ORIGINAL ARTICLE

Occupational exposure to low frequency magnetic fields and dementia: a case–control study

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Background: Several studies point to a potential aetiological relevance to dementia of exposure to low-frequency magnetic fields, but the evidence is inconclusive.
Objective: To further examine the relationship between low frequency magnetic fields and dementia.
Methods: From 23 general practices, 195 patients with dementia were recruited. Of these, 108 had possible Alzheimer's disease, 59 had possible vascular dementia and 28 had secondary or unclassified dementia. A total of 229 controls were recruited: 122 population controls and 107 ambulatory patients free from dementia. Data were gathered in a structured personal interview; in cases, the interview was administered to the next of kin. Exposure to low-frequency electromagnetic fields was assessed by expert rating. To identify occupations suspected to be associated with dementia, major occupations were a priori formed. Odds ratios were calculated using logistic regression, to control for age, region, sex, dementia in parents and smoking.
Results: Exposure to magnetic fields was not significantly associated with dementia; restriction of the analysis to cases with possible Alzheimer's disease or possible vascular dementia did not lead to statistically significant results. We found an increased risk of dementia in blue-collar occupations (electrical and electronics workers, metal workers, construction workers, food and beverage processors and labourers).
Conclusions: Our study does not support a strong association between occupational exposure to low-frequency magnetic fields and dementia. Further studies should consider the relationship between blue-collar work and the late development of dementia.

Alzheimer's dementia and vascular dementia are the two major forms of dementia in elderly people. Some recent epidemiological studies have analysed the role of low-frequency magnetic fields in the aetiology of dementia. On the basis of mortality studies, the evidence is equivocal: several,[1–4] but not all,[5 6] death certificate-based studies—partly showing considerable overlap in the study populations—find a significant association between exposure to magnetic fields and dementia.

Most case–control studies show an association between occupational exposure to magnetic fields and dementia,[7–10] two case–control studies do not confirm the relationship between exposure to magnetic fields and dementia[11] or cognitive impairment.[12] Recently, a prospective cohort study conducted in the Kungsholmen district of Stockholm[13] found a relationship between exposure to electromagnetic fields in the lifetime principal job and Alzheimer's disease in men, but not in women.

As a pathophysiological explanation of the potential association between exposure to magnetic fields and Alzheimer's disease, Sobel and Davanipour[14] hypothesise the following mechanism: initiated by increased intracellular calcium ion levels in some cell systems, soluble amyloid β production might increase (eg, in skin cells). Apolipoproteins E and J might bind to the soluble amyloid β in blood and might therefore assist in its crossing the blood–brain barrier. A cascade of further events might lead to the formation of insoluble neurotoxic β-pleated sheets of amyloid fibril, senile plaques and eventually Alzheimer's disease.[14] Analysing blood and urine samples of male electric utility workers, Noonan et al[15] found a weak relationship between mean exposure to magnetic fields and the concentration of soluble amyloid β in the blood, which was not statistically significant. Therefore, the pathophysiological pathway by which dementia might be linked with exposure to magnetic fields still remains unclear.

The aim of this case–control study is to further examine the relationship between electromagnetic fields assessed by expert rating and dementia. Furthermore, the present study intends to identify occupations suspected to be associated with the risk for lymphoma.

METHODS

Study population

The study design has been described in detail previously.[16 17] The study was conducted in the city of Frankfurt-on-Main and in the neighbouring cities of Darmstadt, Offenbach and Bad Homburg, Germany. Patients with dementia were recruited in 23 general practices. Participating doctors were asked to review in detail their clinical records to identify all patients with dementia aged ⩾65 years within their clientele. To substantiate the cognitive deficit, Mini-Mental State Examinations (MMSEs) were applied by trained interviewers (one psychologist and three medical students). Potential cases were excluded from the study (n = 23) if they had an MMSE score >26.[18] On the basis of the clinical records, the Hachinski Ischaemic Score was calculated[19]: a high score points to possible vascular dementia rather than to possible Alzheimer's disease. On each patient's entry in the study, one psychiatrist (LF) reviewed the medical findings, including the results of investigations performed by neurologists and the results of magnetic resonance imaging or *x* ray computed tomography, if available. The differential diagnosis between Alzheimer's disease, vascular dementia and secondary dementia was based

Abbreviations: BAuA, German Federal Institute for Occupational Safety and Health; MMSE, Mini-Mental State Examination on the German version of International Classification of Diseases, 10th revision.[20] As our differentiation between Alzheimer's disease and vascular dementia is of limited diagnostic validity, hereafter, we use the diagnostic classes ''possible Alzheimer's disease'' and ''possible vascular dementia''. In cases of inconsistency between the computed tomography or magnetic resonance tomography findings, the external neurological diagnosis and the Hachinski Score, diagnosis was reached by a multidisciplinary consensus conference. Altogether, 195 patients with dementia (45 men and 150 women) were included in the analysis (response rate 77%). Of these, 108 (55.4%) had possible Alzheimer's disease, 59 (30.3%) had vascular dementia, 25 (12.8%) were diagnosed with secondary dementia and 3 (1.5%) with unclassified dementia.

