ORIGINAL ARTICLE

Cancer incidence and magnetic field exposure in industries using resistance welding in Sweden

N Håkansson, B Floderus, P Gustavsson, C Johansen, J H Olsen

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See end of article for authors' affiliations

Correspondence to:
N Håkansson, Institute of Environmental Medicine, Karolinska Institutet, Box 210, S-171 77 Stockholm, Sweden;
niclas.hakansson@imm.ki.se

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Aims: To investigate cancer incidence in workers exposed to high levels of extremely low frequency magnetic fields (ELF-MF).
Methods: A cohort based on the engineering industry was established. Industries assumed to use resistance welding in production were chosen in order to increase the prevalence of high exposed subjects and to reduce the influence of confounding factors. All men and women employed in these branches during 1985–94 were selected, 537 692 men and 180 529 women. Occupation, based on census information from 1980, 1985, and 1990, was linked to a job exposure matrix on ELF-MF. Four exposure groups were used by stratifying on mean workday ELF-MF exposure, using the lowest exposure group as reference. Cancer incidence was obtained by linkage to the Swedish Cancer Registry.
Results: Men in the very high exposure group showed an increased incidence of tumours of the kidney, pituitary gland, and biliary passages and liver; for these cancer sites an exposure–response relation was indicated. Women in the very high exposure group showed an increased incidence of astrocytoma I–IV, with a clear exposure–response pattern. An association was suggested in the high exposure group only, for cancer of the corpus uteri and multiple myeloma. Decreased risks in the very high exposure group among men were found for cancer of the colon and connective tissue/muscle.
Conclusions: The results on cancer of the liver, kidney, and pituitary gland among men are in accordance with previous observations. Regarding brain tumours and leukaemia, the outcome for women provided further support of an association. The hypothesis of a biological mechanism involving the endocrine system was partly supported.

Epidemiological studies have shown an association between occupational exposure to extremely low frequency (ELF; <300 Hz) magnetic fields (MF) and certain cancers, such as leukaemia and cancer of the nervous system (mostly brain tumours).[1–3] The findings show inconsistencies and indicate only a small increase in risk among exposed subjects. If the associations between ELF-MF and cancer were causal, the risk of developing cancer would be expected to follow an exposure–response pattern and should be evident in occupations with very high exposure levels.

In general, welders are exposed to extremely high levels of ELF-MF, with a geometric mean of workday mean values estimated at 1.12 μT,[4] compared with the exposure distribution of male workers. There are considerable variations in the exposure, however, depending on work tasks, different electrical equipment, etc.[5] Studies on welders have not shown consistent results for the cancers most often discussed in association with ELF-MF (brain tumours and leukaemia). Calle and Savitz investigated acute lymphocytic leukaemia in welders and did not find an excess risk.[6] One study of brain tumours, based on very few cases, showed no association.[7] Based on 50 exposed cases, Englund *et al* reported a slightly increased risk of brain tumours among Swedish welders.[8] This finding was not confirmed in a later study among US welders.[9] For glioma and astrocytoma of grade III–IV (glioblastoma), an association with welding was indicated in two other Swedish studies.[10 11] With regard to lung cancer, studies on welders are not consistent, but indicate an increased risk for welding in stainless steel.[12–14] Few other malignancies, besides non-Hodgkin's lymphoma,[7 9] have been linked to welding. This could, of course, partly be explained by the difficulty to set up studies with a sufficient statistical power.

In a previous population based Swedish cohort study of ELF-MF (not overlapping the present study base), weak associations were observed for several cancer sites.[15] Among men, associations were found for cancer of the colon, biliary passages and liver, larynx and lung, testis, kidney, urinary bladder, malignant melanoma, non-melanoma skin cancer, and astrocytoma III–IV. For women, associations were seen for cancer of the lung, breast, corpus uteri, malignant melanoma, and chronic lymphocytic leukaemia.

The aim of the present study was to investigate site specific cancer incidence in relation to ELF-MF exposure, restricting the study base in order to increase the fraction of workers with an extremely high exposure to ELF-MF. We wanted to test to what extent previous findings could be verified, and also to investigate exposure–response relations across exposure strata.

