

## ORIGINAL ARTICLE

# Case-control study of occupational exposure to electric shocks and magnetic fields and mortality from amyotrophic lateral sclerosis in the US, 1991–1999

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We investigated the relationship between occupational exposure to electric shocks (ES) and magnetic fields (MF) and amyotrophic lateral sclerosis (ALS) using 1991–1999 US mortality data. For each of the 5886 included ALS deaths, 10 controls—matched on sex-, age-, year- and region—were selected from among other deaths. Usual occupation as reported on death certificates was linked to job-exposure matrices for ES and MF. Education and electric occupations were associated with moderately increased ALS risks (odds ratio (OR) = 1.85, 95% confidence interval (CI) = 1.67, 2.04; OR = 1.23, 95% CI = 1.04, 1.47, respectively). For ES, ALS mortality OR were 0.73 (95% CI = 0.67, 0.79) for high and 0.90 (95% CI = 0.84, 0.97) for medium exposure compared with low exposure. For MF, ALS ORs were 1.09 (95% CI = 1.00, 1.19) for high and 1.09 (95% CI = 0.96, 1.23) for medium exposure as compared with low exposure. For electric occupations, ALS ORs were insensitive to adjustments for ES, MF or both. Consistent with previous publications, an association between electric occupations and ALS was observed. Findings do not support occupational exposure to ES or MF as an explanation.

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## INTRODUCTION

Amyotrophic lateral sclerosis (ALS), the most common of the motor neuron diseases (MNDs), is a fatal, incurable disease striking nerve cells in the brain and the spinal cord. With a worldwide incidence rate of 1.2 to 2.5/100,000 per year, the disease affects people between 40 and 75 years of age with the incidence peaking around 70 years.<sup>1–3</sup> ALS dramatically alters the quality of life for the patients and family, emotionally, economically and socially.<sup>4</sup> No environmental or occupational etiologic risk factors for ALS have been identified. In the epidemiologic literature, ALS is consistently related to “electric occupations”, thus warranting further investigation.<sup>5</sup> Opportunities for primary prevention of ALS might be revealed, if modifiable workplace factors, such as electric shocks (ES) or extremely low frequency magnetic fields (MF) have a role in ALS etiology.

Electric fields, contact currents, micro-shocks and perceptible ES all contribute to the extremely low-frequency electromagnetic field environment, of which, MF is only one aspect. The electric work environment, sources of MF and ES, and worker position with respect to those sources may vary by and within job titles. While an association between electric occupations and risk of ALS is consistently reported in the epidemiologic literature, the evidence for an association between ALS and measured extremely low-frequency MF levels is weaker.<sup>6</sup> ES are suggested as a potential explanatory factor for the association between electrical occupations and ALS.<sup>7–9</sup> Currently, no epidemiologic study has explicitly evaluated exposures to occupational ES and ALS.

Occupational exposures to chemical and physical agents may be considerably higher than exposures in the general populations.

Many chemical human carcinogens (e.g., aromatic hydrocarbons) identified in the occupational arena were later recognized as more general environmental hazards. With important clues garnered from occupational exposures, advances in methods and new approaches to epidemiology provide valuable input to understanding the associations between workplace exposures and neurodegenerative diseases.

Using ES and MF job-exposure matrices (JEM) developed for US mortality data,<sup>10</sup> we present the first attempt to examine the association between occupational ES, extremely low-frequency MF and ALS.

## METHODS

### Data Source and Case Ascertainment

Multiple cause-of-death data collected annually were obtained from the National Center for Health Statistics (NCHS), Center for Disease Control and Prevention through the National Bureau of Economic Research.<sup>11</sup> Since the “occupation” variable coding was different prior to 1990 and non-existent after 2000, we examined data between 1991 and 1999. Our source population was all persons who died in the USA during this period (20,593,110 deaths). The variable “occupation”, coded as a three-digit number, was provided to NCHS by a select number of states, representing ~20% of the source population. To combine all years, we recoded the 1991 and 1992 occupation variable that used the 1980 Bureau of Census (BOC) codes to the 1990 BOC codes that were used for years 1993 and later.<sup>12</sup> The study population was further limited to decedents of age 20 years and older to exclude potential cases of familial ALS and to represent the working population. We identified 41,971 deaths with any mention of MND (International Classification of Diseases (ICD)-9 335.2, ICD-10 G12.2). Because ALS makes

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up 90% of MNDs and numerous studies report ALS synonymously with MND, we analyzed all MND and defined it in our study as ALS. Of 7,419 cases that met our inclusion criteria (Figure 1), 5886 had complete data and were the focus of our analysis.

