

Occupational Magnetic Field Exposure and Neurodegenerative Disease

Maria Feychting,* Fredrik Jonsson,* Nancy L. Pedersen,†‡ and Anders Ahlbom*

Background: Several studies have identified occupational exposure to extremely low-frequency electromagnetic fields (EMF) as a potential risk factor for neurodegenerative disease, but the evidence is contradictory and inconclusive.

Methods: We conducted a cohort study to explore these associations. We studied all economically active individuals in the Swedish 1980 census (4,812,646 subjects), and followed them for neurodegenerative disease mortality from 1981 through 1995. Information about occupation was available for 1970 and 1980. A job-exposure matrix based on magnetic field measurements was used to assess EMF exposure.

Results: An increased risk of Alzheimer's disease mortality was observed among men exposed both in 1970 and 1980 (relative risk = 2.3; 95% confidence interval = 1.6-3.3 for exposure $\geq 0.5 \mu\text{T}$). The associations were most pronounced for early-onset Alzheimer's disease mortality or with follow-up limited to 10 years after the last known occupation. Amyotrophic lateral sclerosis was not associated with EMF exposure, but the risk estimate with "electrical and electronics work" was 1.4 (95% confidence interval = 1.1-1.9).

Conclusions: Our study gives some support to the hypothesis that EMF exposure increases the risk of early-onset Alzheimer's disease, and suggests that magnetic field exposure may represent a late-acting influence in the disease process. Electric shock is an unlikely explanation for the increased risk of amyotrophic lateral sclerosis in "electrical and electronics work" in this study.

Key Words: Alzheimer's disease, amyotrophic lateral sclerosis, electromagnetic fields, neurodegenerative disease, occupation

(*Epidemiology* 2003;14: 413-419)

Several recent studies have identified occupational exposure to extremely low-frequency electromagnetic fields (EMF) as a potential risk factor for neurodegenerative disease, including Alzheimer's disease and amyotrophic lateral sclerosis (ALS).¹ However, the evidence is contradictory and inconclusive. In two studies of Alzheimer's disease, Sobel et al^{2,3} reported a 3-4-fold risk increase associated with occupational EMF exposure. Subsequent studies have not confirmed these findings, although results have not been entirely null.⁴⁻⁶ The studies that have found the strongest associations are characterized by a greater potential for selection bias.^{2,3} On the other hand, several studies are based on mortality data and have a greater potential for misclassification of the disease.^{5,6} Findings have also been inconsistent with regard to latency period, with one study indicating an association with exposure in the distant past,⁵ with another study finding an association with exposure in the most recent occupation before disease onset.⁴

Studies of ALS have more consistently reported a risk increase, but confounding by electric shock is a potential explanation for the findings.^{1,5-12} Again, the strongest associations have been found in studies with the greatest potential for selection bias,^{7,8} but there is also support for an association from well-designed cohort studies.^{5,11,12} Furthermore, using mortality data to identify cases is probably less subject to misclassification for ALS than for Alzheimer's disease. Data for other neurodegenerative diseases such as Parkinson's disease and multiple sclerosis are sparse, but have not indicated increased risks with EMF exposure.^{5,6,11-13}

Most previous studies have either studied neurodegenerative disease in electric utility workers or used a crude grouping of occupational titles into "electrical occupations" to assess exposure. In our previous study of Alzheimer's disease,⁴ we used a job-exposure matrix based on occupational EMF measurements in a sample of the general popu-

Editors' note: an invited commentary on this article appears on page 384. Submitted 28 August 2002; final version accepted 11 March 2003.

From the *Institute of Environmental Medicine, Karolinska Institutet, Stockholm, Sweden and the †Department of Medical Epidemiology, Karolinska Institutet, Stockholm, Sweden; and the ‡University of Southern California, Los Angeles, CA.

This study was funded by a grant from the Swedish Council for Working Life and Social Research.

Correspondence: Maria Feychting, Institute of Environmental Medicine, Karolinska Institutet, Box 210, S-171 77 Stockholm, Sweden. E-mail: Maria.Feychting@imm.ki.se.

