid (AML), chronic myeloid (CML), acute lymphoid (ALL), and chronic lymphoid leukaemia (CLL) were identified.

Cases of brain tumours (ICD code 193.0 7th

revision) restricted to glioma (astrocytoma I-II), glioblastoma (astrocytoma III-IV) and meningioma were also identified.

The identification of the sub-groups of leukaemia and brain tumours was made possible by combining the ICD code with the histopathological codes (PAD codes).

Observed numbers of cases of leukaemia and brain tumours in the occupations were compared with the corresponding expected numbers based on the cumulative incidence in the reference population. The reference population consisted of 1 905 660 Swedish working men born between 1896 and 1940.

Leukaemia and brain tumour risks have also been analysed after exclusion of persons who were aged over 65 at the date of diagnosis.

Control was made for age in five year classes, social class based on employment in three groups, population density in four different groups, and county. Standardised morbidity ratios (SMRs) were used for comparison and 95% confidence intervals (95% CIs) were assessed according to Rothman and Boice.⁹

To get some information on the magnitude of the

Table 1 Leukaemia*: observed no of cases (Obs), SMR, and 95% CI by occupation and industry sub-groups

Occupation: industry	No of workers	Total leukaemia			Myeloid leukaemia		
		Obs	SMR†	95% CI	Acute		
					Obs	SMR†	95% CI
Electrical/electronic engineers and technicians:	19170	62	1.3	1.0–1.7	6	0.8	0.3– 1.7
Machine industry	1173	6	2.6	1.0–5.8	1	2.5	0.0–14.6
Radio/TV industry	949	2	1.1	0.1–4.0	0		
Electronic industry	5575	15	1.1	0.6–1.8	1	0.5	0.0– 2.6
Electrical installation	979	2	0.8	0.1–2.8	0		
Electric power industry	3397	12	1.2	0.6–2.2	1	0.6	0.0– 3.5
Telegraph/telephone	1929	12	2.1	1.1–3.6	1	1.0	0.0– 5.8
Electricians; operators, installers:	34974	81	1.1	0.8–1.3	17	1.2	0.7– 1.9
Machine industry	1839	4	1.1	0.3–2.7	1	1.4	0.0– 7.8
Electronic industry	4243	10	1.2	0.6–2.2	1	0.6	0.0– 3.4
Electrical installation	11727	29	1.2	0.8–1.7	3	0.7	0.1– 1.9
Electric power industry	6748	17	1.0	0.6–1.6	7	2.3	0.9– 4.7
Linesmen:	8837	25	1.3	0.8–1.9	3	0.8	0.2– 2.4
Electric power industry	3358	10	1.2	0.6–2.3	1	0.6	0.0– 3.6
Telegraph/telephone	4192	13	1.5	0.8–2.6	1	0.6	0.0– 3.4
Tele-radio-TV assemblers and repairmen:	7770	15	1.1	0.6–1.8	4	1.5	0.4– 3.8
Radio/TV industry	1516	2	0.8	0.1–2.8	1	2.1	0.0–11.7
Electronics	975	2	1.2	0.1–4.4	0		
Telegraph/telephone	2155	7	1.4	0.5–2.8	1	1.0	0.0– 5.7
Electrical/electronics fitters including movie projectionists:	3705	10	1.2	0.6–2.2	2	1.3	0.1– 4.7
Electronic industry	2366	6	1.2	0.3–1.9	2	2.1	0.2– 7.5
Engine drivers, railway	7031	19	1.2	0.7–1.9	4	1.3	0.4– 3.4
Conductors, railway	14922	24	0.9	0.6–1.4	7	1.3	0.5– 2.6
Welders, and flame cutters:	21045	39	1.0	0.7–1.3	9	1.2	0.5– 2.2
Iron/steel industry	848	0			0		
Iron/steel manufacturing	4601	9	1.1	0.5–2.1	2	1.2	0.1– 4.3
Machine industry	6090	10	0.9	0.4–1.7	2	0.9	0.1– 3.2
Shipyard	2652	5	0.9	0.3–2.1	2	1.9	0.2– 6.8
Miners:	9021	34	1.4	0.9–1.9	9	2.2	1.0– 4.1
Iron/ore mine	2984	10	1.5	0.7–2.8	6	5.7	2.1–12.4
Stonequarry	1237	5	1.2	0.4–2.8	1	1.5	0.0– 8.3
Miners, including railway engine drivers:	2248	11	1.9	0.9–3.3	1	1.0	0.0– 5.6
Iron/ore mine	1082	3	1.2	0.2–3.6	0		
Furnacemen:	6256	14	0.8	0.4–1.4	4	1.7	0.4– 4.3
Iron/steel industry	4745	9	0.7	0.3–1.4	2	1.3	0.1– 4.7

*ICD 7th revision.