### Control Selection

For each ALS death, 10 controls were selected from among other deaths likely not related to ES and MF exposures. Controls were individually matched to cases on year of death, sex, 5-year age groups and four major regions using modified SAS 9.1 SQL code. Of the 3,929,545 potential controls, a total of 1,828,522 records with any mention of the following diseases possibly related to ES or MF in the underlying or contributing cause-of-death were excluded: leukemia (ICD-9: 204–208; ICD-10: C900, C901, C887, C910–912, C917, C919, C920–C923, C927, C929–932, C937, C939, C940–C942, C947, C950–C952, C957, C959), brain tumors (ICD-9: 191, 225; ICD-10: C71, D320, D321, D332–D334, D337, D339), Parkinson's disease (ICD-9: 332; ICD-10: G20, G211–G213, G218, G219), cerebral degenerations including Alzheimer's disease (ICD-9: 331; ICD-10: G309–G311, G318, G319, G910, G911, G937), senile dementia (ICD-9: 290; ICD-10: F03, F051), cardiovascular diseases (CVD) (ICD-9: 410.0–414.9, 426–427, 430–434.91, 437–438; ICD-10: I20–25, I44–49, I60–69), accidental causes of death owing to electrical current, and/or falls or suicides (ICD-9: E880–888, 950–959, 925; ICD-10: W00–W19, X60–X84, Y870 W86–W87). To assess the potential effect of excluding these diseases, we conducted sensitivity analyses selecting controls from all available decedents.

### Exposure Assessment

Based on "usual occupation" as recorded on the death certificate, we linked codes to two previously developed JEMs containing ES exposure as three-tier category, and MF exposure as geometric mean time-weighted average.<sup>10,13</sup> Using an *a priori* cutoff, we categorized MF exposures into a reference group (or low exposure) less than 0.1  $\mu\text{T}$ , medium (0.1  $\mu\text{T}$ –0.3  $\mu\text{T}$ ) and high (0.3  $\mu\text{T}$  or greater) exposure categories. For ES, three pre-assigned categories were used: low, medium and high, based on the probability of incurring ES on the job.<sup>10</sup> When examining high exposure category for grouped occupations, we combined medium and low into the reference for ES and MF, to have sufficient numbers in each category.

### Data Analysis

To assess the associations of ALS with occupational ES and MF exposures, we conducted univariate and multivariate conditional logistic analyses,

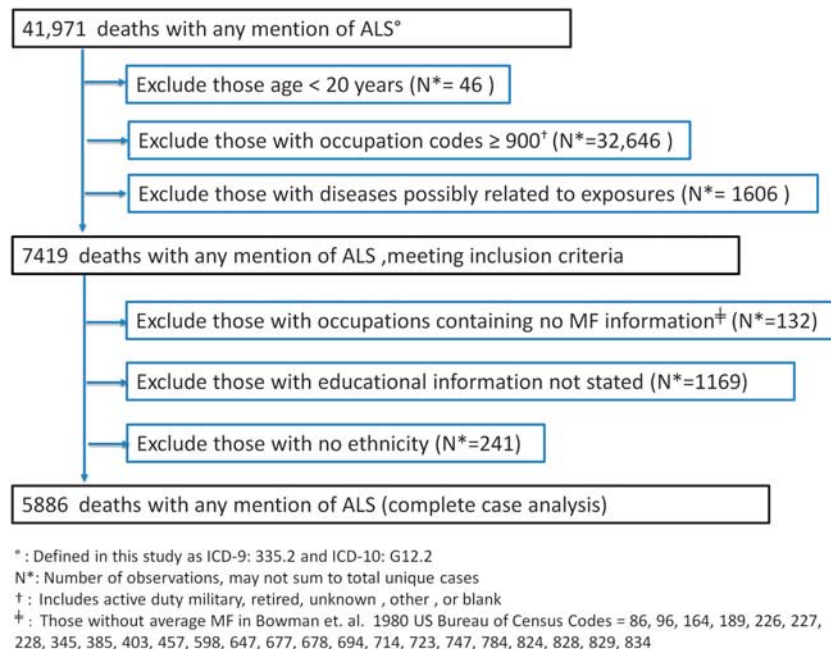
using matching variables based on year of death, sex (male or female), 5-year age groups (20–24, 25–29, 30–34, 35–39, 40–44, 45–49, 50–54, 55–59, 60–64, 65–69, 70–74, 75–79, 80–84, 85–89, 90–94, 95–99, 100–104 or 105–109 year) and region (Northeast, Midwest, South and West). Results are presented as adjusted odds ratios (OR) with 95% confidence intervals (95% CI). Adjustment were made for education (none: 8 years (reference), 9–12 years or 13 or more years), ethnicity (non-Hispanic (reference) or Hispanic) and race (White (reference), Black, Native American or Asian).

