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## Occupational exposure to magnetic fields in case-referent studies of neurodegenerative diseases

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**Objectives** Case-referent studies of Alzheimer's disease, amyotrophic lateral sclerosis, and Parkinson's disease were conducted to explore the relationship between these neurodegenerative diseases and occupational exposure to magnetic fields. Three methods of exposure assessment were used for the comparison, and the consistency of findings between these approaches was evaluated.

**Methods** Separate case-referent sets were formed from among recorded deaths of males in the state of Colorado for the years 1987 through 1996. The following three methods of exposure assessment were used: a dichotomous grouping of electrical versus nonelectrical occupations, a three-tiered grouping of potential magnetic-field exposure based on a combination of job title and industry, and categories of exposure based on the means of the magnetic fields estimated from a job-exposure matrix.

**Results** A positive association was observed for Parkinson's disease with all the methods of magnetic-field exposure assessment, the odds ratio (OR) for the highest category in the job-exposure matrix being 1.50 [95% confidence interval (95% CI) 1.02–2.19]. Amyotrophic lateral sclerosis was associated with a history of electrical occupations (OR 2.30, 95% CI 1.29–4.09) but not with magnetic-field exposure as estimated by the job-exposure matrix. No consistent associations with magnetic fields were observed for Alzheimer's disease.

**Conclusions** This study provides some support for an association between occupational magnetic-field exposure and Parkinson's disease, but the findings are novel and require replication. Associations with the other neurodegenerative diseases were inconsistent and dependent on the method of exposure assessment.

**Key terms** Alzheimer's disease, amyotrophic lateral sclerosis, electrical occupations, job-exposure matrix, Parkinson's disease.

Recent epidemiologic studies of occupational exposure to magnetic fields have found evidence of an increased risk for neurodegenerative diseases. Several investigations have observed an association between magnetic-field exposure and a risk of amyotrophic lateral sclerosis (1–6). Persons employed in occupations considered to have medium-to-high exposure to magnetic fields have also been shown to be at increased risk for Alzheimer's disease (7–9), but this finding has not been observed consistently (1, 2, 6). Currently, there is no strong support for a similar association with Parkinson's disease (1, 2, 6), but welders, who have high exposures to magnetic fields, were overrepresented among the cases in one study (10).

We conducted death-certificate-based case-referent analyses of these outcomes using the following three

approaches to assess exposure: a dichotomous grouping of electrical versus nonelectrical occupations, a three-tiered grouping of potential magnetic-field exposure based on a combination of job title and industry, and estimates of mean magnetic-field values from a job-exposure matrix. Within each case-referent study dataset, we evaluated the consistency of results obtained for the three methods of exposure assessment and identified job titles that accounted for the disparities.

### Subjects and methods

#### Study population

Death certificate data were collected from the Vital Statistics Unit of the Colorado Department of Public Health

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and Environment. Three separate case-referent sets were formed from among recorded deaths for males in the years 1987 through 1996. Cases were selected based on any mention of Alzheimer's disease [International Classification of Diseases (ICD) code 331.0), amyotrophic lateral sclerosis (ICD code 335.2), or Parkinson's disease (ICD code 332.0)]. In an attempt to reduce the the number of early onset cases of presumed familial origin, the inclusion of persons with Alzheimer's disease was restricted to an age at death of 60 years or more. Cases of amyotrophic lateral sclerosis and Parkinson's disease were selected with an age-at-death restriction of 30 years or more to allow for sufficient occupational exposure.

Male referents were selected separately for each disease group and were frequency matched by 5-year age intervals and year of death. Because of the small number of cases of amyotrophic lateral sclerosis, we used a 4:1 referent-to-case ratio for this analysis. A 1:1 referent-to-case ratio was employed for the other diseases. These selection criteria provided an 80% power to detect an odds ratio (OR) of 2.0 at the 95% confidence level for a dichotomous exposure. Death certificates with a mention of leukemia, brain cancer, or breast cancer were ineligible for referent selection since magnetic fields are a putative risk factor for these diseases. Death certificates with any mention of the three neurodegenerative diseases of interest were also ineligible for referent selection. The descriptive data studied are presented in table 1 for the cases and referents for each disease. For all three case-referent groups, there was a higher proportion of cases among non-Hispanic whites, those with 12 or more years of education, and those with professional or managerial occupations.