†Standardised morbidity ratio.

exposure to electromagnetic fields in occupational groups investigated here, some measurements have been performed. The frequency for measuring was 50 Hz except for the measurement of railway workers, which was performed at 16.66 Hz. The different instruments used were measuring at different detection levels.

Results

At the time of the census 133 687 men worked in the selected occupations. Several of the occupations were distributed in sub-groups by industries; mainly electrical installation, electrical power, electronics, telegraph/telephone, radio/TV and machine industries. Table 1 gives the number of workers in each occupation and in the occupational sub-cohorts by industry together with the observed number of cases of leukaemia, SMRs and 95% CIs. Table 2 presents corresponding numbers for brain tumour cases. Table 3 presents selected occupational categories. To qualify for entry into that table the lower limit of the confidence interval had to be close to or exceed unity. Table 4 presents magnetic field exposure. Each median value of the magnetic field represents one person during working hours.

LEUKAEMIA

In the CER 334 cases of leukaemia were recorded for the selected occupations during the study period. The distribution of histopathological sub-types of leukaemia for all selected occupations taken together was 20% for AML, 15% for CML, 2% for ALL, and 32% for CLL. The remaining 31% were coded in the CER as unspecified leukaemia.

The SMR estimate for leukaemia for all occupations taken together was only slightly raised. For the group in the census referred to as electrical/electronic engineers and technicians an excess risk was noted for all leukaemia and CLL with the lower confidence intervals just above unity. The sub-cohort of telegraph/telephone industry showed raised risks for all leukaemia and in the machine industry all leukaemia as well as CLL was increased, although this is based on rather small numbers, six and three cases respectively. All linesmen showed a twofold excess risk for CLL as did the sub-group of power linesmen. AML was raised among all miners and a close to sixfold increased risk was shown for the sub-group of iron ore miners, with nine and six cases respectively. The sub-cohort of miners, including engine drivers in mines, showed increased risks for all leukaemia

			<i>Lymphoid leukaemia</i>					
<i>Chronic</i>			<i>Acute</i>			<i>Chronic</i>		
<i>Obs</i>	<i>SMR†</i>	<i>95% CI</i>	<i>Obs</i>	<i>SMR†</i>	<i>95% CI</i>	<i>Obs</i>	<i>SMR†</i>	<i>95% CI</i>
9	1.2	0.5- 2.3	2	1.5	0.2- 5.4	26	1.7	1.1- 2.5
0			0			3	4.8	1.0-14.0
0			0			2	4.0	0.4-14.4
4	1.9	0.5- 4.7	0			0		
0			0			0		
1	0.7	0.0- 3.7	1	4.1	0.1-22.8	4	1.2	0.3- 3.1
3	3.8	0.8-11.1	0			3	1.5	0.3- 4.4
16	1.2	0.7- 2.0	2	1.0	0.1- 3.7	20	0.8	0.5- 1.2
0			0			1	0.8	0.0- 4.6
0			1	4.2	0.1-23.5	5	1.9	0.6- 4.5
5	1.1	0.4- 2.7	0			13	1.7	0.9- 2.9
4	1.5	0.4- 3.8	0			0		
1	0.3	0.0- 1.7	1	2.1	0.0-11.4	12	2.0	1.0- 3.5
0			0			7	2.8	1.1- 5.7
1	0.7	0.0- 3.7	1	4.3	0.1-23.9	5	1.9	0.6- 4.5
2	0.8	0.1- 2.9	0			6	1.4	0.5- 3.2
0			0			1	1.3	0.0- 7.4
0			0			2	4.6	0.5-16.7
2	2.3	0.3- 8.2	0			3	1.8	0.4- 5.3
2	1.5	0.2- 5.5	0			1	0.4	0.0- 2.1
1	1.3	0.0- 7.1	0			1	0.6	0.0- 3.4
2	0.8	0.1- 2.9	0			8	1.6	0.7- 3.1
4	0.9	0.1- 2.3	0			5	0.7	0.2- 1.6
6	0.8	0.3- 1.8	0			8	0.7	0.8- 2.2
0			0			0		
0			0			2	0.8	0.1- 3.0
3	1.5	0.3- 4.4	0			3	0.9	0.2- 2.7
1	1.0	0.0- 5.4	0			1	0.6	0.0- 3.5
5	1.3	0.4- 3.1	1	1.7	0.0- 9.7	11	1.2	0.6- 2.2
1	1.1	0.0- 6.0	0			2	0.8	0.1- 2.9
0			0			4	2.7	0.7- 6.9
2	2.3	0.3- 8.4	0			5	2.4	0.8- 5.5
1	3.3	0.0-18.3	0			2	2.2	0.2- 7.8
2	0.8	0.1- 2.8	1	2.4	0.3-13.5	5	0.8	0.0- 1.4
2	1.0	0.1- 3.8	0			4	0.8	0.2- 2.0