We examined occupations as 13 aggregate BOC occupational groups, as well as, 15 electric occupations and 7 welding occupations previously defined in the literature.<sup>14,15</sup> We further examined electric and welding occupations separately, stratified by age (dichotomized at age of 65 years), and by subsets of high exposure categories of ES and MF, to separate these correlated exposures. All analyses were performed using SAS software version 9.1 (SAS Institute, Cary, NC, USA).

## RESULTS

Educational information was missing for 11.7% cases and 17.7% controls and ethnicity was missing for 3.2% cases and 2.7% controls. Complete information on ES and MF exposures, education and ethnicity was available for 5886 cases and 57,667 controls. Of the cases and controls, 63% were male and 61% were between 60 and 79 years of age at death. Table 1 shows the demographic characteristics of the study sample. By region, decedents were from the Midwest (42.3%) and South (24.3%) regions; by state, 33.7% cases and 33.8% controls were from New Jersey, North Carolina and Ohio, combined (data not shown). The proportions of occupations in executive, administrative and managerial (13.5% vs 10.3%) and professional specialty groups (16.0% vs 10.6%) were higher among cases compared with controls. With industry, cases tended to work more in professional related services than controls (20.2% vs 17.0%).

Compared with those with the lowest education (8 years of less), workers with 9–12 years of education had higher odds of ALS death (OR = 1.26; 95% CI = 1.16, 1.39) and workers with 13 or more years of education had the highest odds of ALS death (OR = 1.85; 95% CI = 1.67, 2.04). Lower ALS mortality ORs were observed for Blacks (OR = 0.38; 95% CI = 0.33, 0.43), Native Americans (OR = 0.50; 95% CI = 0.29, 0.86) and Asians (OR = 0.64; 95% CI = 0.47, 0.89) compared with Whites.



**Figure 1.** Case selection for the US multiple cause-of-death data 1991–1999.

**Table 1.** Demographic characteristics of study population, the US multiple cause-of-death data 1991–1999.

	Cases (N = 5886)		Controls (N = 57,667)	
	No.	%	No.	%
<i>Sex</i>				
Male	3672	62.4	36,412	63.1
				0.0
<i>Age</i>				
20–44 years	303	5.1	2959	5.1
45–64 years	1869	31.8	11,685	20.3
65–74 years	2031	34.5	19,697	34.2
75 years or greater	1683	28.6	16,635	28.8
<i>Education</i>				
None–8 years of school	688	11.7	9967	17.3
9–12 years of school	2994	50.9	32,590	56.5
13 or more years of school	2204	37.4	15,110	26.2
<i>Ethnicity</i>				
Non-Hispanic	5810	98.7	56,476	97.9
Hispanic	76	1.3	1191	2.1
<i>Race</i>				
White	5565	94.5	50,128	86.9
Black	266	4.5	6686	11.6
American Indian (includes Aleuts and Eskimos)	14	0.2	283	0.5
Asian	41	0.7	570	1.0
<i>Occupational groups</i>				
Executive, administrative and manag.	793	13.5	5915	10.3
Prof. Specialty	944	16.0	6092	10.6
Technicians and rel. support	118	2.0	1083	1.9
Sales	661	11.2	5705	9.9
Administrative support incl. clerical	715	12.1	6286	10.9
Private household	49	0.8	871	1.5
Protective service	99	1.7	911	1.6
Service, except protective and household	377	6.4	5503	9.5
Farming, forestry and fishing	240	4.1	2708	4.7
Precision production, craft, and repair	908	15.4	9228	16.0
Machine operators, assemblers and inspectors	468	8.0	5651	9.8
Transportation and material moving	254	4.3	3378	5.9
Handlers, equipment cleaners, helpers, and laborers	260	4.4	4336	7.5
<i>Industry</i>				
Ag., forestry, and fisheries	236	4.0	2580	4.5
Mining	85	1.4	666	1.2
Construction	422	7.2	5203	9.0
Manufacturing	1559	26.5	15,442	26.8
Transport., comm., and other public utilities	506	8.6	4858	8.4
Wholesale trade	143	2.4	1303	2.3
Retail trade	673	11.4	6726	11.7
Finance, insurance and real estate	295	5.0	2346	4.1
Business and repair services	183	3.1	2105	3.7
Personal service	158	2.7	2308	4.0
Entertainment and recreation services	41	0.7	495	0.9
Professional and related services	1189	20.2	9796	17.0
Public administration	342	5.8	3096	5.4
Active military duty	6	0.1	55	0.1
Retired; with no other industry reported	48	0.8	688	1.2