Copyright © 2003 by Lippincott Williams & Wilkins
1044-3983/03/1404-0413

DOI: 10.1097/01.EDE.0000071409.23291.7b

lation. We found the strongest effect for early-onset Alzheimer's disease (age 75 years or younger at diagnosis), but we also found elevated risk estimates for those with less than 10 years between exposure and disease onset. However, the study was based on a small number of cases. In the present study, our aim was to use the job-exposure matrix in a large cohort study to test the hypothesis that occupational EMF exposure increases the risk of Alzheimer's disease, particularly Alzheimer's disease with a relatively early onset, and ALS, as well as to explore associations with other types of neurodegenerative diseases. The study was approved by the ethics review board at the Karolinska Institutet.

METHODS

This cohort study is based on all individuals included in the Swedish census in 1980 who were economically active in 1970 or in 1980, and who were alive on 1 January 1981, for a total of 4,812,646 subjects (2,649,300 men and 2,163,346 women). We followed the subjects from 1 January 1981 until 31 December 1995 or until death, whichever came first. All deaths with neurodegenerative disease as an underlying or contributing cause were identified in the Cause of Death Registry, in which diagnoses are coded according to the International Classification of Diseases. The eighth revision was used until 1986, and the ninth revision was used from 1987 onward. Alzheimer's disease and vascular dementia were not identified until the 9th International Classification of Diseases revision, and therefore we did not start the follow-up for Alzheimer's disease and vascular dementia until 1 January 1987.

We obtained information about occupation and socioeconomic status from the 1970 and 1980 censuses. A job-exposure matrix developed in a previous case-control study was used to assess the EMF exposure in each occupation.^{4,14} The matrix is based on workday measurements of EMF that were collected for a large number of occupations held by a sample of the general population of men. In the present study, the EMF level in μT for each occupation corresponds to the geometric mean of the arithmetic means of the workday measurements. In addition, we analyzed electricians separately, because this is the occupation with the largest number of electric shock accidents reported to the Swedish National Electrical Safety Board.¹⁵ Reporting electrical accidents to this board is mandatory. All work-related accidents are also reported to the Work Environment Inspectorate, and information on electrical accidents is forwarded to the Swedish National Electrical Safety Board. We also analyzed the occupations with the highest EMF levels in the job-exposure matrix, as well as "electrical" occupations previously reported to be associated with Alzheimer's disease or ALS.^{2,3,6} We focused the analyses on the occupation held in 1970, to allow enough time between exposure and death to assure that the exposure occurred before disease onset. We also analyzed

the occupation held in 1980, as well as combined exposure information from 1970 and 1980. The analyses include only individuals working at least part of the census year from which the occupational information is taken. We decided *a priori* to perform age-specific analyses with a cut-off point of 75 years, and to analyze the effect when follow-up was limited to 10 years, similar to the analyses we made in our previous study.⁴ Exposure information on this economically active cohort was missing for 6% of men, and 33% of women. The job-exposure matrix was constructed from measurements on a random sample of men and, therefore, a larger proportion of the women lack exposure information.

We selected four levels of exposure *a priori*, with cut-off points at the first and third quartile and the 90th percentile. This corresponds to EMF values of 0.11 μT , 0.19 μT and 0.29 μT . We also analyzed EMF levels of $\geq 0.5 \mu\text{T}$ (the 95th percentile).

Statistical Methods

We calculated person-years from 1 January 1981 until death (year and month) or until 31 December 1995. Follow-up for Alzheimer's disease and vascular dementia started on 1 January 1987, when ICD-9 replaced ICD-8 for categorization of causes of death. The association between EMF exposure and neurodegenerative disease risk was estimated through Cox proportional hazards modeling. Relative risk estimates are presented with 95% confidence intervals (CI). All risk estimates are adjusted for age and socioeconomic status. Results are presented for men and women separately.

RESULTS

The age range at the start of follow-up was 16 to 98 years, with a median of 43 years. Table 1 provides the number of deaths and median age at the time of death according to underlying or contributing cause of death.