Table 2 Brain tumours: observed no of cases (Obs), SMR, and 95% CI by occupation and industry sub-groups

Occupation: industry	Brain tumours								
	All			Glioma			Glioblastoma		
	Obs	SMR	95% CI	Obs	SMR	95% CI	Obs	SMR	95% CI
Electrical/electronic engineers and technicians:	39	0.9	0.7-1.3	9	1.5	0.7- 2.8	20	0.8	0.5-1.2
Machine industry	5	2.2	0.7-5.1	0			3	2.1	0.4-6.1
Radio/TV industry	0			0			0		
Electronic industry	14	1.1	0.6-1.9	2	1.1	0.1- 4.1	10	1.3	0.6-2.3
Electrical installation	0			0			0		
Electric power industry	6	0.8	0.3-1.7	3	3.0	0.6- 8.8	3	0.6	0.1-1.8
Telegraph/telephone	2	0.4	0.0-1.5	1	1.6	0.0- 8.9	1	0.3	0.0-1.8
Electricians; operators, installers:	53	0.9	0.7-1.2	5	0.5	0.2- 1.2	34	0.9	0.6-1.3
Machine industry	1	0.3	0.0-1.7	0			1	0.5	0.0-2.6
Electronic industry	4	0.6	0.6-1.4	1	0.9	0.0- 4.8	3	0.7	0.1-2.0
Electrical installation	23	1.2	0.7-1.8	0			17	1.4	0.8-2.2
Electrical power industry	13	1.0	0.5-1.8	4	2.1	0.6- 5.5	5	0.6	0.2-1.5
Linesmen:	18	1.1	0.7-1.8	2	0.8	0.1- 2.9	11	1.1	0.6-2.0
Electric power industry	7	1.1	0.5-2.3	0			5	1.3	0.4-3.0
Telegraph/telephone	6	0.8	0.3-1.8	1	0.8	0.0- 4.5	4	0.9	0.2-2.2
Tele-radio-TV assemblers and repairmen:	15	1.2	0.7-2.0	0			11	1.4	0.7-2.5
Radio/TV industry	7	2.9	1.2-5.9	0			5	3.4	1.1-8.0
Electronics industry	3	2.0	0.4-5.7	0			3	3.2	0.6-9.2
Telegraph/telephone	4	1.0	0.3-2.5	0			2	0.7	0.1-2.7
Electrical/electronics fitters including movie projectionists:	6	0.9	0.3-2.0	0			5	1.2	0.4-2.8
Electronic industry	5	1.2	0.4-2.8	0			4	1.6	0.4-4.0
Engine drivers, railway conductors, railway welders, and flame cutters:	14	1.0	0.5-1.7	2	1.0	0.1- 3.7	9	1.0	0.4-1.9
	26	1.0	0.7-1.5	5	1.2	0.4- 2.9	16	0.9	0.5-1.5
Iron/steel industry	46	1.3	1.0-1.7	6	1.1	0.4- 2.3	34	1.5	1.1-2.1
Iron/steel manufacturing	5	3.2	1.0-7.4	1	4.8	0.1-26.5	2	2.0	0.2-7.3
Machine industry	7	1.0	0.4-2.0	1	0.8	0.0- 4.5	6	1.3	0.5-2.9
Shipyard	15	1.5	0.8-2.4	2	1.2	0.1- 4.5	12	1.8	0.9-3.2
Miners:	8	1.6	0.7-3.3	1	1.5	0.0- 8.6	5	1.6	0.5-3.8
Iron/ore mine	17	1.0	0.6-1.6	4	1.6	0.4- 4.1	10	1.0	0.5-1.8
Stonequarry	3	0.7	0.1-2.0	0			2	0.8	0.1-2.9
Miners including railway engine drivers:	1	0.4	0.0-2.0	0			1	0.5	0.0-3.0
Iron/ore mine	4	1.1	0.3-2.8	0			3	1.4	0.3-4.0
Furnacemen/metal converting:	2	1.4	0.2-4.9	0			2	2.5	0.3-9.2
Iron/steel industry	12	1.0	0.5-1.7	2	1.1	0.1- 4.1	6	0.8	0.3-1.7
	7	0.8	0.3-1.6	1	0.9	0.0- 4.7	4	0.7	0.2-1.8