Source: National Center for Health Statistics.

When assessed by major occupational groups, we observed moderate associations for professional specialty occupations (OR = 1.47; 95% CI = 1.08, 2.01), executive administrative occupations (OR = 1.34; 95% CI = 0.98, 1.83) and administrative support occupations (OR = 1.27; 95% CI = 0.93, 1.73) as compared with, for example, private household occupations. Associations were stronger for “white collar” occupations when no adjustment for education was made,

particularly for professional specialty and executive administrative occupations. A moderately increased ALS mortality OR was observed for those who worked within electric occupations (OR = 1.23; 95% CI = 1.04, 1.47), with stronger associations for unadjusted ORs (OR = 1.38; 95% CI = 1.15, 1.62). The risk increase for electrical occupations was stronger among those less than 65 years of age; no associations were observed for those of age 65 years or older (Table 2).

**Table 2.** Association of amyotrophic lateral sclerosis and electric and welding occupations within strata of age, electric shocks and magnetic fields, the US multiple cause-of-death data 1991–1999.

	Electric occupations <sup>a</sup>				Welding occupations <sup>b</sup>			
	Cases	Controls	Adjusted OR <sup>c,d</sup>	95% CI	Cases	Controls	Adjusted OR <sup>c,e</sup>	95% CI
Overall	160	1160	1.23	1.04, 1.47	79	1137	0.70	0.55, 0.89
Age less than 65	82	450	1.64	1.28, 2.10	29	419	0.69	0.47, 1.02
Age 65 or greater	78	710	0.97	0.74, 1.34	50	718	0.70	0.53, 0.94
High electric shocks	69	693	1.48	1.05, 2.08	68	1001	0.86	0.61, 1.23
Not high electric shocks	91	467	1.46	1.15, 1.85	11	136	0.68	0.36, 1.28
High MF ( $\geq 0.3 \mu\text{T}$ )	66	624	1.05	0.65, 1.72	40	623	0.58	0.32, 1.04
Not high MF ( $< 0.3 \mu\text{T}$ )	94	536	1.34	1.07, 1.69	39	514	0.77	0.55, 1.08

Abbreviations: CI, confidence interval; OR, odds ratio. Source: National Center for Health Statistics.

<sup>a</sup>Electric occupations (1990 US Bureau of Census Codes): Electrical and electronic engineers (55); electrical and electronic technicians (213); broadcast equipment operators (228); electronic repairers; communications and industrial equipment (523); data processing equipment repairers (525); household appliance and power tool repairers (533); telephone line installers and repairers (526); telephone installers and repairers (529); miscellaneous electrical and electronic equipment repairers (533); supervisors, electricians and power transmission installers (555); electricians (575); electrician apprentices (576); electrical power installers and repairers (577); power plant operators (695) and motion picture projectionists (773).

<sup>b</sup>Welding occupations (1990 US Bureau of Census Codes): Millwrights (544); supervisors, plumbers, pipefitters and steamfitters (557); plumbers, pipefitters and steamfitters (585); plumbers, pipefitters and steamfitter apprentices (587); structural metal workers (597); boilermakers (643) and welders and cutters (783).

<sup>c</sup>Conditional logistic regression models adjusted for education (none–8 years (reference), 9–12 years and 13–17 years), ethnicity (Hispanic or not (reference)), and race (White (reference), Black, Native American and Asian).

<sup>d</sup>Reference category: non-electric occupations.