Table 2 shows that, overall, Alzheimer's disease was not associated with EMF exposure of 0.3 μT or more. Similar results were found for both men and women. A modest risk increase was found for Alzheimer's disease in men in relation to exposures of 0.5 μT or more in 1970, and a slightly higher risk estimate in 1980. The risk increases for exposures in 1970 was slightly higher for women than for men, but the results were based on a small number of cases. Among men, stronger associations were found when analyses were limited to mortality before age 75, and even stronger associations were found when follow-up was limited to 10 years after the 1980 census (relative risk [RR] = 3.4; CI = 1.6-7.0 for men with exposures of 0.5 μT or more in 1980). The number of women in these subgroups was too small for meaningful analyses.

There was no risk increase for ALS in any of the analyses (Table 3). There was even an indication of a reduced risk for exposures $\geq 0.3 \mu\text{T}$ in both 1970 and 1980, among

TABLE 1. Number of Deaths with a Neurodegenerative Disease as an Underlying or Contributing Cause Between 1 January 1981 and 31 December 1995, Among People Included in the 1980 Swedish Census Who Were Economically Active in 1970 or 1980

Diagnosis (ICD-9)	Men		Women	
	No. of Deaths	Median age at Death (Years)	No. of Deaths	Median Age at Death (Years)
Alzheimer's disease (331.0)	1321	77	679	76
Vascular dementia (290.4)	2064	80	604	81
Senile dementia (290.0)	8017	81	3736	82
Presenile dementia (290.1)	1336	74	642	74
Amyotrophic lateral sclerosis (335.2)	1411	70	554	69
Parkinson's disease (332.0)	5136	78	1153	78
Multiple sclerosis (340)	521	61	274	57
Epilepsy (345.1-245.9)	1244	66	359	70

both men and women. For men, similar results were found at exposure levels of 0.5 μ T or more, whereas the numbers for women were too small for meaningful analyses.

In Table 4, we present results for combinations of exposures in 1970 and 1980 for men. For Alzheimer's disease the subjects who were exposed at both times had the highest risk increase (RR = 2.3; CI = 1.6-3.3 for exposure $\geq$ 0.5 μ T), whereas those who were exposed only in 1970 had no

suggestion of increased risk. For ALS, all risk estimates were close to unity or below.

Table 5 shows the results for other neurodegenerative diseases. There were no indications of increased risks either for men or women.

Results for specific occupations in 1970 are shown in Table 6. These analyses were limited to men because few women worked in occupations with high EMF levels. Rail-

TABLE 2. Alzheimer's Disease Mortality Risk* According to Occupational Magnetic Field Exposure in 1970 and 1980 (Follow-Up 1987-1995)

	$\leq 0.11 \mu\text{T}$		0.12-0.19 μT		0.20-0.29 μT		$\geq 0.30 \mu\text{T}$		$\geq 0.50^\dagger$	
	N	RR [†]	N	RR (95% CI)	N	RR (95% CI)	N	RR (95% CI)	N	RR (95% CI)
Men										
Occupation in 1970										
Total	178	1.0	696	1.0 (0.9-1.2)	239	1.1 (0.9-1.3)	170	1.1 (0.9-1.4)	90	1.3 (1.0-1.7)
Age at death < 75 years	72	1.0	263	1.0 (0.7-1.3)	101	1.1 (0.8-1.5)	91	1.3 (1.0-1.8)	51	1.6 (1.1-2.3)
Age at death $\geq$ 75 years	106	1.0	433	1.1 (0.9-1.3)	138	1.1 (0.8-1.4)	79	0.9 (0.7-1.2)	39	1.0 (0.7-1.4)
Follow-up to 1990	26	1.0	131	1.3 (0.8-2.0)	51	1.5 (1.0-2.5)	45	2.0 (1.2-3.3)	22	2.2 (1.2-3.8)
Occupation in 1980										
Total	86	1.0	304	0.8 (0.6-1.0)	95	0.8 (0.6-1.1)	83	1.2 (0.9-1.7)	51	1.8 (1.3-2.6)
Age at death < 75 years	70	1.0	209	0.7 (0.6-1.0)	69	0.7 (0.5-1.0)	69	1.2 (0.9-1.7)	43	1.8 (1.2-2.6)
Age at death $\geq$ 75 years	16	1.0	95	1.1 (0.6-1.9)	26	1.1 (0.6-2.0)	14	1.2 (0.6-2.6)	8	1.9 (0.8-4.4)
Follow-up to 1990	14	1.0	49	0.8 (0.4-1.5)	19	1.0 (0.5-2.0)	24	2.2 (1.1-4.2)	16	3.4 (1.6-7.0)
Women										
Occupation in 1970	172	1.0	280	1.0 (0.8-1.3)	68	0.8 (0.6-1.0)	34	1.1 (0.7-1.6)	6	2.3 (1.0-5.2)
Occupation in 1980	123	1.0	138	0.9 (0.7-1.1)	23	0.6 (0.4-0.9)	18	1.0 (0.6-1.6)	2	n.c.