Population controls were randomly selected from a 1% random sample of Frankfurt residents aged ⩾65 years, drawn from the Frankfurt population registration office (n = 122; response rate 61%). To achieve an age distribution comparable to that of the cases, a stratified sample under-representing people <80 years was drawn. Potential population controls were excluded from the study if they had an MMSE Score ⩽26 (n = 25).

As a second control group, we recruited all patients free from dementia aged ⩾65 years who contacted any of the above-mentioned general practices (''ambulatory'' patients) with any complaints on a priori-defined dates (n = 107; response rate 90%). Potential ambulatory controls were also excluded from the study if they had a MMSE score ⩽26 (n = 8). By choosing ambulatory patients of general practitioners as a second control group, we tried to minimise potential selection bias through the case recruitment procedure and through selective participation of population controls. The participation rate of these ambulatory controls was high; furthermore, just as the included cases with dementia, these ambulatory controls regularly consulted a general practitioner. A preliminary data analysis that separated the two control groups yielded comparable results (results are available from the authors), with one exception: the odds ratios (ORs) for blue collar work as the main occupation were markedly higher for the comparison between cases and ambulatory controls than for the comparison between cases and population controls (1.9 *v* 1.3), reaching borderline statistical significance. Because of the rather good agreement between the two control groups, we decided to combine both control groups in the final analysis to increase the power of the study.

A total of 229 controls (75 men and 154 women) were included in the analysis—122 population controls and 107 ambulatory patients free from dementia.

Data collection

In a detailed structured interview, a complete occupational history (including the job phase, job title, industry and specific job tasks) was documented for every occupational period that lasted at least 1 year. The interview was administered to the next of kin of the cases—mostly child (40%) or partner (22%)—and to the controls themselves. When patients had the first signs of dementia and no surrogates were available (n = 37; 19% of the cases), they were asked to answer the questions themselves. However, exclusion of these patients would not have fundamentally influenced the results. In 3.1% of the controls (n = 7), the interview was administered to the next of kin. Participants were not informed of specific aetiological hypotheses. In all, 22 controls did not participate in the detailed personal interview, but answered a short telephone interview.

The median latency period between the onset of the first cognitive symptoms (as reported by the patients' next of kin) and the data collection was 4 years. Therefore, for participants with an unknown date of symptom onset, the point in time 4 years before data collection was taken as the date of symptom onset (n = 54 cases), or, in controls, as the ''reference date''. Only exposure up to the date of symptom onset or reference date was considered for inclusion in the analysis. Exclusion of patients with unknown date of diagnosis would not have substantially altered the results. The mean (standard deviation (SD)) age at symptom onset of patients with any dementia (n = 195) was 79.5 (8.4) years; of patients having Alzheimer's dementia (n = 108), 80.9 (8.4) years; of patients having vascular dementia (n = 59), 78 (8) years; and of patients with secondary (n = 25) or unclassified (n = 3) dementia, 77.1 (8.7) years. The mean (SD) age of population controls (n = 122) 4 years before data collection (reference date) was 78.1 (6.7) years and of ambulatory controls (n = 107) 72.3 (7.3) years.