and CLL with lower confidence intervals close to unity. A twofold excess risk for AML, based on seven cases, was seen among power station operators with a lower confidence interval close to unity.

BRAIN TUMOURS

Altogether, 250 cases of brain tumours were identified in the occupational groups. The histopathological sub-types of malignant brain tumours; glioma and glioblastoma, accounted for 14% and 64% respectively. Meningiomas represented 22% of the brain tumours analysed here.

Table 2 presents results of the analysis of malignant brain tumours; gliomas and glioblastomas. The relative risk estimate for all brain tumours for all occupations was unity. For the sub-cohort of assemblers and repairmen in the radio/TV industry a raised risk for all brain tumours occurred as well as for glioblastomas, although based on small numbers, seven and five cases respectively. An increased risk for the investigated brain tumour group (46 cases) and for glioblastomas (34 cases) was also found for all welders as well as for the sub-group of welders in the iron/steel industry.

Electrical/electronic engineers and technicians in

the machine industry showed a twofold increase in risk for all brain tumours and glioblastomas with five and three cases respectively.

Table 3 presents occupational sub-groups by industry with an increased relative risk for sub-types of leukaemia or brain tumours. None of the occupations investigated showed excess risks for both cancer sites.

RESULTS EXCLUDING THOSE MORE THAN 65 YEARS OLD
When reanalysing the occupational cohort for leukaemia and brain tumours diagnosed during working life, that is before 65 years of age, a reduction was found in leukaemia and brain tumour cases of 26% and 15% respectively. As a whole the SMRs changed only marginally, some increased and some decreased. Based on these data no clear tendency towards increased risks for persons to develop leukaemia or brain tumours earlier in life was seen.

MAGNETIC FIELD EXPOSURE

Table 4 shows the measurements of the magnetic fields. The median values vary considerably within as well as between the occupational groups. The highest as well as the lowest median exposure was noted

Table 3 Leukaemia and brain tumours: occupations and industry sub-groups with an increased SMR and lower CI at or above unity