*Adjusted for age and socioeconomic status.

[†]Reference category.

[‡]Subset of category $\geq$ 0.30 μ T.

n.c. = not calculated.

TABLE 3. Amyotrophic Lateral Sclerosis Mortality Risk* According to Occupational Magnetic Field Exposure in 1970 and 1980 (Follow-Up 1981–1995)

	$\leq 0.11 \mu\text{T}$		$0.12\text{--}0.19 \mu\text{T}$		$0.20\text{--}0.29 \mu\text{T}$		$\geq 0.30 \mu\text{T}$		$\geq 0.50^\ddagger$	
	N	RR [†]	N	RR (95% CI)	N	RR (95% CI)	N	RR (95% CI)	N	RR (95% CI)
Men										
Occupation in 1970										
Total	227	1.0	723	0.9 (0.7–1.0)	210	0.8 (0.7–1.0)	166	0.8 (0.7–1.0)	70	0.8 (0.6–1.0)
Age at death < 75 years	165	1.0	521	0.9 (0.8–1.1)	157	0.8 (0.7–1.0)	133	0.9 (0.7–1.1)	53	0.7 (0.5–1.0)
Age at death ≥ 75 years	62	1.0	202	0.7 (0.5–1.0)	53	0.7 (0.5–1.0)	33	0.7 (0.4–1.0)	17	0.7 (0.4–1.2)
Follow-up to 1990	155	1.0	439	0.8 (0.6–1.0)	121	0.7 (0.5–0.9)	95	0.7 (0.6–0.9)	41	0.6 (0.5–0.9)
Occupation in 1980										
Total	116	1.0	465	1.0 (0.8–1.2)	146	1.0 (0.8–1.3)	79	0.9 (0.7–1.2)	29	0.7 (0.5–1.1)
Age at death < 75 years	112	1.0	422	1.0 (0.8–1.2)	129	0.9 (0.7–1.2)	72	0.8 (0.6–1.1)	24	0.6 (0.4–0.9)
Follow-up to 1990	31	1.0	124	0.9 (0.6–1.4)	33	0.8 (0.5–1.4)	21	0.9 (0.5–1.5)	8	0.7 (0.3–1.6)
Women										
Occupation in 1970	133	1.0	228	1.2 (0.9–1.5)	57	0.9 (0.7–1.2)	15	0.6 (0.4–1.1)	1	n.c.
Occupation in 1980	118	1.0	152	1.1 (0.9–1.5)	35	1.1 (0.8–1.7)	12	0.8 (0.4–1.4)	1	n.c.

*Adjusted for age and socioeconomic status.

[†]Reference category.[‡]Subset of category $\geq 0.30 \mu\text{T}$.

n.c. = not calculated.

way engine drivers had the highest EMF level ($4.03 \mu\text{T}$), which was associated with more than a doubling of the risk of Alzheimer's disease. An increased risk of Alzheimer's dis-

TABLE 4. Alzheimer's Disease and Amyotrophic Lateral Sclerosis Mortality Risk* According to Occupational Magnetic Field Exposure in 1970 and 1980