Exposure assessment

Job titles were coded blind to the case–control status by experienced coders in the Frankfurt Institute for Occupational Medicine, Frankfurt, Germany, according to the Classification of the Federal Statistical Office Germany Statistisches Bundesamt[21] and to the Occupational Classification of Finnish Censuses. Major occupations were a priori formed on the basis of the two-digit Statistisches Bundesamt job-title codes. Among male patients with dementia, the mean number of occupations held during their working life was 3.3; among female patients with dementia, 2.4; among male controls, 3.9; and among female controls, 3. The median time interval between the end of the last job phase and the diagnosis of dementia was 17 years in men and 24 years in women. In controls, the median time interval between the end of the last job phase and the reference date (4 years before the data collection) was 10 years in men and 21 years in women. The individual exposure to low-frequency magnetic fields was estimated by an expert (SE) of the German Federal Institute for Occupational Safety and Health (BAuA), Berlin, Germany, blind to the case–control status. On the basis of the probands' occupations, industries and job task descriptions, the time-specific exposure to magnetic fields was classified for each job held applying the following exposure categories: <0.1 μT, 0.1–0.2 μT, 0.2–1 μT, 1–10 μT, 10–100 μT and >100 μT. No participant had an exposures to magnetic fields >100 μT. Table 1 gives the average (job group-specific) daily mean exposure to magnetic fields according to expert assessment. For every job held, the arithmetic mean of the expert-rated exposure category was multiplied by the corresponding duration of the job phase and summed up. For every non-working year of life between 16 and 65 years (including times of unemployment or non-occupational housework), the background exposure to magnetic fields was assumed as 0.05 μT. The background exposure of 0.05 μT was based on results from two previous German studies, providing measurements for indoor and outdoor sources of exposure to magnetic fields.[22 23] If, for example, a proband had worked as a toolmaker for 5 years (0.6 μT mean daily exposure to magnetic fields according to expert rating) and had—after a 4-year interruption during World War II—subsequently worked as a railway engine driver for 42 years (5.5 μT mean daily exposure to magnetic fields), this would result in a cumulative exposure to magnetic fields of 234.2 μT-years (0.6 μT*5 years+ 0.05 μT background exposure*4 years +5.5 μT*42 years).

To calculate categorised exposure levels, the resulting ''μT-years'' were categorised according to the distribution of exposure to magnetic fields among the controls as follows: ''very low occupational exposure to magnetic fields'' (reference category) if the cumulative exposure to magnetic fields was

Table 1 Average daily mean exposure to magnetic fields (along with minimum and maximum exposure) according to expert assessment

Occupational group	Number of occupational phases	Number of working years	BAuA expert rating: Median of exposure to MF (μT)	Min (μT)	Max (μT)
White-collar workers	774	8232	0.05	0.05	5.50
Agricultural, animal husbandry and forestry workers	43	454	0.05	0.05	0.15
Miners	2	5	0.33	0.05	0.60
Chemistry and plastics workers	3	32	0.05	0.05	0.05
Manufacturers of paper and paper products; printers	18	214	0.05	0.05	0.15
Woodworkers	1	2	0.05	0.05	0.05
Metal processors, blacksmiths	12	143	0.15	0.05	55.00
Metal workers (machinery fitters, machine assemblers, mechanics, manufacturers of precision instruments; plumbers, welders, sheet metal and structural metal preparers and erectors)	47	430	0.15	0.05	5.50
Electrical and electronics workers	15	194	0.15	0.05	55.00
Fitters	4	39	0.60	0.15	5.50
Spinners, weavers, knitters, dyers; tailors, dressmakers	85	772	0.05	0.05	0.15
Tanners, fellmongers, pelt dressers; shoemakers and leather goods makers	14	205	0.10	0.05	0.60
Food and beverage processors; tobacco product makers	32	271	0.05	0.05	0.15
Construction workers (structural engineers, civil engineers)	12	103	0.05	0.05	0.15
Plasterers, insulators, glaziers, terrazzo workers, construction carpenters, roofers, upholsterers	9	211	0.05	0.05	0.05
Woodworkers and plastic workers (carpenters, cabinet makers, wooden or plastic models makers, wood-frame construction)	17	137	0.15	0.05	0.60
Painters, lacquerers	2	30	0.05	0.05	0.05
Quality checkers	4	64	0.05	0.05	0.05
Labourers*	14	183	0.05	0.05	0.60
Machinists	3	55	0.15	0.15	0.60
Technicians (engineers, architects, chemists, physicists, electrical engineering technicians)	35	522	0.15	0.05	5.50
Other workers	2	21	0.15	0.15	0.15

BAuA, German Federal Institute for Occupational Safety and Health; max, maximum; min, minimum.
*Unskilled workers who performed various—mostly short-term—jobs (eg, factory work, assembly-line work, home help).

<2.5 μT-years (33rd centile); "low" if the cumulative exposure to magnetic fields was between 2.5 and 4.5 μT-years (66th centile); "medium" if the cumulative exposure to magnetic fields was between 4.5 and 16.6 μT-years (95th centile); and "high" if the cumulative exposure to magnetic fields was ⩾16.6 μT-years.