### Exposure assessment

All death certificates included the person's primary lifetime occupation and industry, classified with 3-digit codes based on the 1980 United States Bureau of Census Classified Index of Industries and Occupations (11). For male decedents in Colorado during 1987 through 1996, less than 2% of the death certificates had the occupation recorded as unknown.

We assessed risk using three systems of exposure classification. The first method applied a dichotomous exposure classification used previously to identify persons with electrical occupations as having probable high exposure to magnetic fields (1, 12, 13). The electrical occupations used in these studies included electrical and electronic technicians and engineers, repairers of electronic equipment, telephone and telephone line installers and repairers, electricians, electric power installers and repairers, supervisors of electricians and power transmission installers, power plant operators, motion

picture projectionists, and broadcast equipment operators (1, 12, 13).

The second method used a tiered assignment of exposure that has been employed in death-certificate-based case-referent studies of magnetic-field exposure and brain cancer (14, 15). This approach classified people into one of four exposure categories according to a combination of occupation and industry codes. For this study, the two highest categories (definite and probable magnetic-field exposure) were combined due to the low number of persons found in the second tier of exposure.

In the third method of exposure assessment, a population-based job-exposure matrix was used to assess exposures to power-frequency magnetic fields. The job-exposure matrix compiled approximately 2400 magnetic-field measurements taken in 10 studies in the United States, Sweden, New Zealand, Finland, and Italy. A large fraction (97%) of the magnetic-field data collected with this matrix came from full-shift personal sampling; spot measurements comprised only 3% of the

**Table 1.** Descriptive data for the male cases and referents for Alzheimer's disease, amyotrophic lateral sclerosis, and Parkinson's disease in Colorado, 1987–1996.

Attribute	Alzheimer's disease <sup>a</sup>		Amyotrophic lateral sclerosis <sup>b</sup>		Parkinson's disease <sup>c</sup>	
	Cases (N)	Referents (N)	Cases (N)	Referents (N)	Cases (N)	Referents (N)
Age at death						
30–39 years	–	–	7	28	1	1
40–49 years	–	–	21	84	1	1
50–59 years	–	–	43	172	10	10
60–69 years	80	80	95	380	80	80
70–79 years	489	489	98	392	553	553
≥ 80 years	987	987	48	192	832	832
Race						
Non-Hispanic white	1532	1504	309	1197	1455	1441
Other	24	52	3	51	22	36
Education <sup>d</sup>						
≥ 12 years	797	740	200	715	800	716
< 12 years	445	483	61	310	398	475
Year of death						
1987–1991	717	717	148	592	647	647
1992–1996	839	839	164	656	830	830
Occupational grouping <sup>e</sup>						
Managerial or professional	410	368	114	283	405	358
Technical, etc	295	256	61	227	297	240
Service, etc	851	932	137	738	775	879

<sup>a</sup> Total number: 1556 cases and 1556 referents.

<sup>b</sup> Total number: 312 cases and 1248 referents.

<sup>c</sup> Total number: 1477 cases and 1477 referents.

<sup>d</sup> There were no educational data available for 1987–1988 records.

<sup>e</sup> Occupations were grouped into the following broad categories: (i) managerial or professional, (ii) technical or sales or administrative support, (iii) service or farming or craft or repair or operators or fabricators or laborers.

total data of the matrix. Job descriptions from each study were coded into the 1980 Standard Occupational Classifications and then translated to the 1980 job categories of the United States Bureau of the Census. The job categories recorded on the death certificates were assigned workday-average geometric mean magnetic-field values from the job-exposure matrix. Based on these values, people were assigned to one of four exposure groups determined by cut points that have been used previously in epidemiologic studies (9). The highest exposure category ( $\geq 0.30 \mu\text{T}$ ) captured the top 4–6% of the cases for the three diseases studied. The job-exposure matrix contained geometric mean values for 85% of the job titles in our data sets, accounting for 79–84% of the persons. The proportions of cases and referents for which the data of the job-exposure matrix were missing were similar.

