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ORIGINAL ARTICLE

Extremely low-frequency magnetic field exposure, electrical shocks and risk of Parkinson's disease

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Abstract

Purpose Previous studies did not provide strong evidence for an increased Parkinson's disease (PD) risk after exposure to extremely low-frequency magnetic fields (ELF-MF), but were limited in their scope to address other exposures related to the use of electricity such as electrical shocks. We evaluated the associations of PD with exposure to ELF-MF, electrical shocks and having worked in "electrical occupations."

Methods We conducted a hospital-based case–control study, including 444 PD patients and 876 age- and sex-matched controls. Occupational histories were collected in telephone interviews and were linked to job-exposure matrices on ELF-MF exposure and on electrical shocks. In addition, questions on use of household appliances involving ELF-MF exposure, experienced electrical shocks and potential confounders were asked.

Results No association of PD risk with any of the evaluated exposures related to electricity was observed. We did, however, observe quite consistently reduced risk estimates across the majority of the exposure categories explored. Given the results of the previous studies and the absence of any postulated mechanism, this is unlikely to represent a true protective effect of ELF-MF or electrical shocks on the occurrence of PD.

Conclusions The results of this study suggest that no association exists between PD and exposure to ELF-MF, electrical shocks or having worked in "electrical occupations."

Keywords Parkinson's disease · Extremely low-frequency magnetic fields · Electrical shocks · Case–control study · Job-exposure matrix

Introduction

Environmental factors probably play an important role in the development of Parkinson's disease (PD) (Cannon and Greenamyre 2011). Exposure to extremely low-frequency magnetic fields (ELF-MF), as well as working in an

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"electrical occupation" has been linked to increased risks of two other neurodegenerative diseases, Alzheimer disease and amyotrophic lateral sclerosis (ALS), and it has been suggested that especially for ALS, electrical shocks rather than ELF-MF might be a more relevant exposure (Li and Sung 2003; Vergara et al. 2013). For PD, fewer studies on ELF-MF exposures and only one study on electrical shocks have been published (Grell et al. 2012). Overall, neither occupational ELF-MF exposure (Feychting et al. 2003; Hakansson et al. 2003; Johansen 2000; Noonan et al. 2002; Park et al. 2005; Roosli et al. 2007; Savitz et al. 1998a, b; Sorahan and Kheifets 2007) nor residential exposure to ELF-MF from power lines (Frei et al. 2013; Huss et al. 2009) has been shown to increase risk of PD. To our knowledge, none of the previous studies investigated ELF-MF exposure from household appliances in relation to PD. The one study on electrical shocks did not find increased risk of PD in a cohort of survivors of electrical accidents, but because only four PD cases were identified in this cohort, no conclusion could be drawn (Grell et al. 2012).

We comprehensively investigated the possible association of PD with exposure to ELF-MF and to electrical shocks from both occupational and non-occupational sources, and in addition evaluated "electrical occupations" using data of a recently conducted hospital-based case–control study.

Methods

Cases and controls

Cases and controls were recruited between April 2010 and June 2012 from five hospitals in the Netherlands (St. Elisabeth Hospital Tilburg, TweeSteden Hospital Tilburg, Canisius-Wilhelmina Hospital Nijmegen, UMCG Groningen and Vlietland Hospital Schiedam). Patients with a first diagnosis of PD between January 2006 and December 2011 in one of these hospitals were eligible. Subjects initially diagnosed in another hospital and referred to one of the participating hospitals for follow-up care or for second opinion were excluded. Eligible study subjects were identified using DBC codes, which is the standardized accounting system for hospital care based on diagnostic groups in the Netherlands (Oostenbrink and Rutten 2006). In each hospital, one neurologist reviewed the medical files of all subjects identified with DBC codes 0501 (PD) or 0502 (other extrapiramidal disorders) to select all PD patients. For each confirmed PD patient, two matched controls were selected from individuals who attended the same departments of neurology within the same specified time frame with DBC codes 0801 (median nerve neuropathy; ICD-10 G56.0 and G56.1), 0802 (ulnar nerve neuropathy; ICD-10 G56.2), 1203 (thoracic and lumbar disk disease; ICD 10 G55.1, G54.3 and G54.4) or 1204 (sciatica; ICD-10 M54.3 and M54.4). The controls were matched to the cases on hospital, visiting date (±3 years), sex and age. When one individual was the best match to more cases, he/she was allowed to serve as a control for more than one case. A total of 1,001 subjects with an initial diagnosis of PD between 2006 and 2011 and still alive at the time of recruitment (93 % of total) were identified. For eight subjects, no current address was known. Of the 993 invited persons, 448 persons agreed to participate (45 %), 406 persons declined participation and 139 did not reply. Among potential controls, the participation rate was 35 %; for 12 cases, only one suitable control was found, and for four cases no controls were found, leaving 444 cases and 876 controls that were included in the present analyses. The median age difference between case and matching controls was 15 days with a maximum of 512 days. The study was approved by the Medical Ethics Committee of St Elisabeth Hospital, Tilburg, the Netherlands. All participants gave their informed consent prior to their inclusion in the study.