<sup>e</sup>Reference category: non-welding occupations.

**Table 3.** Exposure distribution and association of amyotrophic lateral sclerosis and occupational ES and MF, US multiple cause-of-death data 1991–1999.

	Cases		Controls		Adjusted OR <sup>a</sup>	95% CI
	Number	%	Number	%		
<b>ES</b>						
High	832	14.2	11,941	20.7	0.73	0.67, 0.79
Medium	1356	23.0	14,509	25.2	0.90	0.84, 0.97
Low	3698	62.8	31,217	54.1	1.0	1.0
<b>MF</b>						
High	503	8.5	5171	9.0	1.09	1.00, 1.19
Medium	4748	80.7	45,517	78.9	1.09	0.96, 1.23
Low	635	10.8	6979	12.1	1.0	1.0

Abbreviations: CI, confidence interval; ES, electric shocks; MF, magnetic fields; OR, odds ratio. Source: National Center for Health Statistics

<sup>a</sup>Conditional logistic regression models adjusted for education (none–8 years (reference), 9–12 years and 13–17 years), ethnicity (Hispanic or not (reference)), and race (White (reference), Black, Native American and Asian).

**Table 4.** Association of amyotrophic lateral sclerosis and ES, MF and electric and welding occupations, US multiple cause-of-death data 1991–1999.

With additional adjustment for	Electric occupations <sup>a</sup>		Welding occupations <sup>a</sup>	
	Adjusted OR <sup>b,c</sup>	95% CI	Adjusted OR <sup>b,d</sup>	95% CI
—	1.23	1.04, 1.47	0.70	0.55, 0.89
ES	1.37	1.14, 1.63	0.83	0.65, 1.06
MF	1.24	1.04, 1.48	0.69	0.54, 0.87
ES and MF	1.34	1.12, 1.60	0.80	0.63, 1.02

Abbreviations: CI, confidence interval; ES, electric shocks; MF, magnetic fields; OR, odds ratio. Source: National Center for Health Statistics

<sup>a</sup>Crude ORs: Electric Occupations, OR = 1.38; 95% CI = 1.15, 1.62, Welding Occupations, OR = 0.65; 95% CI = 0.52, 0.82.

<sup>b</sup>Conditional logistic regression models adjusted for education (none–8 years (reference), 9–12 years and 13–17 years), ethnicity (Hispanic or not (reference)), and race (White (reference), Black, Native American and Asian).

<sup>c</sup>Reference category: non-electric occupations.

<sup>d</sup>Reference category: non-welding occupations.

After controlling for ethnicity, race and education, exposure to ES were inversely associated with ALS mortality. As compared with low ES exposure, the ORs were 0.73 (95% CI = 0.67, 0.79) for high exposure and 0.90 (95% CI = 0.84, 0.97) for medium exposure (Table 3). For MF, ALS mortality ORs were 1.09 (95% CI = 1.00, 1.19) for high exposure and 1.09 (95% CI = 0.96, 1.23) for medium exposure as compared with low exposure (Table 3). We did not detect appreciable changes in the ORs when the analyses were restricted to age 65 or less (data not shown).

We observed moderate associations between electric occupations and ALS mortality (OR = 1.23; 95% CI = 1.04, 1.47). Table 2 also provides stratum-specific ORs for electric occupations and for welding occupations. Similar risk increases were observed in both high ES and low ES strata for electric occupations (Table 2). Within the high MF stratum, the associations for electric

occupations approached the null, which was not observed in the lower stratum. For electric occupations, risk estimates remained consistent regardless of adjustment for ES, MF or both (Table 4).

We observed inverse associations for welding occupations (OR = 0.77; 95% CI = 0.55, 0.89). Among welding occupations, we observed an association similar in magnitude for those less than 65 years of age and age 65 years or greater and within the high and low strata of ES and MF exposures (Table 2). Among welding occupations, no appreciable changes in risk estimate were observed with adjustment for ES, MF or both (Table 4).

To assess the impact of our disease exclusion criteria and investigate selection bias, we analyzed all cases and re-selected controls from among decedents with all other diseases except

ALS. Our findings for ES and MF were similar in magnitude and direction to the above analyses (data not shown).