A cohort with an increased prevalence of resistance welders (welding by pressure) was established. Resistance welders are exposed to extremely high levels of ELF-MF. The process involves electrical currents as high as 1000–100 000 Ampere, yielding peak exposures in the milliTesla range.[16] There are five major types of resistance welding: spot welding, flash welding, butt welding, projection welding, and seam welding. The technique is used in various types of production; some examples of the most common are the car industry, manufacturing of radio and television transmitters, and manufacturing of metal equipment (such as kitchen sinks, metal signs, and thermos flasks).

Another reason for focusing on this type of industry was to reduce the potential for confounding. Exposures to potential carcinogenic agents occurring in connection with welding by fusion (welding fumes) are less prevalent among resistance

Abbreviations: ELF, extremely low frequency; JEM, job exposure matrix; MF, magnetic field; RR, relative risk

Table 1 Description of the cohort of engineering industry workers (number of subjects, cancer events, and deaths, by exposure category)

	Men				Women			
Exposure	No. of subjects*	Person years	No. of first cancer events	No. of deaths	No. of subjects*	Person years	No. of first cancer events	No. of deaths
Low	94706	734541	1947	2840	56801	436388	1127	672
Medium	257171	2116042	4542	6252	71765	577498	1490	960
High	72437	550055	1194	1715	28184	214486	670	411
Very high	60329	485560	912	1513	5301	42142	115	70
Total	484643	3886198	8595	12320	162051	1270514	3402	2113
Subjects with exposure information missing	53049	273965	213	707	18478	100489	123	159
Grand total	537692	4160163	8808	13027	180529	1371003	3525	2272

*The exposure classification may change during the study period, the numbers given refer to the highest exposure values.

welders, who should have a comparatively clean work environment.

MATERIALS AND METHODS

The first step in the formation of the cohort was to identify industrial branches where resistance welding could take place. The list of standard codes of branches used in Sweden (SNI 92) was scrutinised in order to select relevant branches. Around 40 types of branches were selected. The second step was to identify all companies and workplaces within these branches during the study period, by searching the "BASUN" registry at Statistics Sweden, for the years 1985–94. The reason for starting the study period in 1985 was that the BASUN registry was not available before this year, and 1985 also meant no overlapping with the previous study.[15] Two different coding systems (SNI69, SNI92) had to be taken into account in order to find the workplaces. Thirdly, the file of income tax returns for each year, 1985 to 1994, was searched to identify the cohort—that is, all subjects ever employed during 1984–94 at any of the selected workplaces, no matter what their work tasks had been. The cohort comprised 537 692 men and 180 529 women.

Information on occupation was obtained from the censuses of 1980, 1985, and 1990. The censuses provide occupational codes corresponding to the Nordic version of the international standard for classification of occupations (ISCO), as it was used in the census of 1980. We also utilised the work descriptions given in text by the subjects in their income tax returns; this enabled us to identify additional resistance welders—that is, those who had specified resistance welding but who showed an occupational code other than "welder". These subjects were also allocated to the highest exposure group in the analyses.

Occupation specific levels of exposure were obtained from a previously elaborated job exposure matrix (JEM), comprising the 100 most common occupations (among men) in Sweden.[4] In order to increase the number of subjects and occupations in the analysis, we used additional exposure information for some rare occupations.[17] The exposure metric used in the analysis was the geometric mean of average workday mean values. The geometric mean was used because it decreases the influence of outliers. Cut offs were determined from the exposure distribution for men and women in 1985. Cut offs at the 25th, 75th, and 90th centiles gave four exposure groups: low exposure (<0.1636 μT), medium exposure (0.1637–0.2500 μT), high exposure (0.2501–0.5300 μT), and very high exposure (>0.5301 μT). Approximately 75% of the very high exposure group were welders.

To increase the number of women in the analysis, we classified and added three occupations common among women, and not included in the JEM: "domestic service" (low exposure), "computer operator, computress", and "other needlework" (high exposure). These classifications were based on comparisons with similar occupations in the JEM and were also supported by unpublished exposure measurements.

There were 53 049 (10%) men and 18 478 (10%) women for whom there was no information on occupation, for example, those entering working life after the 1990 census, or where the exposure could not be estimated. These subjects were excluded from the analysis. Table 1 shows some characteristics of the cohort.

If a subject, according to the three censuses, changed from a higher to a lower exposure level during the study period, the higher level was retained for the subject. If information was lacking for a certain census year, the information from a previous census was used—that is, if there was no useful information from either 1985 or 1990, we used data from 1980, if available.