Agreement between participants and next of kin

To evaluate the agreement between the participants and next of kin on exposure to magnetic fields, in 49 interviewed controls, the next of kin were also interviewed. We calculated κ values to compare exposure to magnetic field levels derived from the control's job declarations (applying the same exposure categories as described in the Exposure assessment section) with the corresponding levels derived from the next of kin interview. Furthermore, we used the Wilcoxon test to compare the interval-scaled cumulative exposure to magnetic fields (μT-years) derived from the self-reported job titles and job task descriptions, with the corresponding values based on the next of kin reported job titles/job task descriptions. Agreement was relatively weak for expert-rated cumulative exposure to magnetic fields ($\kappa = 0.39$) and maximum exposure to magnetic fields ($\kappa = 0.33$). The Wilcoxon test did not show any significant differences between self-interviews and next of kin interviews. On the basis of the expert assessment, the median cumulative exposure to magnetic fields was 4.1 μT-years according to the self-interviews and 4.2 μT-years according to the next of kin interviews. The median peak exposure was 0.1–0.2 μT according to the self-interviews and to the next of kin interviews. Altogether, there is no evidence for a systematic overestimation or underestimation of exposure to magnetic fields on the basis of the next of kin job history.

Data analysis

Logistic regression analysis was used to calculate ORs and 95% confidence intervals (CIs) separately for all cases with dementia, for cases solely with possible Alzheimer's disease and for cases solely with possible vascular dementia. All statistical analyses were adjusted for age (in 5-year categories), region, sex, dementia in parents and smoking (in pack-years). All covariates were included as categorised variables in the multivariate analyses.

ORs were calculated for having worked ever versus never in major occupations. Those who had never worked in a single occupational group and had held a white-collar job as the main occupation were included in the reference category ("never exposed" category). Only the results for occupational groups with at least five probands are reported. Occupational groups with <5 probands were combined in the category "other blue-collar work" (miners, woodworkers, fitters, painters, quality checkers, machinists and not otherwise classified occupations). Missing values were analysed as a separate category (results

Table 2 Occupational groups and dementia (dementia of any type, Alzheimer's dementia and vascular dementia)

	Referents		All cases with dementia (n = 195)						Cases with possible AD (n = 108)						Cases with possible VD (n = 59)					
			Cases				Per 10 years		Cases				Per 10 years		Cases				Per 10 years	
	Never*	Ever	Never*	Ever	OR†	95% CI	OR†	95% CI	Never*	Ever	OR†	95% CI	OR†	95% CI	Never*	Ever	OR†	95% CI	OR†	95% CI
Agriculture and mining																				
Agricultural, animal husbandry and forestry workers	107	19	75	17	1.9	0.8 to 4.3	1.7	0.9 to 3.1	36	8	2.3	0.7 to 7.1	2.2	1.0 to 4.7	25	6	1.9	0.6 to 6.5	1.4	0.7 to 2.8
Production																				
Manufacturers of paper and paper products; printers	113	5	77	6	2.9	0.7 to 11.6	1.4	0.7 to 2.6	36	4	4.4	0.8 to 24.1	1.2	0.4 to 3.1	27	2	1.7	0.2 to 12.3	1.2	0.5 to 2.9
Metal processors, blacksmiths	112	4	77	4	2.1	0.4 to 11.3	1.0	0.3 to 3.0	37	1	1.7	0.1 to 33.2	0.9	0.04 to 18.9	26	2	3.0	0.4 to 24.2	0.2	0.01 to 3.4
Metal workers (machinery fitters, machine assemblers, mechanics, manufacturers of precision instruments, plumbers, welders, sheet metal and structural metal preparers and erectors)	108	19	75	10	1.3	0.5 to 3.6	1.3	0.7 to 2.2	37	5	2.8	0.7 to 10.5	2.2	1.0 to 5.1	26	3	0.7	0.1 to 3.5	1.2	0.5 to 2.5
Electrical and electronics workers	112	7	77	4	2.2	0.5 to 9.4	2.0	1.0 to 4.2	37	1	1.0	0.1 to 11.1	2.7	0.9 to 8.1	26	3	3.9	0.7 to 22.6	3.0	1.2 to 7.6
Spinners, weavers, knitters, dyers, tailors, dressmakers	107	26	76	27	1.3	0.6 to 2.7	1.4	0.9 to 2.1	36	20	1.7	0.7 to 3.9	1.4	0.9 to 2.2	27	2	0.6	0.1 to 2.5	1.5	0.8 to 2.9
Tanners, fellmongers, pelt dressers; shoemakers and leather goods makers	113	5	78	5	0.9	0.2 to 4.1	0.8	0.4 to 1.6	37	2	0.4	0.1 to 3.6	0.9	0.5 to 2.0	27	2	2.1	0.3 to 16.2	0.7	0.2 to 2.7
Food and beverage processors, tobacco product makers	110	7	73	17	4.1	1.4 to 11.8	3.6	0.8 to 16.9	36	7	2.9	0.8 to 11.2	2.3	0.5 to 10.6	23	9	7.3	2.0 to 27.3	8.7	0.7 to 102
Construction workers (structural engineers, civil engineers)	113	3	77	5	4.6	0.7 to 30.8	6.8	1.2 to 39.3	37	2	2.4	0.2 to 25.6	12.9	0.9 to 186	26	2	3.2	0.2 to 46.1	10.1	0.5 to 199
Plasterers, insulators, glaziers, terrazzo workers, construction carpenters, roofers, upholsterers	113	3	78	4	2.4	0.4 to 13.8	1.1	0.6 to 2.1	37	1	—	—	—	—	27	1	–	–	–	–
Woodworkers and plastic workers (carpenters, cabinet makers, wooden or plastic models makers, wood-frame construction)	114	3	77	3	0.8	0.1 to 5.2	0.7	0.3 to 1.5	37	1	—	—	—	—	26	2	1.4	0.2 to 11.6	0.6	0.05 to 7.1
Labourers‡	113	3	78	10	7.6	1.7 to 34.2	5.3	0.5 to 55.1	37	3	2.2	0.3 to 17.7	0.7	0.03 to 152	27	4	6.3	1.0 to 39.2	4.0	0.7 to 23.4
Technology																				
Technicians (engineers, architects, chemists, physicists, electrical engineering technicians)	110	15	77	7	0.7	0.2 to 2.3	1.1	0.7 to 1.7	37	2	0.5	0.1 to 3.3	1.4	0.6 to 3.0	26	5	1.0	0.2 to 3.9	1.0	0.6 to 1.9
Other blue-collar work§																				
Miners, quarrymen, woodworkers, fitters, painters, quality checkers, machinists	109	11	78	7	1.2	0.4 to 4.2	1.3	0.6 to 2.6	37	5	2.3	0.5 to 10.4	1.5	0.6 to 3.6	27	–	–	–	–	–
Total: Blue-collar work as the main occupation	114	111	78	115	1.6	1.0 to 2.5			37	70	1.7	1.0 to 3.1			27	31	1.2	0.6 to 2.5		