Occupation: Industry sub-group	Leukaemia						Brain tumour			
	Total		Myeloid (acute)		Lymphoid (chronic)		Total		Glioblastoma	
	SMR	95% CI	SMR	95% CI	SMR	95% CI	SMR	95% CI	SMR	95% CI
Electrical/electronic engineers and technicians:	1.3	1.0-1.7	0.8	0.3- 1.7	1.7	1.1- 2.5	0.9	0.7-1.3	0.8	0.5-1.2
Telegraph/telephone	2.1	1.1-3.6	1.0	0.0- 5.8	1.5	0.3- 4.4	0.4	0.0-1.5	0.3	0.0-1.8
Machine	2.6	1.0-5.8	2.6	0.0-14.6	4.8	1.0-14.0	2.2	0.7-5.1	2.1	0.4-6.0
Linesmen:	1.3	0.8-1.9	0.8	0.2- 2.4	2.0	1.0- 3.5	1.1	0.7-1.8	1.1	0.6-2.0
Electric power	1.2	0.6-2.3	0.6	0.0- 3.6	2.8	1.1- 5.7	1.1	0.5-2.3	1.3	0.4-3.0
Tele-radio-TV assemblers and repairmen:	1.1	0.6-1.8	1.5	0.4- 3.8	1.4	0.5- 3.2	1.2	0.7-2.0	1.4	0.7-2.5
Radio/TV	0.8	0.1-2.8	2.1	0.0-11.7	1.3	0.0- 7.4	2.9	1.2-5.9	3.4	1.1-8.0
Welders and flame cutters:	1.0	0.7-1.3	1.2	0.5- 2.2	0.7	0.3- 1.3	1.3	1.0-1.7	1.5	1.1-2.1
Iron/steel works							3.2	1.0-7.4	2.0	0.2-7.3
Miners:	1.4	0.9-1.9	2.2	1.0- 4.1	1.2	0.6- 2.2	1.0	0.6-1.6	1.0	0.5-1.8
Iron ore mine	1.5	0.7-2.8	5.7	2.1-12.4	0.8	0.1- 2.9	0.7	0.1-2.0	0.8	0.1-3.0

amongst linesmen in the electric power industry. Railroad workers spent most of their working hours exposed to fields exceeding 0.35 μ T.

Discussion

We report raised risks of all leukaemia, CLL, AML, all brain tumours and glioblastomas in some occupations in which exposure to electromagnetic fields are expected. Because this study is based on the job titles in the 1960 census and no information on job turnover is available, results should be considered with caution. In particular we have very limited information on intensity and duration of exposure to magnetic fields and other potential risk factors, which most likely vary considerably within as well as between the occupational categories we have studied here.

CHRONIC LYMPHOID LEUKAEMIA

Increased risks for total, acute, and myeloid leukaemia in occupations like electrical/electronic engineers, power and telephone linesmen, and radio-telegraph operators were reported as the most consistent findings in one of the reviews,³ but CLL, which we found increased among electrical/electronic engineers and power linesmen, had not been reported.

Our findings of increased risks of CLL in electrical workers are supported in a recent case-referent study.¹⁰ An association between CLL and electrical line work, including both power and telegraph/telephone linesmen, was earlier reported in a population based study in Sweden.¹¹ Investigation of CLL in a case-referent study showed no increased risk for electrical workers.¹²

ACUTE MYELOID LEUKAEMIA

Increased risk of AML was reported among electrical

technicians and electrical welders in an earlier Swedish case-referent study.¹³ This result was not confirmed in our study. Magnetic field exposure in underground mines and increased risk of leukaemia have been reported in a case-referent study.¹⁴ Our results support their findings of increased AML and CLL among miners.

BRAIN TUMOUR

Assemblers and repairmen in the radio/TV industry showed increased risk for all brain tumours as well as glioblastomas. This agrees with results in earlier reports of increased risks of brain tumours in electrically related jobs.^{15,16}

A study of incidence of cancer among welders found no increased risk for leukaemia,¹⁷ which agrees with our results. Increased brain tumour risks among welders were not noted in that study.

EXPOSURE

Published occupational studies on "electrical occupations" have been criticised for the lack of information about the exposure to magnetic fields as well as to other potential carcinogens.

Spot measurements in several occupations have been presented in a study where the authors emphasised the great variability of magnetic field exposure within as well as between "electrical occupations" and the importance of time weighted average exposures and full shift monitoring.¹⁸

We found that workers in most occupations selected for this study were distributed over many industries representing various working environments with different potential confounders. Table 4 presents the measurement of magnetic fields over four to eight hours. Within the various occupations work tasks exist giving high exposure levels, for instance linesmen testing isolators on 400 kV lines,¹⁹ and power station operators working on circuit break-

Table 4 Measurements of 50 Hz magnetic field exposure in studied occupations. (Dosimetry, each value represents one person.)