The cohort was matched against the Cancer Registry for the years 1985–94. Mortality data up to 1994 were obtained from

Table 2 Relative risk (RR) of all cancer, cancer of the nervous system, and leukaemia in relation to occupational ELF-MF exposure

	Men Exposure, µT							Women Exposure, µT						
	Low <0.164	Medium 0.164–0.250		High 0.250–0.530		Very high >0.530		Low <0.164	Medium 0.164–0.250		High 0.250–0.530		Very high >0.530	
Site, ICD7	n	n	RR* (95% CI)	n	RR* (95% CI)	n	RR* (95% CI)	n	n	RR* (95% CI)	n	RR* (95% CI)	n	RR* (95% CI)
All cancer, 140–209	1947	4542	0.9 (0.9 to 1.0)	1194	1.0 (0.9 to 1.1)	912	0.9 (0.9 to 1.0)	1127	1490	1.0 (1.0 to 1.1)	670	1.1 (1.0 to 1.3)	115	1.1 (0.9 to 1.3)
Nervous system, 193	105	256	0.9 (0.7 to 1.1)	90	1.2 (0.9 to 1.6)	47	0.8 (0.5 to 1.1)	51	76	1.2 (0.8 to 1.7)	40	1.6 (1.0 to 2.4)	9	1.9 (0.9 to 3.9)
Astrocytoma I–IV, 193 (pad† 475–476)	61	134	0.8 (0.6 to 1.1)	50	1.2 (0.8 to 1.7)	31	0.9 (0.6 to 1.3)	18	24	1.1 (0.6 to 2.0)	19	2.3 (1.1 to 4.4)	5	3.0 (1.1 to 8.6)
Astrocytoma I–II, 193 (pad† 475)	15	37	0.9 (0.5 to 1.6)	15	1.4 (0.7 to 2.9)	14	1.6 (0.8 to 3.4)	9	7	0.7 (0.2 to 1.9)	10	2.7 (1.0 to 7.1)	1	1.3 (0.2 to 10.9)
Astrocytoma III–IV, 193 (pad† 476)	46	97	0.8 (0.6 to 1.1)	35	1.1 (0.7 to 1.7)	17	0.6 (0.4 to 1.1)	9	17	1.4 (0.6 to 3.3)	9	1.9 (0.7 to 4.9)	4	4.6 (1.3 to 15.9)
All leukaemia, 204–205	54	45	0.8 (0.6 to 1.1)	26	0.8 (0.5 to 1.3)	26	0.9 (0.6 to 1.5)	11	16	1.1 (0.5 to 2.4)	12	2.0 (0.8 to 4.6)	2	1.8 (0.4 to 8.5)
Lymphocytic leukaemia, 204	21	51	1.0 (0.6 to 1.6)	8	0.7 (0.3 to 1.5)	11	1.0 (0.5 to 2.1)	3	5	1.5 (0.3 to 6.5)	3	2.3 (0.4 to 12.3)	0	
Acute lymphocytic leukaemia, 204.0	5	12	0.9 (0.3 to 2.4)	3	0.8 (0.2 to 3.5)	2	0.7 (0.1 to 3.6)	0	2		0		0	
Chronic lymphocytic leukaemia, 204.1	16	39	1.0 (0.6 to 1.8)	5	0.6 (0.2 to 1.6)	9	1.1 (0.5 to 2.6)	3	3	1.0 (0.2 to 5.3)	3	2.8 (0.5 to 15.0)	0	
Myeloid leukaemia, 205	33	64	0.7 (0.5 to 1.1)	18	0.9 (0.5 to 1.6)	15	0.9 (0.5 to 1.7)	8	11	0.9 (0.4 to 2.4)	9	1.8 (0.7 to 5.0)	2	2.2 (0.4 to 10.8)
Acute myeloid leukaemia, 205.0	27	32	0.5 (0.3 to 0.8)	12	0.7 (0.4 to 1.4)	11	0.8 (0.4 to 1.7)	7	5	0.5 (0.1 to 1.6)	6	1.4 (0.4 to 4.4)	1	1.3 (0.1 to 10.8)
Chronic myeloid leukaemia, 205.1	5	27	2.0 (0.8 to 5.2)	6	2.2 (0.7 to 6.9)	4	1.5 (0.4 to 5.9)	1	6	4.1 (0.5 to 35.7)	3	5.0 (0.5 to 51.1)	1	8.6 (0.5 to 148.6)