## DISCUSSION

Among deaths occurring in the USA between 1991 and 1999, we found an association between electric occupations and increased mortality from ALS. We found inverse associations between occupational ES exposure and ALS mortality and no consistent associations between occupational MF exposure and ALS mortality. In our analysis, exposure to ES or MF did not account for the association observed for electric occupations. To our knowledge, we present the first attempt to disentangle two correlated exposures within the electric occupational environment of the general population with respect to ALS mortality.

Currently, there are no known or generally accepted biological mechanisms for the potential effects of ES or MF. According to various hypotheses, electroporation, Joule heating and electro-conformational protein changes are proposed mechanisms through which high electric fields (60–160 V/cm strength) may cause damage to skeletal and peripheral nerve membranes.<sup>16,17</sup> Scientists have postulated several potential biological mechanisms for MF, including reactive oxygen species, disruption of melatonin levels and calcium channels.<sup>18</sup> Note however, that biological mechanisms for neurodegenerative diseases and ES and MF remain as unconfirmed theories.

Several occupational ALS case reports and case-control studies have implicated electrical trauma injuries, although differential reporting bias or the possibility that limb weakness led to the electrical injury (reverse-causation) was not investigated.<sup>7,8,19–21</sup> ES as an etiologic risk factor for ALS among “electric occupations”,<sup>7,8,22</sup> has not been evaluated to date. Authors recently conducted a retrospective cohort study to examine the role of ES in neurologic diseases, finding an insufficient number of ALS cases for analysis.<sup>23</sup> To ensure sufficient power, we applied an ES JEM, containing *a priori* exposure assignment by occupation, to a large mortality dataset to gain insight on potential ALS etiologic risk factors.

An electrical shock is an “effect resulting from direct or indirect passage of an external electrical current through the body”,<sup>24</sup> which may over-stimulate the nervous system or damage organs.<sup>25</sup> Conceivably, a worker may not report a shock at electric current levels above perception thresholds, but below those of adverse sensory effects. The developed ES JEM likely reflects severe ES rather than barely perceptible shocks. Given the severity and shock perception ranges, the ES JEM would likely underestimate the full extent of workplace events.<sup>10</sup> In our dataset, 81 occupations were highly exposed to ES including drafting occupations (217), guards and police, executive public service (426), cooks (436), janitors and cleaners (453), plumbers, pipefitters and steamfitters (558), miscellaneous machine operators (777), construction laborers (869) and miscellaneous laborers except construction (889). Severe ES may cause someone, to modify their work practices to reduce ES severity, or to seek a new job entirely and avoid repeated, perhaps less severe ES. Examining physical trauma and ALS in Washington, Cruz et al.<sup>26</sup> found elevated ALS risk and ES involving loss of consciousness (OR = 1.9; 95% CI = 0.5–8.3), based on four cases and four controls. Lending support that severity could play a factor, Cruz et al.<sup>26</sup> also found that the ALS OR among those with one ES without injury was 1.2 (95% CI = 0.6–1.4) and multiple ES without injury was 0.7 (95% CI = 0.5–1.1). In a review of electrical injury case reports and studies, Abhinav et al.<sup>27</sup> found that stronger ES resulted in non-progressive MND whereas mild ES in progressive ALS. In future work, severity scale might be added to the ES JEM to examine associations across severe to mild ES levels.

Death certificate occupation might be a poor surrogate for lifetime occupational history.<sup>28</sup> In our analyses, we assumed that

the “usual occupation” indicated on the death certificate represented the longest held occupation. People who live longer may have more than one occupation, leading to misclassification of occupation, consequently ES and MF exposures. Type of occupation and socioeconomic status (SES) may determine whether or not workers seek multiple jobs in a lifetime. One US prospective ALS study reported that more than 40% of the cohort held more than one job.<sup>29</sup> Low SES may require a person to have many jobs while high SES may not. Death certificates may serve as a better proxy for lifetime occupation among a highly educated or trained workforce. However, in a recent meta-analysis we obtained materially same results in studies using several jobs vs representative jobs (as on a death certificate) for MND.<sup>6</sup>

Death certificate occupational coding practices could vary by state. The death certificate may record occupation at time of death, job according to employer paying the insurance or longest held occupation, rather than the “usual” job, the kind of work done during most of working life, even if retired.<sup>30</sup> Coding protocols assist funeral directors and registrars and reduce inaccuracies with occupation.<sup>31</sup> Since only 16 to 21 states were required to report occupation during the study period, missing occupational titles could create selection bias if “missingness” is dependent upon the outcome of interest, exposure and SES.<sup>32</sup> However, our ability to replicate an association with electric occupations found in other studies, argues against the quality of occupational information as a reason for our findings.