	Alzheimer's Disease [†]		ALS [‡]	
	N	RR (95% CI)	N	RR (95% CI)
Exposed $\geq 0.3 \mu\text{T}$				
1970 and 1980	54	1.5 (1.1–2.1)	48	0.8 (0.6–1.1)
1970 or 1980	199	1.1 (0.9–1.4)	197	0.8 (0.7–1.0)
1970 only	100	1.0 (0.8–1.3)	79	0.8 (0.6–1.0)
1980 only	9	1.4 (0.7–2.7)	10	0.6 (0.3–1.1)
Exposed ≥ 0.5				
1970 and 1980	35	2.3 (1.6–3.3)	16	0.6 (0.4–1.0)
1970 or 1980	106	1.3 (1.0–1.7)	83	0.7 (0.6–1.0)
1970 only	50	1.1 (0.8–1.4)	41	0.8 (0.6–1.1)
1980 only	5	1.7 (0.7–4.1)	4	0.5 (0.2–1.4)
Unexposed both in 1970 and in 1980 [§]	168	1.0	211	1.0

*Adjusted for age and socioeconomic status.

[†]Follow-up 1987–1995.[‡]Follow-up 1981–1995.[§]Reference category.

ease was also found among welders. There was no overall risk increase for electricians; however, when analyses were limited to mortality before age 75 or to a shorter follow-up, there was some evidence of increased risk. Mostly similar results were found for occupations held in 1980 (although based on smaller numbers). Welders had a higher risk increase (RR = 3.4; CI = 2.1–5.5, based on 17 exposed cases) (data not shown).

ALS was not associated with the occupations having the highest EMF exposure, but an increased risk was found among welders (Table 6). Radio and television assemblers and repairmen, as well as telephone and telegraph installers and repairmen had a slightly stronger risk increase of ALS. When a less detailed occupational classification is used in the Swedish census, these occupations, together with recording, sound and light equipment operators, belong to the category "electrical and electronics work." The operator category had too few observations for separate analyses. Analyses of "electrical and electronics work" gave a risk estimate for ALS of 1.4 (CI = 1.1–1.9). Age-specific analyses or shorter follow-up did not change the results for ALS (data not shown). The results were virtually the same for an occupation held in 1980 as for an occupation in 1970, except for welders, who had no increased risk (RR = 1.0; CI = 0.5–1.9), based on 9 exposed cases.

For women, the risk estimate for work as a seamstress was below unity for Alzheimer's disease (RR = 0.6; CI = 0.4–1.0) and for ALS (RR = 0.7; CI = 0.4–1.2).

TABLE 5. Other Neurodegenerative Disease Mortality Risk* According to Occupational Magnetic Field Exposure in 1970

Disease	$\leq 0.11 \mu\text{T}^\dagger$		0.12–0.19 μT		0.20–0.29 μT		$\geq 0.30 \mu\text{T}$	
	N	RR	N	RR (95% CI)	N	RR (95% CI)	N	RR (95% CI)
Men								
Vascular dementia [‡]	296	1.0	1093	1.0 (0.8–1.1)	398	1.1 (1.0–1.3)	238	1.0 (0.8–1.1)
Senile dementia	1295	1.0	4400	0.9 (0.8–1.0)	1265	0.9 (0.8–1.0)	954	0.9 (0.9–1.0)
Presenile dementia	185	1.0	726	1.1 (0.9–1.3)	221	1.0 (0.8–1.2)	168	1.1 (0.9–1.3)
Parkinson's disease	658	1.0	2987	1.1 (1.0–1.2)	837	1.1 (1.0–1.2)	566	1.1 (0.9–1.2)
Multiple sclerosis	71	1.0	254	1.0 (0.8–1.4)	101	1.2 (0.9–1.7)	48	0.8 (0.5–1.1)
Epilepsy	240	1.0	512	1.0 (0.8–1.2)	175	1.1 (0.9–1.4)	138	1.0 (0.8–1.2)
Women								
Vascular dementia [‡]	165	1.0	277	1.0 (0.8–1.2)	83	1.0 (0.7–1.3)	19	0.7 (0.4–1.1)
Senile dementia	1122	1.0	1712	1.0 (0.9–1.1)	524	0.8 (0.8–0.9)	170	0.9 (0.8–1.1)
Presenile dementia	165	1.0	280	1.1 (0.8–1.3)	78	0.9 (0.7–1.2)	28	0.9 (0.6–1.4)
Parkinson's disease	323	1.0	538	0.9 (0.8–1.1)	147	0.8 (0.7–1.0)	45	0.8 (0.6–1.1)
Multiple sclerosis	63	1.0	98	0.9 (0.6–1.3)	26	0.9 (0.6–1.5)	13	1.0 (0.5–1.8)
Epilepsy	93	1.0	112	0.8 (0.6–1.2)	38	0.8 (0.5–1.2)	13	0.7 (0.4–1.3)

*Adjusted for age and socioeconomic status.