Occupation	Industry	Magnetic field (μT)		Hours: min of measurement	
		Median	% Of time at exposure $< 0.35 \mu T$		
Power station operators	Electrical power	From prospective study			
		5-10	18	5:24	
		3-25	8	7:14	
		5-15	32	5:55	
		0-16	55	8:14	
		1-35	42	7:04	
		0-14	90	6:07	
		1-09	34	6:46	
		3-16	21	6:16	
		0-37	57	8:20	
Linesmen	Electrical power	2-02	17	7:30	
		< 0.04	100	8:20	
		0-15	68	7:32	
		0-10	88	8:06	
		< 0.04	85	8:20	
		0-44	48	6:26	
		< 0.35	100	6:59	
		1-91	0	6:43	
		15-64	2	4:00	
		16-54	4	4:06	
Electricians'/general electrical repairmen and installers	Electrical installation	0-78	5	6:59	
		From pilot study			
		< 0.35	95	7:46	
		< 0.35	67	6:24	
		< 0.35	68	6:59	
		< 0.35	91	6:27	
		0-12	88	7:18	
		0-05	99	7:11	
		0-07	86	7:38	
		0-04	100	6:20	
Tele-radio and TV assemblers and repairmen	Telegraph-telephone	0-11	99	6:47	
		0-09	97	7:14	
		< 0.04	100	7:51	
		TV industry	< 0.35	70	5:30
		Telegraph-telephone	0-08	94	7:47
Electrical/electronics fitters including movie projectionists	TV industry	0-05	99	7:50	
		< 0.35	77	5:28	
Conductors	Railway	0-53	24	3:42	
		0-85	16	17:52	
		3-29*	< 1	8 $\times$ 5 min†	
Engine drivers	Railway	2-67*	< 1	6 $\times$ 5 min†	
		2-90*	3	3:47	
		0-75	15	17:52	
Welders	Shipyards	0-48	42	8:03	
	Machine	< 0.35	90	6:16	
Miners	Iron ore mine	< 0.35	80	4:51	
		< 0.35	99	2:18	
		< 0.35	62	4:53	
		< 0.35	65	3:35	
		< 0.35	100	5:15	
		< 0.35	100	4:30	
		< 0.35	100	5:15	

*16-66 Hz.

†Spot measurements.

ers.²⁰ Other occupations in a work environment with magnetic field exposures are railroad engine drivers and conductors where the sources of exposure are the electric power line and the engine. Measured magnetic fields for railway workers showed median values ranging from 2–17 μT . These occupational categories are most likely a homogeneous group in relation to magnetic field exposure with levels between 2–4 μT as presented in table 4. Besides, no

other occupational carcinogenic agents are known or expected in that work environment.

Welders are exposed to magnetic fields at work but because the arc time (the time that welding actually occurs) is less than 50% of the measurement time the median value is fairly low. The arc time fields are in the range of 10–10 000 μT , however, and in some cases even more. Depending on the method of welding and the welded material, agents like alumin-

ium, hexavalent chromium, and other metal compounds could be present.²¹

Among occupations with increased risks in this study, power linesmen at 400 kV lines (highest voltage in Sweden) and welders probably have the highest magnetic field exposures. If magnetic fields were the cause of leukaemia and brain tumours, the same effect would be expected in both occupations. However, we found increased lymphoid leukaemia but not the earlier reported myeloid leukaemia, among power linesmen, and increased malignant brain tumour risks among welders.

Radio/TV repairmen within the TV industry are at increased risk of malignant brain tumours but presumably not exposed to such high magnetic fields as the welders. On the other hand furnacemen who are expected to be highly exposed to magnetic fields, as they are working near induction heaters, did not show any increased risk. The most homogeneous occupations with a high magnetic field exposure are the railway categories (see table 4), but no increased risks of leukaemia or brain tumour were found here.

Increased risks of leukaemia among electrical engineers have been reported with some consistency over several studies. Electrical engineers, however, are most likely a heterogeneous group in relation to magnetic field exposure; many may have no exposure as they generally work in an office environment.

In summary, no homogeneous pattern of increased risks of leukaemia or brain tumour in occupations with a presumed exposure to high magnetic fields was found in this study. The study has a limited power of resolution, however, and, based on the present data, we cannot so far reject the hypothesis that magnetic fields might play a part in the origin of cancer.²²

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