Data collection

Selected cases and controls were contacted via an invitation letter from their neurology department containing study information and a reply form. Non-responders were sent a reminder after 1 month, and one phone call attempt was performed after another month. Cases and controls were informed that the study objective was to study risk factors for neurological disorders, without specification of which neurological disease or potential risk factors.

Study participants were interviewed in a standardized computer-assisted telephone interview by one of three trained interviewers. The questionnaire contained a complete residential and occupational history; questions about selected dietary items, smoking, anthropometric measures; and a medical history. For each job in the occupational history, the study participants were asked to report on years worked, job title, type of industry, company name and main tasks of participant. Of several household appliances that could substantially contribute to ELF-MF exposure to the head, the use at current age and at the age of 20, 40 and 60 was ascertained. These appliances included weekly use of a hairdryer, use of an electrical shaver plugged into a socket while shaving (men only), sleeping within 1 m of the head with an electrical alarm clock plugged into a socket, sleeping on a water bed and sleeping with an electrical blanket turned on while sleeping. For non-work-related electrical welding, the number of years of welding, average number of days per year and average welding duration was asked. Moreover, the estimated lifetime number of experienced electrical shocks was asked.

Exposure assessment

All jobs were coded by one author (MM) according to the International Standard Classification of Occupations 1968 and 1988 (ISCO68 and ISCO88). All job codes were linked to a modified version of an existing measurement-based ELF-MF job-exposure matrix (JEM) containing mean exposure intensity per job, in microtesla (μT) (Bowman et al. 2007). This JEM used 4-digit ISCO88 codes on the job axis except for about 30 electrical jobs where the more detailed 5-digit ISCO68 codes were used. In the modified JEM, jobs were (re-)classified into low, medium and high ELF-MF exposure based on not only intensity of exposure, but also probability of exposure (Koeman et al. 2013). The job histories were also linked to a recently developed electrical shock JEM that categorized 3-digit ISCO88 jobs into low, medium and high potential for electrical shocks (Huss et al. 2013). This JEM was based on national registry data of accidents resulting in electrical injury at work that had been registered in five European countries, including data from the Netherlands.

We analyzed three exposure metrics for occupational exposure to ELF-MF and electrical shocks: ever exposure (medium and high exposure), duration of exposure and cumulative exposure. Duration was defined as the number of years a participant had worked with medium or high exposure up to a year before diagnosis. Cumulative exposure was calculated summing exposed years in the job history using weights of 0 for low, 1 for medium and 4 for high exposure (Koeman et al. 2013). Furthermore, risk analyses for existing classifications of "electrical occupations" were performed (Deapen and Henderson 1986; Feychting et al. 2003) (see Supplementary material table 1 for lists of jobs).

To evaluate ELF-MF exposure from household appliances, estimates of exposure intensity, weekly frequency and duration of use were used. Based on exposure values reported in the literature and for usual distance of use from the appliances, we estimated intensity of exposure to be around 0.5 μT for water beds and electrical alarm clocks, 1 μT for electrical blankets, and 10 μT for shavers and hairdryers [World Health Organization (WHO) 2007] and personal communication with Myron Maslanyj, Centre for Radiation, Chemical and Environmental Hazards, Public Health England, Chilton, UK). Using measurement data from the ELF-MF JEM, we estimated an exposure intensity of 5 μT during self-reported non-occupational electrical welding (Bowman et al. 2007). We assumed an exposure frequency and duration for hairdryers and shavers of three times a week for 5 min, for alarm clocks, blankets and water bed seven times a week for 8 h, where for blankets only use during half of the year (during wintertime) was assumed. These assumptions correspond with a yearly exposure of alarm clocks, blankets and water beds that is ten times higher than exposure from shavers and hairdryers. The number of years of use for each of those appliances was estimated from reported use at age 20, 40 and 60. For non-occupational electrical welding, the individually reported frequencies, durations and years of use by cases and controls were used to estimate cumulative exposure. Cumulative exposure to these appliances together was expressed in microtesla-years (μT-years), whereby one μT-year is an average exposure of one μT during one year.