[†]Reference category.[‡]Follow up from 1987.

DISCUSSION

Our data provide some support for the hypothesis that occupational EMF exposure increases the risk of Alzheimer's disease with a relatively early onset. The findings also suggest that EMF exposure may represent a late-acting influence in the disease process. Contrary to previous studies, we found

no risk increase for ALS, regardless of EMF level. We found an indication of an increased risk for ALS among men working in the job category "electrical and electronics work;" within this category, the individual occupations with the highest risk increase were radio and television assemblers and repairmen, and telephone and telegraph installers. If electric

TABLE 6. Alzheimer's Disease and Amyotrophic Lateral Sclerosis Mortality Risk* According to Occupation in the 1970 Census

Occupation 1970	Alzheimer's Disease [†]						ALS [‡]	
	Total		Age at Death < 75 years		Follow-Up to 1990		Total	
	No.	RR (95% CI)	No.	RR 95% CI	No.	RR (95% CI)	No.	RR (95% CI)
	Cases		Cases		Cases		Cases	
Railway engine drivers (4.03 μT)	14	2.7 (1.6–4.5)	9	2.2 (1.2–4.2)	2	2.1 (0.5–8.4)	5	0.9 (0.4–2.1)
Glass, pottery, tile work (2.47 μT)	3	1.4 (0.4–4.3)	0		0		2	0.8 (0.2–3.3)
Welders (1.12 μT)	17	1.4 (0.9–2.3)	8	1.3 (0.6–2.5)	6	2.6 (1.2–6.0)	24	1.6 (1.1–2.4)
Forest workers and log-drivers (0.76 μT)	28	1.0 (0.7–1.5)	16	1.6 (1.0–2.6)	9	1.7 (0.9–3.4)	16	0.5 (0.3–0.9)
Electricians (0.30 μT)	23	1.0 (0.6–1.5)	12	1.0 (0.6–1.8)	7	1.6 (0.7–3.4)	34	1.2 (0.9–1.7)
Radio & television assemblers & repairmen (0.18 μT)	3	1.0 (0.3–3.0)	1	0.6 (0.1–4.4)	0		7	1.6 (0.8–3.5)
Telephone & telegraph installers & repairmen (0.14 μT)	1	0.5 (0.1–3.2)	0		0		6	2.1 (0.9–4.6)

*Adjusted for age and socioeconomic status.

[†]Follow-up 1987–1995.[‡]Follow-up 1981–1995.

shock had been the explanation for the increased risk in the "electrical and electronics work" category, then the highest risk would have been expected among electricians, which is the occupation with the greatest number of reported accidents due to electric shock. According to the Swedish National Electrical Safety Board, almost 50% of reported work-related electrical accidents in 1991 occurred among electricians.¹⁵ We did not have information about electric shocks on the individual level, and therefore we could not control for confounding from electric shock. Mortality from other neurodegenerative diseases was not associated with occupational EMF exposure.

The first two studies of Alzheimer's disease designed to study EMF exposure reported a 3-4-fold increase in risk associated with EMF exposure in subjects' primary occupation.^{2,3} A Swedish study also found increased risks, but the results were not entirely consistent with the previous studies.⁴ Later studies based on a utility cohort⁵ and on mortality registry data⁶ have found little or no increase of Alzheimer's disease. The occupations with the highest EMF levels in the job-exposure matrix used here were not included as exposed in these studies.