### Data analyses

We performed unconditional logistic regression with SAS 6.12 (SAS Institute, Inc., Cary, NC) on each case-referent group to test for associations between each disease and each of three magnetic-field exposure methods. All the odds ratios for the magnetic-field exposure methods were adjusted for age, race, and a social class variable. Social class was assigned to three levels that were based on broad occupational categories. This approach was taken to control for socioeconomic status as a potential confounder rather than years of education since data for education were not available for the first 2 years of our study. There were no substantial changes in the risk estimates when education was included in the

analyses. We also explored the effect of classifying by specific job titles posthoc to determine how different classification schemes may have accounted for varied results.

### Results

The results of the analyses of each case-referent group are shown using three different approaches to exposure assessment (table 2). When magnetic-field exposure was defined by electrical occupations (method 1) or the job-exposure matrix (method 3), we did not observe any elevation in risk for Alzheimer's disease. With the use of a combination of job title and industry (method 2), a weak imprecise association was found for Alzheimer's disease in the highest category of exposure [adjusted OR 1.21, 95% confidence interval (95% CI) 0.83–1.76]. A posthoc review of the occupational distribution of the cases and referents indicated that the change in the risk estimate with this method was due primarily to the inclusion of aerospace engineers in the high-exposure stratum and the reassignment of electrical technicians not employed in the utility or telecommunications industry to a lower stratum.

For amyotrophic lateral sclerosis, there was an elevation in risk using both methods 1 and 2 (adjusted OR 2.30, 95% CI 1.29–4.09, and 1.75, 95% CI 1.00–3.06, respectively). No elevated risk for amyotrophic lateral sclerosis was observed when the job-exposure matrix

**Table 2.** Adjusted odds ratios (OR) for each case-referent group using three methods of magnetic field exposure assessment. <sup>a</sup> (95% CI = confidence interval)

	Alzheimer's disease			Amyotrophic lateral sclerosis			Parkinson's disease		
	Cases	Adjusted OR	95% CI	Cases	Adjusted OR	95% CI	Cases	Adjusted OR	95% CI
<b>Method 1</b>									
Nonelectrical	1503	1.00	.	293	1.00	.	1430	1.00	.
Electrical	53	1.05	0.71–1.56	19	2.30	1.29–4.09	47	1.55	0.98–2.45
<b>Method 2<sup>b</sup></b>									
No exposure	1209	1.00	.	242	1.00	.	1141	1.00	.
Possible exposure	285	1.15	0.95–1.39	51	1.18	0.83–1.67	272	1.17	0.96–1.42
Definite or probable exposure	62	1.21	0.83–1.76	19	1.75	1.00–3.06	64	1.76	1.17–2.65
<b>Method 3</b>									
< 0.10 $\mu\text{T}$	218	1.00	.	59	1.00	.	202	1.00	.
0.10–0.19 $\mu\text{T}$	786	0.95	0.76–1.19	134	0.79	0.54–1.15	739	1.16	0.92–1.45
0.20–0.29 $\mu\text{T}$	229	0.83	0.63–1.10	51	1.21	0.75–1.93	216	1.04	0.78–1.37
$\geq 0.30 \mu\text{T}$	73	1.01	0.68–1.49	12	0.77	0.37–1.59	88	1.50	1.02–2.19
Unknown	250	0.99	0.75–1.31	56	0.83	0.52–1.31	232	1.02	0.77–1.36

<sup>a</sup> All odds ratios adjusted for age, race (white or nonwhite) and occupational grouping (managerial or professional, technical or sales or administrative support, service or farming or craft or repair operators or fabricators or laborers).