AD, Alzheimer's dementia; VD, vascular dementia.
*''Never exposed''-category: having never worked in the mentioned occupational group and having held a white-collar job as the main occupation (= reference category).
†Adjusted for age, region, sex, dementia in parents and smoking (pack-years).
‡Unskilled workers who performed various—mostly short-term—jobs (eg, factory work, assembly-line work, home help).
§Occupational groups with <5 probands were combined in the category ''other blue-collar work''.
–Less than five probands (OR are not reported).

Table 3 Exposure to low-frequency magnetic fields and dementia (dementia of any type, possible Alzheimer's disease and possible vascular dementia)

		All cases with dementia (n = 195)			Cases with possible AD (n = 108)			Cases with possible VD (n = 59)		
Variable	Referents (%)	Cases (%)	Adjusted OR*	95% CI	Cases (%)	Adjusted OR*	95% CI	Cases (%)	Adjusted OR*	95% CI
Cumulative exposure to electromagnetic fields (according to expert rating)										
<2.5 μT*years	90 (39.3)	105 (53.8)	1.0	—	61 (56.5)	1.0	—	28 (47.5)	1.0	—
2.5–<4.5 μT*years	66 (28.8)	41 (21.0)	0.6	0.4 to 1.1	25 (23.1)	0.7	0.3 to 1.3	11 (18.6)	0.8	0.3 to 1.8
4.5–<16.6 μT*years	62 (27.1)	43 (22.1)	0.8	0.4 to 1.4	20 (18.5)	0.8	0.4 to 1.8	16 (27.1)	1.0	0.4 to 2.3
⩾16.6 μT *years	11 (4.8)	6 (3.1)	1.4	0.4 to 4.9	2 (1.9)	1.8	0.3 to 10.6	4 (6.8)	2.7	0.6 to 12.0
Maximum exposure to electromagnetic fields (according to expert rating)										
⩽100 nT	83 (37.4)	91 (50.3)	1.0	—	53 (53.0)	1.0	—	26 (45.6)	1.0	—
100 nT–200nT	115 (51.8)	74 (40.9)	0.8	0.5 to 1.2	40 (40.0)	0.8	0.4 to 1.5	25 (43.9)	0.9	0.4 to 1.9
200 nT–1 μT	19 (8.6)	12 (6.6)	0.7	0.3 to 1.8	6 (6.0)	0.7	0.2 to 2.6	3 (5.3)	0.7	0.2 to 3.2
>1 μT†	5 (2.3)	4 (2.2)	2.3	0.5 to 11.8	1 (1.0)	2.1	0.2 to 23.6	3 (5.3)	3.3	0.5 to 21.6

AD, Alzheimer's dementia; VD, vascular dementia.
*Adjusted for age, region, sex, dementia in parents and smoking (pack-years).
†Owing to small numbers, exposure to magnetic fields >1 μT is combined into one exposure category.

not shown here). We give ORs for having worked 10 years in specific occupations in addition to ORs for the ever–never comparison.