Statistical analysis

Duration and cumulative exposure of occupational ELF-MF and electrical shock exposure were analyzed as categorical variables, using the study participants who had only jobs classified in the low category as the reference group and dividing the rest in three categories based on the tertiles of exposed controls. Exposure categories for household electrical appliances, non-occupational welding and self-reported number of electrical shocks were created in a comparable way. Odds ratios (OR) and 95 % confidence intervals (CI) for exposure categories were calculated using conditional logistic regression. Models were corrected for education (two categories), cumulative smoking (five categories) and cumulative coffee consumption (four categories). Furthermore, we performed a stratified analysis by median number of years since last job with medium or high exposure to address the timing of exposure as previous studies were inconclusive (Roosli et al. 2007; Savitz et al. 1998a, b; Sorahan and Kheifets 2007). Finally, in order to investigate the influence of skill and status of jobs, we divided the jobs in four categories of occupational skill and status according to major ISCO groups (first digit of the ISCO 88 job codes) (Dumont 2006): 1–3: high-skilled white-collar jobs, 4–5: low-skilled white-collar jobs, 6–7: high-skilled blue-collar jobs and 8–9: low-skilled blue-collar jobs. The participants were categorized according to the group in which they had worked most years during their career.

Results

Table 1 shows the age and sex distribution of the cases and controls included in the analyses together with the variables included as potential confounders in the adjusted analyses.

Table 1 General characteristics of cases and controls

	PD cases (n = 444)	Controls (n = 876)
Men, no (%)	281 (63.3 %)	557 (63.6 %)
Age at interview, median (range)	68 (34–91)	68 (34–90)
Age at diagnosis, median (range)	67 (34–90)	–
Higher education, no (%)[a]	268 (60.5)	477 (54.5)
Cigarette smoking[b]		
Never smoked, no (%)	207 (46.6 %)	243 (27.7 %)
>0–7.8 pack-years, no (%)	86 (19.4 %)	161 (18.4 %)
>7.8–17.5 pack-years, no (%)	67 (15.1 %)	155 (17.7 %)
>17.5–29.4 pack-years, no (%)	45 (10.1 %)	160 (18.3 %)
>29.4–103 pack-years, no (%)	39 (8.8 %)	157 (17.9 %)
Coffee consumption[c]		
0–97 consumption-years, no (%)	128 (28.8 %)	220 (25.1)
>97–156 consumption-years, no (%)	146 (32.9 %)	221 (25.3)
>156–214 consumption-years, no (%)	90 (20.3 %)	216 (24.7)
>214–720 consumption-years, no (%)	80 (18.0 %)	218 (24.9)

[a] Information on education was missing for one case

[b] Pack-years of cigarette smoking was calculated by dividing average number of cigarettes per day by 20 multiplied by the number of years of smoking. Ever smokers were divided based on the quartiles of the exposure distribution among the controls. Never smokers constitute a separate category

[c] Consumption-years was calculated by multiplying the average amount of coffee consumptions per day with the estimated number of years of coffee consumption. The participants were divided based on the quartiles of the exposure distribution among the controls. The number of never coffee drinkers was too low (3 %) to constitute a separate group. Coffee consumption information was missing for one control

Of the PD patients, 63.3 % were men with a median age at diagnosis of 67. On average, cases were higher educated, smoked less and consumed less coffee. With respect to differences in skill and status of jobs performed by cases and controls, Table 2 illustrates that more cases than controls were in the high-skilled white-collar category and more controls than cases were in the low-skilled blue-collar category. Using high-skilled white workers as the reference category, a significant decreased OR for PD was still visible for low-skilled blue-collar workers after adjusting for smoking.