<sup>b</sup> Definite or probable magnetic-field exposure for method 2 included serviceman, lineman, and foreman in the electric or telephone industry; engineer and technician in the railroad, electric, aerospace, or telecommunications industry; electrician; dispatcher; repairman in the appliance or telecommunications industry; and welder [based on Lin et al (14)].

was used to assess the exposure. Most of the elevated risk for amyotrophic lateral sclerosis in methods 1 and 2 was due to electrical or electronic technicians and engineers, job titles assigned geometric mean exposure values that were relatively low (0.19–0.26  $\mu\text{T}$ ).

The most consistent associations with estimated magnetic-field exposure across the methods of exposure assessment were found for Parkinson's disease (table 2). The use of a tiered system of estimated exposure (method 2) provided the strongest evidence of an association. The adjusted odds ratio for combinations of job title and industry with definite or probable magnetic-field exposure was 1.76 (95% CI 1.17–2.65). A review of nonelectrical magnetic-field-related occupations used in method 2 found welders to be overrepresented among the Parkinson's disease deaths. We observed 12 welders with Parkinson's disease versus 6 welders among the referents (adjusted OR 2.26, 95% CI 0.85–6.06). When the job-exposure matrix was used, persons in the highest exposure category had an elevated odds ratio (adjusted OR 1.50, 95% CI 1.02–2.19), but there was no evidence of a trend by exposure level.

The definition of the high-exposure job titles differed according to the different exposure assessment methods used. Table 3 lists the 15 electrical job titles traditionally considered to have high magnetic-field exposure and their corresponding geometric means from the job-exposure matrix. Some of these job titles, such as electric power installers or repairers and power plant operators, were assigned high exposure values. However, several titles within this group had considerably lower values and ranked relatively low when compared with other job titles represented in the Alzheimer's disease case-referent study. Four of these electrical occupations for which there were adequate data did not fall into the top two tiers of estimated exposure according to the job-exposure matrix (0.20–0.29  $\mu\text{T}$  and  $\geq 0.3 \mu\text{T}$ ). Of the 15 job titles with the highest geometric mean assigned by the job-exposure matrix, only 6 were included among the electrical occupations (data not shown). The two occupations in the case-referent study on Alzheimer's disease with magnetic-field-exposure estimates higher than any of the electrical occupations were textile sewing machine operators (2.99  $\mu\text{T}$ ) and welders (0.95  $\mu\text{T}$ ).

Nevertheless, the overall estimates of magnetic-field intensity using the job-exposure matrix correlated well with the other methods of exposure assessment. For the Alzheimer's disease case-referent group, the mean job-exposure matrices for electrical versus nonelectrical workers (method 1) were 0.40  $\mu\text{T}$  and 0.15  $\mu\text{T}$ , respectively. The mean job-exposure matrices for persons in the three tiers of exposure based on job title and industry (method 2) were 0.47, 0.20, and 0.14  $\mu\text{T}$ . The occupational grouping of service or labor and others used in the social class variable also had higher overall estimates

of magnetic-field exposure when the job-exposure matrix was used. Eleven of the fifteen electrical occupations were included in this broad occupational category, and the mean of the job-exposure matrices assigned to persons in this group was 0.18  $\mu\text{T}$  versus 0.13  $\mu\text{T}$  for the professional and managerial group.

## Discussion

Previous reports suggested an association between amyotrophic lateral sclerosis and occupations with potential magnetic-field exposure. In a clinic-based study of patients with amyotrophic lateral sclerosis, odds ratios of 7.5 and 5.5 were found for the upper quartiles of magnetic-field exposure when total occupational exposure and average occupational exposure, respectively, were used (3). A review of occupational data from five electric utilities found an association between magnetic fields and amyotrophic lateral sclerosis deaths, particularly for exposures of long duration (2). A study of diseases of the central nervous system among a cohort of former Danish utility workers reported an increase in the standardized incidence ratio for motor neuron

**Table 3.** Geometric mean magnetic field values and rank of electrical occupations based on the job-exposure matrix and their ranking among all occupations observed in the Alzheimer's disease case-referent study.