To analyse the relationship between exposure to magnetic fields and dementia, the categorised cumulative exposure to magnetic fields according to the expert assessment was included in the logistic regression model. As peak exposure rather than cumulative exposure might raise the risk for dementia, we additionally calculated ORs for the maximum exposure to magnetic fields according to expert rating. We calculated the ORs for the single factors separately for all cases with dementia, for cases solely with possible Alzheimer's disease and for cases solely with possible vascular dementia.

RESULTS

Occupational groups and dementia

Table 2 gives the ORs for the relationship between major occupational groups and dementia in total. The OR was significantly increased for people having ever worked as a food or beverage processor (OR 4.1; 95% CI 1.4 to 11.8) or as a labourer (unskilled workers who performed various—mostly short-term—jobs; OR 7.6; 95% CI 1.7 to 34.2). When the years having worked in specific occupational groups was included as a continuous variable in the logistic regression model, we found an OR of 2 (95% CI 1.0 to 4.2) having worked 10 years as electrical or electronics workers. Furthermore, we found an OR of 6.8 (95% CI 1.2 to 39.3) having worked 10 years as a construction worker. When participants with blue-collar jobs as the main occupation were compared with those with white-collar jobs, the OR for dementia of any type was increased to 1.6 (95% CI 1.0 to 2.5).

When the case group was restricted to patients with possible Alzheimer's disease (table 2), having worked as an agricultural, animal husbandry, and a forestry worker was positively associated with the diagnosis of dementia (OR for having worked 10 years as an agricultural worker 2.2; 95% CI 1 to 4.7). The association between the duration of work as a metal worker and the diagnosis of possible Alzheimer's disease was of borderline statistical significance (OR for 10 years 2.2; 95% CI 1 to 4.7. When participants with blue-collar jobs as the main occupation were compared with those with white-collar jobs, the OR for Alzheimer's disease was increased to 1.7 (95% CI 1 to 3.1).

As table 2 shows, having worked as an electrical and electronics worker (OR for 10 years 3; 95% CI 1.2 to 7.6) as well as a food and beverage processor (OR for having ever worked as a food and beverage processor 7.3; 95% CI 2.0 to 27.3) and a labourer (OR for having ever worked as labourer 6.3; 95% CI 1 to 39.2) was associated with possible vascular dementia. However, the numbers are very small. Blue-collar work in general was not significantly associated with vascular dementia.

Exposure to magnetic fields and dementia

Table 3 shows the ORs for the association between exposure to magnetic fields and dementia of any type, possible Alzheimer's dementia and possible vascular dementia. Cumulative exposure to magnetic fields and maximum exposure to magnetic fields were not significantly associated with any diagnosis of dementia.

DISCUSSION

In this study, some occupations with probable exposure to magnetic fields were significantly associated with the diagnosis of dementia. We observed an increased risk for dementia among electrical and electronics workers as well as among construction workers; furthermore, we found an increased risk for Alzheimer's disease among metal workers. However, we could not find any association between cumulative or peak (maximum) exposure to magnetic fields and dementia.

The relationship between the above-mentioned occupational groups and dementia might be alternatively explained by chemical exposures (eg, solvents), psychosocial factors (eg, scarcely challenging jobs[17]) or by chance. When challenge at work—assigned to cases and controls by linking lifetime job titles with a Finnish job-exposure matrix called FINJEM[17 24]—was included as a confounder in an additional occupational group analysis, electrical and electronics workers were no longer significantly associated with Alzheimer's disease; also, metal workers were no longer significantly associated with dementia of any type. When adjusting for challenge at work, likewise, the association between dementia and blue-collar work in general lost its statistical significance. The increased risk for dementia of subjects having worked in blue-collar occupations potentially exposed to magnetic fields might therefore at least partly reflect the increased risk for dementia in less challenging jobs.

Next of kin might frequently not be familiar with detailed job tasks, potentially introducing differential misclassification of BAuA expert assessment. Indeed, agreement between subjects and next of kin was relatively weak for expert-rated cumulative exposure to magnetic fields (see section Agreement between participants and next of kin). However, the comparison of magnetic fields according to expert assessment based on self-interviews versus next of kin interviews did not provide evidence for a systematic misclassification of exposure to magnetic fields on the basis of the next of kin job history. We therefore regard a differential misclassification of the BAuA expert assessment as rather improbable. Furthermore, when exposure to magnetic fields was assessed by the Finnish job-exposure matrix FINJEM[24] (a method less prone to misclassification by next of kin interviews), again, we did not find any significant relationship between exposure to magnetic fields and the diagnosis of dementia (results not shown; supplementary tables are available from the authors).