ELF-MF

Cases were less likely to be occupationally exposed to medium or high ELF-MF exposure levels than controls, 57 and 64 %, respectively (see Table 3). Only 1.5 % of the female study participants had ever worked in a high ELF-MF-exposed job compared with 18 % of the male participants, while 58 % of the women and 45 % of the men had ever had a medium ELF-MF-exposed job as highest exposure (data not shown). Odds ratios were consistently below one for most of our exposure categories, although most were not statistically significant (see model 1 in Table 3). Adjusting the ELF-MF analyses for the four categories of occupational skill and status instead of educational level resulted in odds ratios closer to unity (see model 2 in Table 3). No trend in PD risk was observed with duration of ELF-MF exposure or cumulative ELF-MF exposure. Results of analyses whereby the medium and high exposed were divided on number of years since last job with ELF-MF exposure did not show differential results [last exposure ≤26 years ago: OR 0.80 (95 % CI 0.58–1.10), last exposure >26 years ago: OR 0.80 (95 % CI 0.59–1.08)]. Risk analyses of ELF-MF exposure from household electrical appliances did not show any associations with PD risk (see Table 3).

Electrical shocks

Pearson's correlation between cumulative ELF-MF exposure and cumulative electrical shocks exposure was 0.51. Table 4 presents the results of the analyses on electrical shocks. Similar to ELF-MF exposure, cases (39 %) were less likely to have ever had a job with medium or high risk of electrical shocks than controls (47 %). Most of the exposed were men; 61 % of the men as compared to 16 % of the women had ever had a job with medium or high risk of electrical shocks (data not shown). As with the analyses for ELF-MF, adjusted analyses showed in general risk estimates below unity for all shock exposure metrics, but were not statistically significant after adjustment for confounders (see model 1 in Table 4). Adjusting the analyses for the four categories of occupational skill and status

Table 2 PD and longest duration category job status

	Cases	Controls	Crude		Smoking adjusted	
	N (%)	N (%)	OR	95 % CI	OR	95 % CI
High-skilled white-collar worker (ISO88 1–3)	198 (44)	335 (38)	1	–	1	–
Low-skilled white-collar worker (ISCO88 4–5)	87 (20)	187 (21)	0.75	0.54–1.04	0.80	0.57–1.12
High-skilled blue-collar worker (ISCO88 6–7)	101 (23)	202 (23)	0.84	0.62–1.14	0.87	0.63–1.19
Low-skilled blue-collar worker (ISCO88 8–9)	58 (13)	152 (17)	0.60	0.42–0.87	0.67	0.46–0.97

Table 3 PD and ELF-MF exposure: conditional logistic regression analysis

	Cases	Controls	Crude		Model 1[a]		Model 2[b]	
	N (%)	*N* (%)	OR	95 % CI	OR	95 % CI	OR	95 % CI
JEM ELF-MF								
Only low	190 (43)	319 (36)	1	–	1	–	1	–
Ever exposure								
Medium	209 (47)	447 (51)	0.78	0.61–1.00	0.82	0.63–1.06	0.85	0.65–1.12
High	45 (10)	110 (13)	0.68	0.46–1.01	0.72	0.48–1.10	0.78	0.50–1.20
Duration[c]								
1–8 years	83 (19)	185 (21)	0.75	0.55–1.03	0.81	0.58–1.14	0.83	0.59–1.17
9–23 years	82 (18)	197 (22)	0.71	0.52–0.96	0.74	0.53–1.03	0.78	0.56–1.10
24–55 years	89 (20)	175 (20)	0.85	0.62–1.17	0.86	0.62–1.21	0.94	0.65–1.36
Cumulative exposure[d]								
1–9 unit–years	91 (20)	187 (21)	0.82	0.60–1.12	0.87	0.63–1.22	0.90	0.64–1.25
10–26 unit–years	72 (16)	191 (22)	0.63	0.46–0.88	0.68	0.48–0.96	0.71	0.50–1.02
27–188 unit–years	91 (20)	179 (20)	0.86	0.62–1.18	0.86	0.61–1.20	0.93	0.64–1.34
Household appliance exposure + non-occupational welding[e]								
0 μT-years	35 (8)	67 (8)	1	–	1	–	1	–
>0–1–2.0 μT-years	90 (20)	209 (24)	0.83	0.51–1.35	0.72	0.43–1.20	0.73	0.43–1.23
>2.0–3.8 μT-years	92 (21)	196 (22)	0.90	0.55–1.47	0.82	0.48–1.39	0.84	0.49–1.41
>3.8–5.7 μT-years	102 (23)	206 (24)	0.96	0.59–1.57	0.79	0.47–1.34	0.82	0.48–1.38
>5.7–14.0 μT-years	125 (28)	198 (23)	1.26	0.77–2.06	1.11	0.66–1.88	1.13	0.67–1.90