*Adjusted for age and socioeconomic status; †histopathology code.

the Causes of Death Registry. In total, 11 997 subjects had one or more cancer events, and 14 433 died during the study period. We calculated relative risk estimates (RR) based on Cox regression.[18 19] All risk estimates were computed using the SAS Software.[20] In the Cox regression the basic time dimension was calendar years, and the subjects were considered to be at risk from entry to end of follow up, year of death, or year of diagnosis, whichever came first. The four exposure levels were entered as three dummy variables into the regression model. Age was entered into the model by 10 year groups based on age at start of follow up. We also used a socioeconomic variable in the analyses, roughly divided in two categories: blue collar workers and others. By means of Cox regression we also evaluated potential exposure–response associations, by tests of trends with the assumption of equal distance between the four exposure levels.

RESULTS

All cancer, cancer of the nervous system, and leukaemia

The incidence of cancer (all sites) was equivalent across all exposure groups for men (table 2). A similar outcome seemed to pertain to women, but because of the high statistical power, the slight increase in risk with increasing exposure yielded $p = 0.017$ in the test for trend.

There was no indication of an increased risk among high exposed men for tumours of the nervous system, or for the subgroup of astrocytoma III–IV. For astrocytoma I–II, however, an association was indicated with $p = 0.076$ in the test for trend. This result was mainly attributable to men below 30 years of age ($RR_{High} = 10.0$ (95% CI 1.2 to 83.3) and $RR_{Very\ high} = 9.8$ (95% CI 1.1 to 86.2), with only one of the 22 cases in the reference group). Among women there was an increasing risk of brain tumours with increasing level of exposure: test for trend, $p = 0.004$ (all astrocytoma), and a threefold increase in risk (based on five cases) in the very high exposure group.

With respect to lymphocytic and myeloid leukaemia combined, no increase in risk was seen for men in the high exposure groups. For women an increased relative risk was suggested in the two highest exposure groups, but the precision was low; for trend, $p = 0.120$. For the more detailed diagnoses of leukaemia the number of cases was small; more cases of chronic myeloid leukaemia were found among exposed men and also women.

Other cancer sites with previous suggestions of an association

For men we found an association between ELF-MF and tumours of the kidney in the very high exposure group (table 3). The RR across exposure groups showed an exposure response pattern ($p = 0.044$). An association was also indicated for tumours of the biliary passages and liver, and for tumours of the pituitary gland; the test for trend yielded p values of 0.087 and 0.057, respectively. The outcome among women gave some support for an association with liver cancer and pituitary tumours, while no support was added regarding kidney cancer.

In all, there were 12 cases of male breast cancer, with one case occurring in the reference category, yielding a threefold increase in risk in the exposure groups. Among women, the risk of breast cancer was only marginally increased in the high and very high exposure groups. No increased risk was seen for testicular cancer among exposed men; for women the risk of cancer of the corpus uteri was slightly increased in the high exposure group, with $p = 0.150$ in the test for trend.

No exposure response pattern was shown for lung cancer of either sex; the incidence was marginally increased among men of the very high exposure group, and among women of the medium and high exposure groups. For laryngeal cancer

Table 3 Relative risk (RR) of cancer in relation to occupational ELF-MF exposure; cancer sites with previous suggestion of an association with ELF-MF