Studies of ALS have more consistently reported a modest risk increase, but confounding from electric shock has been discussed as a potential explanation for the findings.^{1,5-12} Savitz et al⁶ found an increased risk of ALS among telephone installers and repairers. A Swedish study found indications of an increased risk of ALS associated with electric shocks.¹⁰ Data for other neurodegenerative diseases are sparse. The risk of Parkinson's disease was analyzed in the utility cohort studies by Savitz et al,⁵ Johansen et al^{11,12} and in a mortality registry study,⁷ but no indication of an increased risk related to EMF exposure was found. In the Danish study, an analysis was also performed for multiple sclerosis.^{11,13} No risk increase was found.

An obvious limitation in our study is the quality of information about diseases in the Cause of Death Registry. There is no information about date of disease onset. Kay et al¹⁶ reported a 6-year median survival time for Alzheimer's disease, with the majority of the subjects having symptoms less than 2 years before diagnosis. Similarly, Keene et al¹⁷ reported a mean survival time of 8.5 years from the first symptom. The survival time for ALS is generally shorter, with an average of 2 to 5 years.¹⁸

Using death certificates to identify cases will inevitably lead to misclassification of the disease. Neurodegenerative diseases are not always mentioned on the death certificate. The degree of underreporting differs among diseases, as well as among countries or geographical areas. A study from Pennsylvania (U.S.) reported that only about one quarter of demented subjects had dementia mentioned on their death certificates;¹⁹ in contrast, the corresponding figures were 73% in a study from Oxford,¹⁷ and 90% among Alzheimer's disease subjects and 50% among subjects with vascular

dementia in a Scottish study.²⁰ There is no similar Swedish study of Alzheimer's disease. In a Swedish study of motor neuron disease, 95% of clinically identified patients with this disease had the diagnosis mentioned in the Mortality Registry, whereas the diagnosis could not be confirmed in 4% of subjects identified through the Mortality Registry.²¹ An Italian study of ALS found that 75% of cases had ALS mentioned on the death certificates.²² There will be some confusion among different types of neurodegenerative diseases, especially among categories of dementia. About half of the Alzheimer's disease cases identified in this study had pre-nile dementia mentioned on the death certificate in addition to Alzheimer's disease. Other neurodegenerative diseases were rarely mentioned together with Alzheimer's disease. The problem with misclassification is likely to be less pronounced for ALS, and only 1% of the ALS cases had another neurodegenerative disease mentioned on the death certificate. Because there is no reason to think that disease misclassification would vary with EMF exposure, the likely result of misclassification is a dilution of the risk estimates. It is unlikely, however, that this type of misclassification can explain the lack of an association with ALS.

A strength of the study is that it is population based, with prospectively collected information about the exposure; thus, selection bias or differential misclassification of the exposure is unlikely. However, the use of job titles to assess exposure will introduce nondifferential exposure misclassification, which may have diluted the effect estimates. A further limitation is that information about occupation was available only for the years 1970 and 1980, and we had no information about occupation in the time interval between these years. We analyzed the risk among subjects exposed both in 1970 and in 1980, which strengthened the findings for Alzheimer's disease. For ALS, the results were close to or below unity. Lack of information about cumulative exposure may lead to nondifferential exposure misclassification, which could dilute the risk estimates, but there is no reason to believe that this would affect Alzheimer's disease and ALS differently.

The job-exposure matrix was based on EMF measurements performed on a random sample of male workers, and may therefore have been less suitable for characterizing the exposure in female occupations for two reasons. First, there may be differences in the exposure situation between male and female workers within the same job title, and second, exposure information was missing for a large proportion of typical female occupations. This may have caused a greater misclassification of the exposure among females, and limited the number of female subjects that could be included in the analyses.

We have been able to control for only a limited number of potential confounding factors (*ie*, socioeconomic status and age), and cannot exclude confounding as an explanation for the findings. It is clear, however, that the increased risk of

Alzheimer's disease is not limited to a specific type of occupation, and the findings changed only marginally when, for example, all railway train drivers were excluded from the analyses.

In conclusion, our study gives some support to the hypothesis that occupational EMF exposure increases the risk of relatively early-onset Alzheimer's disease, and suggests that EMF exposure may represent a late-acting influence in the disease process. ALS does not seem to be associated with EMF exposure, but our study supports the findings of an increased risk of ALS associated with some types of electrical and electronics work. The risk increase was not primarily for electricians, which would have been expected if electric shock had been the explanation for the observed risk increase.