[a] The first adjusted model includes educational level, cigarette smoking and coffee consumption

[b] The second adjusted model includes collar worker category, cigarette smoking and coffee consumption

[c] Duration was defined as the number of years a participant had jobs with medium or high ELF-MF exposure as assessed with a JEM

[d] Cumulative exposure was calculated summing exposure of all years in the job history using weights (0 for low, 1 for medium and 4 for high exposure)

[e] Cumulative exposure was calculated from reported years of use of several electrical appliances and assumptions about exposure intensity, frequency and duration of use

instead of educational level resulted, similar as for the analyses on ELF-MF, in odds ratios closer to unity (see model 2 in Table 4). Results of analyses whereby the exposed were divided on number of years since last job with medium or high shock risk were not materially different [last exposure ≤21 years ago: OR 0.79 (95 % CI 0.56–1.10), last exposure >21 years ago: OR 0.80 (95 % CI 0.57–1.12)]. The self-reported number of electrical shocks experienced during life at home, at work or elsewhere was only moderately correlated with the occupational shock exposure estimates as assessed by the JEM (Pearson's correlation coefficient: 0.28). Risk analyses resulted in non-significant odds ratios below unity as well (see Table 4).

Electrical occupations

Analyses by ever having worked in an "electrical occupation" did not indicate any associations with PD. For the list of electrical occupations given in (Deapen and Henderson 1986), the OR was 0.90 (95 % CI 0.59–1.37) and for the list evaluated in (Feychting et al. 2003) the OR was 1.01 (95 % CI 0.62–1.63).

Discussion

Our analyses did not provide evidence of an increased risk of PD in persons exposed to ELF-MF or having experienced electrical shocks. In addition, no association with working in so-called electrical occupations was observed. However, we did observe marginally but consistently reduced risk estimates across the majority of the exposure categories explored here.

No mechanism is known by which electromagnetic fields might cause PD, which makes the choice of the relevant exposure metric difficult. Strength of our study is that we were able to include several sources of exposures (occupational exposure to ELF-MF but also exposure to ELF-MF from household appliances) and several exposure metrics into our analysis: Evaluating electrical occupations,

Table 4 PD and electrical shocks: conditional logistic regression analysis

	Cases	Controls	Crude		Model 1[a]		Model 2[b]	
	N (%)	*N* (%)	OR	95 % CI	OR	95 % CI	OR	95 % CI
JEM-based occupational shocks								
Only low	269 (61)	459 (52)	1	–	1	–	1	–
Ever exposure								
Medium	67 (15)	177 (20)	0.62	0.44–0.86	0.75	0.53–1.05	0.77	0.54–1.10
High	108 (24)	240 (27)	0.71	0.52–0.96	0.81	0.58–1.13	0.85	0.59–1.21
Duration[c]								
1–10 years	58 (13)	139 (16)	0.68	0.48–0.96	0.80	0.55–1.16	0.83	0.57–1.21
11–30 years	56 (13)	145 (17)	0.61	0.43–0.88	0.74	0.50–1.08	0.77	0.52–1.15
31–59 years	61 (14)	133 (15)	0.71	0.49–1.03	0.81	0.54–1.21	0.83	0.53–1.29
Cumulative exposure[d]								
1–17 unit-years	50 (11)	143 (16)	0.57	0.39–0.82	0.69	0.47–1.01	0.71	0.48–1.05
18–68 unit-years	67 (15)	143 (16)	0.75	0.53–1.06	0.88	0.61–1.27	0.93	0.64–1.37
69–218 unit-years	58 (13)	131 (15)	0.69	0.47–1.01	0.79	0.52–1.19	0.81	0.51–1.28
Self-reported number of shocks								
Never	288 (65)	491 (56)	1	–	1	–	1	–
1–2 shocks	74 (17)	188 (21)	0.62	0.45–0.86	0.68	0.48–0.96	0.69	0.49–0.97
3–10 shocks	62 (14)	154 (18)	0.61	0.42–0.87	0.63	0.43–0.92	0.64	0.44–0.94
11–150 shocks	20 (5)	43 (5)	0.71	0.41–1.25	0.90	0.50–1.62	0.91	0.50–1.66