	Men Exposure, μT							Women Exposure, μT						
	Low <0.164	Medium 0.164–0.250		High 0.250–0.530		Very high >0.530		Low <0.164	Medium 0.164–0.250		High 0.250–0.530		Very high >0.530	
Site, ICD7	n	n	RR* (95% CI)	n	RR* (95% CI)	n	RR* (95% CI)	n	n	RR* (95% CI)	n	RR* (95% CI)	n	RR* (95% CI)
Colon, 153	139	285	0.8 (0.7 to 1.0)	74	0.9 (0.6 to 1.1)	46	0.7 (0.5 to 0.9)	57	51	0.6 (0.4 to 1.0)	38	1.1 (0.7 to 1.7)	6	1.0 (0.4 to 2.3)
Liver and biliary passages, 155	29	88	1.3 (0.8 to 1.9)	24	1.4 (0.8 to 2.4)	22	1.6 (0.9 to 2.8)	16	29	1.3 (0.7 to 2.4)	12	1.2 (0.6 to 2.7)	2	1.2 (0.3 to 5.3)
Liver, not specified as primary, 156	5	17	1.4 (0.5 to 3.7)	6	1.8 (0.5 to 5.9)	4	1.4 (0.4 to 5.4)	1	2	1.5 (0.1 to 18.6)	1	2.0 (0.1 to 35.7)	1	11.2 (0.5 to 230.7)
Larynx, 161	18	54	1.2 (0.7 to 2.1)	20	1.7 (0.9 to 3.3)	7	0.7 (0.3 to 1.7)	0	3		0		0	
Trachea, bronchus, lung, and pleura, 162	207	544	1.1 (0.9 to 1.2)	135	1.0 (0.8 to 1.3)	117	1.1 (0.9 to 1.4)	52	89	1.3 (0.9 to 1.8)	41	1.3 (0.9 to 2.1)	5	0.9 (0.4 to 2.4)
Lung, not specified as primary, 163	3	9	1.1 (0.3 to 4.1)	1	0.4 (0.0 to 4.3)	6	3.0 (0.7 to 12.3)	0	1		2		0	
Breast, 170	1	7	2.9 (0.4 to 23.4)	2	3.1 (0.3 to 34.2)	2	3.8 (0.3 to 43.5)	402	492	1.0 (0.9 to 1.2)	221	1.1 (0.9 to 1.3)	37	1.1 (0.8 to 1.5)
Corpus uteri, 172								53	85	1.2 (0.8 to 1.7)	42	1.4 (0.9 to 2.2)	6	1.2 (0.5 to 2.7)
Testis, 178	51	181	1.2 (0.9 to 1.7)	38	1.0 (0.6 to 1.5)	23	0.7 (0.4 to 1.1)							
Kidney, 180	81	207	1.0 (0.8 to 1.3)	56	1.1 (0.8 to 1.5)	62	1.4 (1.0 to 2.0)	29	29	0.6 (0.4 to 1.1)	15	0.7 (0.4 to 1.4)	4	1.1 (0.4 to 3.1)
Urinary organs (excl. kidney), 181	118	367	1.3 (1.0 to 1.5)	78	1.1 (0.8 to 1.4)	46	0.8 (0.6 to 1.1)	23	27	0.9 (0.5 to 1.7)	13	1.1 (0.5 to 2.2)	2	1.0 (0.2 to 4.3)
Malignant melanoma of skin, 190	117	274	0.9 (0.7 to 1.1)	92	1.2 (0.9 to 1.6)	37	0.7 (0.5 to 1.0)	73	70	0.8 (0.6 to 1.1)	26	0.8 (0.5 to 1.2)	2	0.3 (0.1 to 1.3)
Skin (melanoma excl.), 191	49	134	1.1 (0.8 to 1.6)	38	1.3 (0.9 to 2.0)	22	1.0 (0.6 to 1.6)	16	21	1.1 (0.5 to 2.1)	6	0.7 (0.3 to 2.0)	3	2.3 (0.6 to 8.2)
Pituitary, 195.3	8	31	1.4 (0.6 to 3.0)	9	1.6 (0.6 to 4.2)	11	2.4 (0.9 to 6.2)	7	7	0.7 (0.2 to 2.0)	7	1.6 (0.5 to 4.8)	0	

*Adjusted for age and socioeconomic status.

the outcome was also inconsistent, with an increased risk only among men in the high exposure group.

For urinary organs, malignant melanoma, and other skin cancer in men, slight increases in risk were seen for single intermediate exposure categories only; for cancer of the colon a protective effect was suggested.

Cancer sites with no a priori hypothesis of an association

Some cancer sites showed results that could indicate an association (in either direction), without any a priori expectation (table 4). For tumours of the mesopharynx and "other male genital organs" among men, the test for trend yielded p values of 0.142 and 0.135, respectively. A protective effect was suggested for cancer of the small intestine ($p = 0.150$) and connective tissue ($p = 0.011$). Among women associations were indicated for Hodgkin's disease ($p = 0.136$) and multiple myeloma ($p = 0.208$).

DISCUSSION

Among men, tumours of the kidney, the biliary passages and liver, and the pituitary gland showed an association with ELF-MF exposure, with an exposure–response relation indicated. For high and very high exposed women, the risk of cancer of the brain (astrocytoma) was increased, and an increased incidence of cancer of the corpus uteri, and multiple myeloma was found in the high exposure group. The number of very high exposed women was too small to generate cases for many of the diagnoses. We also found some negative associations—for cancer of the colon and connective tissue among men.