Previous studies on the relationship between electromagnetic fields and dementia lead to ambiguous results. This might depend on differences in the exposure assessment. Although, for example, three case–control studies[7–9] assigned dressmakers, seamstresses and tailors to the ''medium to high'' exposure to magnetic field category, two other studies[4 11] applying a Swedish job-exposure matrix[25] did not regard these occupations as exposed at all. Interestingly, in the first study conducted by Sobel *et al*,[7] 23 of 36 patients with Alzheimer's disease in the ''medium to high'' exposure category had worked as dressmakers, seamstresses or tailors as their main occupation. When dressmakers and tailors are regarded as non-exposed in the case–control studies conducted by Sobel *et al*,[7 8] the relationship between exposure to magnetic fields and Alzheimer's disease loses its statistical significance (own calculation based on Sobel *et al*[7 8]). As a potential alternative explanation, the authors take into consideration that some seamstresses, dressmakers and

Main messages

- In a case–control study, low-frequency magnetic fields assessed by expert rating were not associated with the diagnosis of dementia.
- The increased risk for dementia of subjects in blue-collar occupations potentially exposed to magnetic fields might at least partly reflect the increased risk for dementia in less challenging jobs.

Policy implications

- Further studies should consider the increased risk for dementia in blue-collar occupations.

tailors might have worked in dry-cleaning establishments. This might be also the case in our study, in which dyers were explicitly included in the occupational group ''spinners, weavers, knitters, dyers, tailors or dressmakers''. Although in our study the occupational group ''spinners, weavers, knitters, dyers, tailors or dressmakers'' is non-significantly associated with dementia (OR for having worked 10 years in this occupations 1.4; 95% CI 0.9 to 2.1), the heterogeneity of this group might mask increased risks among specific occupations (eg, dyers). However, the numbers in our study are too small to further examine the risks among specific occupations. Altogether, there is a need for further epidemiological research considering the possibly increased risk for dementia of dyers, tailors and dressmakers.

In a nested case–control study using US mortality data, Savitz *et al*[2] found a slightly increased risk for Alzheimer's disease among electricians and among power-plant operators, but not among others in occupations exposed to magnetic fields (eg, electrical engineers). Analysing virtually the same dataset, but using ''all mentions'' on the death certificate rather than underlying causes alone, Schulte *et al*[3] found increased proportionate mortality ratios for Alzheimer's disease among occupations that could have been exposed to electromagnetic fields. However, no specific assessment was conducted relating to exposure to magnetic fields. Estimating cumulative exposure to magnetic fields in a death certificate-based cohort study of electric utility workers, Savitz *et al*[6] did not find a significant association between exposure to magnetic fields and mortality from Alzheimer's disease. By contrast, two recently published Swedish death certificate-based studies[1 4] showed significantly increased risks for Alzheimer's disease in subjects exposed to magnetic fields. These two studies show considerable overlap in the observed study populations; moreover, they use the same job-exposure matrix[25] to assess exposure and the same method to identify occupations. In the Swedish study mentioned, [1] which included relatively young subjects (very few subjects were >76 years at the end of follow-up), welders comprised 70% of the highest exposure group. As welders are exposed to metal fumes containing established neurotoxicants such as lead, aluminium and manganese, a possible role of other risk factors cannot be excluded in the mentioned study.[26] In the second Swedish study,[4] significantly increased risks for Alzheimer's disease could be found among subjects who died before 75 years, but not among subjects who died after 75 years. As our study predominantly includes patients with dementia >75 years at the time of diagnosis, our study allows no conclusions with regard to early-onset dementia. In general, mortality studies are not able to take disease onset or age at diagnosis into account. Therefore, the results based on mortality data might be biased by a long latency and survival if the diagnosis or a long premorbid phase has an effect on the exposure.

As preclinical onset of dementia might precede its clinical manifestation by many years or even decades[27–29]; in an additional lag-time analysis, we restricted our analysis to exposure to magnetic fields which had occurred ⩾30 years before diagnosis (the results of this sub-analysis are available from the authors). However, we could not find any significant positive relationships.