Job Title <sup>a</sup>	Geometric mean ( $\mu\text{T}$ ) <sup>b</sup>	Rank <sup>c</sup>
Electric power installers and repairers (577)	0.94	3
Power plant operators (695)	0.78	4
Motion picture projectionists (773)	0.63	7
Electricians (575)	0.55	9
Electrician apprentices (576)	0.55	9
Miscellaneous electrical and electronic equipment repairers (533)	0.47	11
Electrical and electronic technicians (213)	0.26	24
Electronic repair, communication, and industrial equipment (523)	0.24	28
Household appliance and power tool repairers (526)	0.23	41
Electrical and electronic engineers (055)	0.19	71
Telephone line installers and repairers (527)	0.17	87
Telephone installers and repairers (529)	0.14	129
Data processing equipment repairers (525)	0.09	198
Broadcast equipment operators (228) <sup>d</sup>	..	..
Supervisors of electricians and power installers and repairers (555) <sup>d</sup>	..	..

<sup>a</sup> Code of the Bureau of Census Classified Index of Occupations and Industry in parentheses.

<sup>b</sup> Time-weighted average geometric mean based on job-exposure matrix.

<sup>c</sup> Exposure ranking of electrical occupations among all job titles represented in the Alzheimer's disease case-referent study.

<sup>d</sup> The job-exposure matrix used in this study did not contain data on the geometric means for these job titles.

disease (6). Each of these recent studies utilized assessments of magnetic-field exposure specific to job title and duration of employment. Three case-referent studies have also identified electrical occupations as a risk factor for amyotrophic lateral sclerosis (1, 4, 16).

Persons with electrical occupations may, however, have greater potential for electric shock events. Three case-referent studies reported history of electrical shock as a specific trauma associated with amyotrophic lateral sclerosis (4, 17, 18), although others failed to support this relationship (19). In our study, the moderate risk for electrical occupations was no longer evident when the persons were assigned to categories of estimated magnetic-field exposure based on the job exposure matrix. These findings support the hypothesis that electric shock or another unidentified variable associated with electrical occupations, rather than magnetic-field exposure, was responsible for the observed associations with amyotrophic lateral sclerosis.

Our findings do not support an association between occupational magnetic-field exposure and Alzheimer's disease when exposure is classified by electrical work (method 1) or the job-exposure matrix (method 3). In a recent series of studies, risk estimates for this association ranged from 2.9 to 3.9, and they were particularly influenced by sewing occupations (7, 8). We were unable to corroborate an association with sewing machine work in this analysis since there were inadequate numbers of men with these job titles in our study population. A Swedish study with more quantitative exposure assessment found a higher risk (OR 2.4 and 2.7) for Alzheimer's disease among subjects whose most recent job had an average magnetic-field exposure of more than 0.2  $\mu\text{T}$  (9). Schulte et al (20) suggested an association between occupations with probable magnetic-field exposure and Alzheimer's disease mortality based on death certificates in over 27 states from 1982 to 1991. Although not hypothesized a priori, an occupational clustering of electrical workers with Alzheimer's disease was found, particularly for electricians, power transmitter installers, electrical and electronic technicians, broadcast operators, and electrical and electronic engineers (21). Savitz et al (1) reported a slightly elevated risk for Alzheimer's disease among persons with electrical occupations (OR 1.2, 95% CI 1.0–1.4), the strongest association being observed for electricians and power plant operators. The first 5 years of our data partially overlapped with this multistate case-referent study (1), but with approximately one-fifth the number of exposed cases we did not have adequate power to detect an elevation in risk of this magnitude. Finally, two cohort studies failed to find elevated risks for Alzheimer's disease deaths among electric utility workers (2, 6), although one analysis demonstrated a modest, yet imprecise, rate ratio of 2.1 for persons with magnetic-field-exposed jobs

for more than 20 years (2). We were unable to evaluate the duration of employment with our data.