The results are partly consistent with the population based Swedish cohort study of occupational exposure to ELF-MF and cancer diseases.[15] In that study (based on the same JEM, but with another study base) there were also increased risks for cancer of the kidney and tumours of the biliary passages and liver among high exposed men. Our result for cancer of the corpus uteri in women is also consistent with the previous study. The risk estimates for these sites were slightly higher than those previously obtained. For other sites the previous findings were not verified, in particular for cancer of the colon and testis.

Few occupational risk factors are known for cancer of the biliary tract and liver, besides an established association between liver angiosarcoma and vinyl chloride exposure, and the increased risk of cancer of the biliary passages in PCB exposed workers.[21–24] There are sporadic reports for different occupations and industries—for example, suggestions of an increased incidence of biliary tract cancer among painters[25] and textile workers.[26 27] Based on Swedish population data, an increased incidence was reported for a variety of industries and occupations, such as coal and petroleum refining, paper mills, chemical processing, and the gold, silver, and silver plating industry[28]—that is, work environments not included in our study. It seems unlikely that the present findings on biliary tract and liver should be confounded by exposures occurring in this type of industrial environment.

Renal cell cancer, the most common type of kidney cancer, is not generally considered an occupationally associated tumour.[29] A variety of occupational groups have shown sporadic increases in the risk of renal cancer, with different exposures suggested as the potential risk factor. The findings have, for example, pointed at asbestos exposure in insulators or shipyard workers,[30] exposure to cadmium and lead, employment in the petroleum industry, and exposure to gasoline. It is unlikely that any of these factors could have a significant influence on the results of the present study.

Several previous studies on ELF-MF exposure,[3 31] have reported associations with tumours of the nervous system and leukaemia (especially lymphocytic leukaemia). Our findings show a heterogeneous outcome for these cancer sites. For

Table 4 Relative risk (RR) of cancer in relation to occupational ELF-MF exposure; cancer sites with no previous suggestion of an association with ELF-MF

	Exposure, μT						
	Low <0.164	Medium 0.164–0.250		High 0.250–0.530		Very high >0.530	
Site, ICD7*	n	n	RR† (95% CI)	n	RR† (95% CI)	n	RR† (95% CI)
Men							
Mesopharynx, 145	6	17	1.1 (0.4 to 2.7)	6	1.4 (0.4 to 4.2)	8	2.0 (0.7 to 6.1)
Oesophagus, 150	21	49	1.0 (0.6 to 1.6)	22	1.7 (0.9 to 3.0)	12	1.1 (0.5 to 2.2)
Other male genital organs, 179	8	26	1.2 (0.6 to 2.7)	6	1.2 (0.4 to 3.6)	8	2.3 (0.8 to 6.4)
Small intestine, 152	20	13	0.3 (0.1 to 0.5)	8	0.6 (0.3 to 1.4)	5	0.5 (0.2 to 1.4)
Pancreas, 157	66	110	0.7 (0.5 to 0.9)	27	0.7 (0.4 to 1.1)	38	1.2 (0.8 to 1.9)
Connective tissue, muscle, 197	30	45	0.6 (0.4 to 0.9)	11	0.5 (0.3 to 1.0)	7	0.4 (0.2 to 0.9)
Women							
Eye, 192	1	3	2.5 (0.2 to 25.4)	3	5.9 (0.6 to 61.0)	0	
Adrenal glands, 195.0	2	9	2.6 (0.5 to 12.8)	2	1.4 (0.2 to 10.5)	1	3.3 (0.3 to 39.3)
Hodgkin's disease, 201	4	15	2.7 (0.9 to 8.4)	6	3.0 (0.8 to 10.9)	1	2.5 (0.3 to 23.1)
Multiple myeloma, plasmocytoma, 203	3	12	2.9 (0.8 to 10.7)	7	3.8 (0.9 to 15.6)	0	

*Inclusion criteria: either RR >2.0 in the high or very high exposure group, or the lower limit of the CI >0.9 or RR <0.5 in the high or very high exposure group, or the upper limit of the CI <1.1; †adjusted for age and socioeconomic status.

men, we did not observe any increased risk for tumours of the nervous system, except for astrocytoma I–II, while there was an association for women, especially for astrocytoma grade III–IV (glioblastoma). The pattern of an increase in risk attributable to the very youngest men, mentioned in the results section, is in accordance with previous observations.[17 32] We did not see an increased risk for leukaemia among men, while there were increased risks among exposed women, but based on small numbers.