In their methodologically striking long-term cohort study, Qiu *et al*[13] based their exposure assessment on the above-mentioned Swedish job-exposure matrix,[25] completed with direct measurements for occupations that were not listed in the matrix. The authors did not find an association between exposure to magnetic fields in the last job and the diagnosis of dementia, whereas exposure to magnetic fields in the primary occupation is related to late-onset dementia in men, but not in women. As a possible explanation for the sex difference, the authors discuss a generally lower exposure to magnetic field level combined with a greater misclassification of the exposure among women. When our case–control study was analysed separately for both sexes, we did not find any significant increase in risk either among men or women exposed to magnetic fields. However, numbers are low particularly in the analysis of men alone.

The strengths of our study include the calculation of cumulative exposure to magnetic fields during the entire worktime and adjustment for multiple potential confounders. However, limitations of this analysis should be considered when interpreting the results. In our study, the moderate agreement between the job-exposure assessment and the expert rating of exposure to magnetic fields suggests a considerable misclassification of exposure. Furthermore, we were not able to control for potential confounding by residential exposure to magnetic fields. However, the community degree of urbanisation (rural, mixed or urban) did not constitute a significant predictor of the exposure to magnetic fields in a measurement-based German study.[22]

Subjects who were exposed to high magnetic fields might have died before they had a chance to develop dementia. In a cohort of utility workers, Savitz *et al*[30] found evidence of increased risk of mortality from acute myocardial infarction and arrhythmia-related heart disease in workers exposed to magnetic fields. However, several other epidemiological studies have failed to confirm this result.[31–33] Summarising, there is no conclusive evidence for an increased cardiac mortality of workers exposed to magnetic fields.

Recall bias might have been introduced into the study by the choice of the interviewed persons: in cases, mostly children or partners were interviewed; in controls, predominantly self-interviews were conducted. To further elucidate this potential bias, we evaluated the agreement between the participants and next of kin on exposure to magnetic fields among controls by conducting 49 additional next of kin interviews (39 partner interviews, 7 child interviews and 3 other next of kin interviews). Agreement was relatively weak for expert-rated cumulative exposure to magnetic fields. However, we found no evidence for a systematic overestimation or underestimation of exposure to magnetic fields on the basis of the next of kin job history. We nevertheless admit that the partner might remember the job and duration of the job better than a child or another person. In fact, with regard to expert-based cumulative exposure, agreement tended to be higher between partner and self-interviews than between child and self-interview. However, when we restricted cases to patients whose partner had been interviewed (n = 42; excluding, among other things, child interviews), this did not substantially alter the risk estimates for exposure to magnetic fields (results not shown). Finally, we cannot totally exclude that the presence of a patient with dementia in the family might have influenced the next of kin report of the job titles. However, we believe that ''bare facts'' such as job titles and industries might, to a low extent, be influenced by the knowledge about the dementia status.

The results of the occupational group analysis have to be interpreted with caution, as multiple testing might have led to false-positive results. The occupational group analysis should therefore be regarded as hypothesis-generating.

Owing to its relatively small sample size, the ability of our study is strongly limited to detect high-dose magnetic field effects. However, in three recently conducted cohort studies estimating magnetic field levels, a pronounced increase in risk for dementia was found even for relatively low exposure to magnetic field levels. Hakansson *et al*[1] found a relative risk for mortality from Alzheimer's disease of 4 (95% CI 1.4 to 11.7) for people exposed to >0.53 μT. Feychting *et al*[4] observed an increased risk of mortality from Alzheimer's disease of 2.3 (95% CI 1.5 to 3.3) among men exposed $\geqslant 0.5$ μT both in 1970 and 1980; the risk of mortality from Alzheimer's disease was 1.5 (95% CI 1.1 to 2.1) among men exposed to $\geqslant 0.3$ μT. Among men whose exposure to magnetic fields in the lifetime principal job was $\geqslant 0.2$ μT, Qui *et al*[13] found a relative risk of 2 (95% CI 1.1 to 3.7) for dementia in total and a relative risk of 2.3 (95% CI 1.0 to 5.1) for Alzheimer's disease. Owing to small numbers, the power of our study is limited to detect slight increases in risk: if the prevalence of peak exposure to magnetic fields $\geqslant 0.2$ μT (10.9%) among the controls was equal to the true prevalence, the power of our study would be sufficient ($\beta = 80\%$) to detect an OR of 2.3; the power would be 66% to detect an OR of 2. The power of our study might therefore have been insufficient to detect a slightly increased risk for dementia. Furthermore, the power of our study is limited to detect increased risks for dementia subgroups. Mainly owing to the limited power of our study, we cannot exclude an aetiological relevance of high-dose electromagnetic fields on dementia. According to our data, we nevertheless regard a strong effect of low-dose electromagnetic fields on the development of late-onset dementia as rather improbable.

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