Potential ALS risk factors previously examined include cigarette smoking and race.<sup>33,34</sup> A recent meta-analysis of 18 publications observed an OR of 1.28 (95% CI = 0.97–1.68), for current vs never smokers.<sup>35</sup> Mortality rates have been observed to be higher among whites compared with blacks and other ethnicities,<sup>3</sup> in whom we found similar results. A Dutch study identified lower SES as a risk factor, using education level as a proxy<sup>36</sup> and other studies have been inconsistent.<sup>37</sup> SES reflects occupation, education, income and household conditions and depends upon the population. In our data, cases were higher educated than the controls, and to the extent education misclassifies SES<sup>38</sup> and underlying SES is related to ALS, residual confounding owing to SES may be present.

A recent ALS cohort demonstrated higher prevalence of co-morbidities, such as dementia and Parkinson’s disease, implying that a proportionally higher number of cases than controls might be excluded from our study.<sup>39</sup> Inclusion of cases with co-morbidities in the analyses—if there was a relationship between the investigated exposures (ES and MF) and the co-morbidities—may theoretically introduce some selection bias. Nonetheless, we did not observe differences in associations when we included cases with those co-morbidities.

The association between electric occupations and ALS mortality was consistent with previous studies. However, we did not find increased ALS mortality odds within strata of high ES or MF exposure. Our findings suggest that some factor unrelated to ES and MF may account for the association between electric occupations and ALS. Suspected occupational risk factors for ALS include metals, such as lead, pesticides, solvents, aspects of strenuous physical activity, and physical trauma, including head injury, and skeletal fractures.<sup>34</sup> We had no data on these other potential occupational risk factors.

Despite often-cited limitations of mortality data, publicly available data present the largest source of US ALS cases with occupational information. Further, despite the limited occupation and industry information available, occupational mortality studies have a key role in informing science.<sup>40</sup> As opposed to countries with established disease and population registries, the USA has only recently started an ALS disease registry<sup>41</sup>—*albeit* its use for epidemiologic studies remains to be explored. ALS mortality data may reasonably substitute for incidence data, as ALS is a fatal disease with a relatively short survival (an average of 1–5 years).<sup>42</sup>

In a follow-up study of ALS patients, death certificate data reporting accuracy was 72–92%.<sup>43</sup> Case ascertainment could reflect regional differences in physician knowledge of ALS diagnosis,<sup>44</sup> changes in disease coding and worker access to health care, which might vary by SES.<sup>44</sup> Although disease misclassification is present to some extent (by our grouping of all MND into the ALS definition), ALS mortality data are well-suited to explore the electric occupations, ES and MF hypotheses. Thorough quantification of exposure rather than disease misclassification is prudent as, in our opinion, exposure is likely the largest source of bias. Bias analysis could demonstrate whether our assumptions are correct and where future research effort might be best directed.

## CONCLUSIONS

With important clues gleaned from occupational exposure studies, we present an evaluation of the potential relationship between electric occupations, exposures to ES and MF and ALS mortality from deaths in the USA occurring between 1991 and 1999. Similar to past studies, we observed an association between electric occupations and death owing to ALS. In our analysis, neither ES nor MF explained the association between electric occupations and ALS. We observed exposure to occupational ES to be inversely associated with death owing to ALS. No previous studies examined the relationship between occupational ES and ALS, a devastating disease of unknown etiology. Further studies are needed to evaluate whether our observations might be owing to bias. An informative, useful effort would be to apply the ES JEM to a separate data source, containing complete job histories and incidence of ALS, and to assess the electric occupation-ALS association. Future work should expand a JEM to collect available MF measurement data on missing and female-dominated occupations, quantify the degree of potential biases in the analyses, and incorporate new information on workplace ES, such as, industry-level data and degree of severity.

## ABBREVIATION

ALS, amyotrophic lateral sclerosis; BOC, Bureau of Census; ES, electric shocks; ICD, International Classification of Diseases; JEM, job-exposure matrices; MF, magnetic fields; MND, motor neuron disease; NCHS, National Center for Health Statistics; OR, odds ratio; SES, socioeconomic status.

## CONFLICT OF INTEREST

The authors declare no conflict of interest.

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