REFERENCES

1. Ahlbom A. Neurodegenerative diseases, suicide and depressive symptoms in relation to EMF. *Bioelectromagnetics*. 2001;(Suppl 5):S132–S143.
2. Sobel E, Davanipour Z, Sulkava R, et al. Occupations with exposure to electromagnetic fields: a possible risk factor for Alzheimer's disease. *Am J Epidemiol*. 1995;142:515–524.
3. Sobel E, Dunn M, Davanipour Z, et al. Elevated risk of Alzheimer's disease among workers with likely electromagnetic field exposure. *Neurology*. 1996;47:1477–1481.
4. Feychting M, Pedersen NL, Svedberg P, et al. Dementia and occupational exposure to magnetic fields. *Scand J Work Environ Health*. 1998;24:46–53.
5. Savitz DA, Checkoway H, Loomis DP. Magnetic field exposure and neurodegenerative disease mortality among electric utility workers. *Epidemiology*. 1998;9:398–404.
6. Savitz DA, Loomis DP, Tse C-KJ. Electrical occupations and neurodegenerative disease: analysis of US mortality data. *Arch Environ Health*. 1998;53:71–74.
7. Davanipour Z, Sobel E, Bowman JD, et al. Amyotrophic lateral sclerosis and occupational exposure to electromagnetic fields. *Bioelectromagnetics*. 1997;18:28–35.
8. Deapen DM, Henderson BE. A case-control study of amyotrophic lateral sclerosis. *Am J Epidemiol*. 1986;123:790–799.
9. Gunnarsson L-G, Lindberg G, Söderfeldt B, et al. Amyotrophic lateral sclerosis in Sweden in relation to occupation. *Acta Neurol Scand*. 1991;83:394–398.
10. Gunnarsson L-G, Bodin L, Söderfeldt B, et al. A case-control study of motor neurone disease: its relation to heritability, and occupational exposures, particularly to solvents. *Br J Ind Med*. 1992;49:791–798.
11. Johansen C, Olsen JH. Mortality from amyotrophic lateral sclerosis, other chronic disorders, and electric shocks among utility workers. *Am J Epidemiol*. 1998;148:362–368.
12. Johansen C. Exposure to electromagnetic fields and risk of central nervous system disease in utility workers. *Epidemiology*. 2000;11:539–543.
13. Johansen C, Koch-Henriksen N, Rasmussen S, et al. Multiple sclerosis among utility workers. *Neurology*. 1999;52:1279–1282.
14. Floderus B, Persson T, Stenlund C. Magnetic-field exposures in the workplace: reference distribution and exposures in occupational groups. *Int J Occup Environ Health*. 1996;2:226–238.
15. Elsäkerhetsverket. Elolycksfall 1998. [In Swedish] Elanders Gotab, Stockholm, 1999.
16. Kay DWK, Forster DP, Newens AJ. Long-term survival, place of death, and death certification in clinically diagnosed pre-senile dementia in northern England. *Br J Psychiatry*. 2000;177:156–162.
17. Keene J, Hope T, Fairburn CG, et al. Death and dementia. *Int J Geriatr Psychiatry*. 2001;16:969–974.
18. Ginsberg G, Lowe S. Cost effectiveness of treatments for amyotrophic lateral sclerosis. A review of the literature. *Pharmacoeconomics*. 2002; 20:367–387.
19. Ganguli M, Rodriguez EG. Reporting of dementia on death certificates: a community study. *J Am Geriatr Soc*. 1999;47:842–849.
20. Thomas BM, Starr JM, Whalley LJ. Death certification in treated cases of presenile Alzheimer's disease and vascular dementia in Scotland. *Age Ageing*. 1997;26:401–406.
21. Gunnarsson LG, Palm R. Motor neuron disease and heavy manual labor: an epidemiological survey of Värmland County, Sweden. *Neuroepidemiology*. 1984;3:195–206.
22. Chiò A, Magnani C, Oddenino E, et al. Accuracy of death certificate diagnosis of amyotrophic lateral sclerosis. *J Epidemiol Commun Health*. 1992;46:517–518.