The study comprises comparatively young subjects, with 50% below 35 years of age at entry into the cohort. Together with a maximum of 10 years of follow up, this means an age dependent selection of the cases observed, and an under representation of cancer diseases with incidence extremely dependent on high age, for example, chronic lymphocytic leukaemia. It is generally assumed that if the associations observed between ELF-MF and cancer reflect causality, the factor should act not as an initiator but as a promoter. A focus on the exposure situation remote from the diagnosis should therefore be of lesser importance than the period closer in time to disease onset and diagnosis. Our study allows for a shorter time of promotion and a shorter latency period compared with previous study designs. Study characteristics like these can contribute to inconsistencies between study results.

The study was set up to increase the fraction of high exposed subjects in the cohort compared to the general population, in order to improve the possibility of analysing exposure–response patterns, which could contribute to the evaluation of causality. The very high exposure group comprises a large proportion of welders/resistance welders. Nevertheless, we could identify only about 1700 subjects as resistance welders through their job descriptions. The actual number is higher, as many of the welders did not explicitly define themselves as resistance welders. The majority of these workers should appear in the two highest exposure groups, however.

The question of overall erroneous classification of exposure in the cohort must be considered. The exposure assessment was based on a job exposure matrix and not on individual exposures, an ideal but unrealistic approach. The method we have used should mainly lead to non-differential misclassification and to risk estimates closer to unity, particularly for the very high exposure group.[33]

Another reason for focusing on resistance welding was to reduce the potential for confounding from other occupational exposures. The work environments included in the study should be comparatively free from, for example, welding fumes, chemical agents, and metal dust occurring in the traditional welding environment. Nevertheless, some of the results could be a result of confounding from such factors. Presumably, the potential for confounding effects is greater in the very high exposure group compared with the high exposure group, because the latter group consists of a large variety of occupations and job tasks, while the very high exposure group mainly consists of welders. We cannot rule out the possibility of confounding from non-occupational agents, connected with behavioural or lifestyle risk factors. There is no evidence, however, of an association between, for example, smoking and ELF-MF exposure.[17]

Hormonal factors have often been discussed as a link between ELF-MF exposure and cancer development. A potential influence from ELF-MF on the pineal gland with a decrease in the secretion of melatonin, subsequently affecting oestrogen concentrations, has been suggested.[34 35] There was just a marginally higher risk of breast cancer among exposed women, but there were indications of an association with male breast cancer and with cancer of the corpus uteri, which clearly has a hormonal aetiology.[36] The hypothesis that hormones might be involved in the potential biological pathway between ELF-MF and cancer was further supported by the excess of tumours of the pituitary gland among highly exposed men. The result is in line with previous findings of an increased incidence of these tumours among train engineers and conductors—that is, occupational groups, other than those represented in this study, with extremely high ELF-MF exposures.[32] Another indication of an interaction with the endocrine system is the increased number of cases of tumours of the adrenal glands in exposed women, although this was based on small numbers (table 4). The hypothalamic–pituitary–adrenal axis is of major significance of the endocrine system, and tumours of the pituitary and adrenal glands may be hormone producing with a diversity of potential secondary effects.

The outcome of the present study, involving various types of cancer, could be explained by different biological pathways. The results for cancer of the kidney and liver might also, however, fit into a biological mechanism involving hormones. Recent discoveries show that not only genital organs like the uterus, ovary, and testis, or the pituitary gland, but also tissues of, for example, the adrenal glands, the kidney, liver (and bile duct epithelial cells), lung, brain, and lymphocytes have oestrogen receptors.[37 38] These findings may be taken into consideration in the attempts to interpret the results from the present study.

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Authors' affiliations

N Håkansson, B Floderus, Institute of Environmental Medicine, Karolinska Institutet, Stockholm, Sweden; National Institute for Working Life, Solna, Sweden

P Gustavsson, Department of Occupational Health, Stockholm County Council, Stockholm, Sweden; Division of Occupational Health, Department of Public Health Sciences, Karolinska Institutet, Stockholm, Sweden

C Johansen, J H Olsen, Institute of Cancer Epidemiology, Danish Cancer Society, Denmark

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