We found consistent evidence of an association between Parkinson's disease and history of electrical and other magnetic-field-related occupations using each of the three methods of exposure assessment, but these findings must be considered within the context of previous studies that have assessed this potential relationship. Two retrospective cohort studies (2, 6) and a death certificate-based case-referent study (1) failed to find an association between Parkinson's disease and occupational magnetic-field exposure. However, the death-certificate-based study found modest risks for power plant operators and telephone installers and repairers (1). We did not have adequate data to assess these specific occupations, but we found that welders accounted for some of the observed risk for Parkinson's disease when two of our exposure assessment methods were used. Welders are exposed to high levels of magnetic fields (22), as well as other potentially neurotoxic agents such as metals, and our findings agree with previous observations of an association between welding and a risk of Parkinson's disease (10, 23).

The primary limitation of this study was the inherent inaccuracy associated with the use of death certificates in collecting disease and exposure data. This problem is particularly apparent when neurological disorders with complex case definitions and a high potential for misdiagnosis are considered. Among the three diseases of concern in this study, amyotrophic lateral sclerosis has been accurately reported in at least 87% of cases (24, 25). In contrast, Alzheimer's disease and Parkinson's disease are disorders of long duration, and patients are likely to die of unrelated primary causes. The reporting accuracy for these two diseases was shown to be 60% to 65% for any mention on death certificates (26, 27), but recent trends suggest better reporting for neurodegenerative conditions (28).

Associations with social class and race have been described for several neurodegenerative diseases, especially Alzheimer's disease, and they existed in this population as well (data not shown). Professional and managerial workers, who are less likely to have magnetic-field exposure, were more likely to have these diseases listed on their death certificates. This finding is contrary to reports that higher education and socioeconomic status is protective for Alzheimer's disease (29–31), suggesting that the elevated reporting of these diseases for the professional and managerial occupations in our population may reflect, in part, diagnostic sensitivity bias rather than true risk. Thus we cannot rule out the possibility that the odds ratios presented in table 2 suffer from ascertainment bias and underestimate the risk between these diseases and occupational magnetic-field exposure.

The validity of this study was also dependent upon the accurate recording of occupational data on death certificates. Occupations reported on death certificates have been found to be in agreement with next-of-kin interview or employment records 48% to 76% of the time (32–35). White males, comprising over 97% of our study population, had the highest rate of accuracy for occupational reporting (33). In a study of brain cancer and magnetic-field exposure among utility workers, the accuracy of death certificate coding for exposed occupations was low overall but similar to that for unexposed occupations, and the concordance rates ranged from 54% to 80% for lineman, electricians, power plant operators, mechanics, and welders (35). Reporting accuracy of industry on death certificates, a variable used in one of our exposure assessment methods, ranged from 67% to 75% in previous studies (33–35). Furthermore, death certificate reporting of job titles and industry was restricted to the subject's primary occupation and was limited by the lack of data for duration of employment. Exposure misclassification due to the lack of historical information on individual occupations and the recognized limitations in death certificate reporting of job title and industry would bias the risk estimates toward the null.

In this paper we have shown that the findings for associations between neurodegenerative diseases and magnetic-field exposure are sensitive to the method of exposure assessment used. The grouping of electrical occupations (method 1) as the means of identifying persons having probable occupational magnetic-field exposure has been used in several studies (1, 12, 13). However, this grouping of occupations is not specific with regard to any particular exposure of interest. The use of multiple exposure levels based on job title and industry (method 2) captured additional nonelectrical occupations that had been classified as unexposed, but these exposure categories still included several job titles that would not be described as highly exposed when magnetic-field measurements are evaluated in the occupational setting. The job-exposure matrix (method 3) identified discrepancies between several hypothetically high-exposure electrical occupations and their respective magnetic-field measurements and suggested that the other methods contributed additional misclassification of high-exposure nonelectrical occupations.

This study provides some support for an association between occupational magnetic-field exposure and Parkinson's disease. In view of the fact that associations between magnetic-field exposure and Parkinson's disease have not been described previously, this observation requires replication. The associations with the other neurodegenerative diseases studied were inconsistent and dependent on the method of exposure assessment. Future studies will need to be designed carefully to

assure that the methods of exposure assessment used provide an accurate assessment of each subject's true exposure.

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