[a] The first adjusted model includes educational level, cigarette smoking and coffee consumption

[b] The second adjusted model includes collar worker category, cigarette smoking and coffee consumption

[c] Duration was defined as the number of years a participant had jobs with medium or high risk of electrical shocks as assessed with a JEM

[d] Cumulative exposure was calculated summing electrical shock risk of all years in the job history using weights (0 for low, 1 for medium and 4 for high risk)

occupational ELF-MF exposure, exposure to ELF-MF sources (appliances) at home, and occupational and non-occupational exposure to electrical shocks makes our study the most comprehensive study to date on PD risk and electricity-related exposures.

Another strength of our analysis is that we were able to use incident cases confirmed by neurologists. This can be seen as an improvement to the far majority of the previous occupational studies that relied on PD as registered on death certificates [only one study used hospital records (Johansen 2000)]. PD is a chronic condition that in itself is non-fatal and is therefore often not mentioned on death certificates (Pennington et al. 2010; Pressley et al. 2005). Also, the information from death certificates might be inaccurate if also atypical parkinsonian syndromes such as multiple systems atrophy are listed as PD on death certificates, although this would only be expected to affect a small proportion of the cases (Nath et al. 2005; Schrag et al. 2008). In addition, we evaluated the complete occupational history to assess exposure to ELF-MF, enabling us to account for potential preclinical symptoms resulting in job changes that could affect occupational ELF-MF exposure. Particularly, the use of primary occupation on death certificate as done by a few of the previous studies (Noonan et al. 2002; Park et al. 2005; Savitz et al. 1998a, b) is of limited value for exposure assessment (Andrews and Savitz 1999). Other previous studies used occupation at baseline (Feychting et al. 2003; Hakansson et al. 2003; Johansen 2000) or job histories within certain companies (Roosli et al. 2007; Savitz et al. 1998a, b; Sorahan and Kheifets 2007).

It cannot be excluded that a small effect of ELF-MF exposure or electrical shocks on PD risk exists but that results were attenuated by exposure misclassification. Particularly, the analyses on ELF-MF sources at home were limited in that the available data on duration and years of use of household appliances were not very detailed. However, we included the most relevant appliances that may add to ELF-MF exposure to the head, and believe we were thus able to generate a meaningful ranking of individuals' exposure to ELF-MF from residential use of electrical appliances.

Another limitation of our study is a potential bias caused by low participation rates for cases and controls. Health-related reasons were most often brought forward for non-participation, but about 50 % of the non-participants did not provide an explanation for non-participation.

Participation depended on age: The participation rate among cases and controls age 70 or younger was 66 and 39 %, respectively. However, analyses on participants aged 70 or younger did not result in differential results (data not shown). Also, among women (for cases 40 %, for controls 32 %), the participation was lower than among men (for cases 49 %, for controls 38 %). Because women in the study were working less frequently in high-exposed jobs, odds ratios as reported in the overall analyses were driven by men. Stratified analyses by gender provided similar result for men and women (data not shown), but, given the low numbers of exposed women, analyses for women were imprecise.

Furthermore, hospital controls may not be representative for the general population, and some neurological conditions included in the control group might be related to occupations with high ELF-MF or electrical shock exposures. For example, electrical injury may induce peripheral nerve damage (Grell et al. 2012). Although shock-related peripheral nerve damage would be rare, it would have been covered in the DBC codes 0801 and 0802. Similarly, carpal tunnel syndrome (falling under DBC code 0801) is associated with regular and prolonged use of handheld vibratory tools (Palmer et al. 2007). This could have attenuated any true risk. Sensitivity analyses, however, leaving out one subgroup of the controls at a time (based on DBC codes) or analyses leaving out all controls with DBC codes 0801 and 0802, did not materially affect the reported odds ratios, suggesting that our results were not unduly influenced by characteristics within the subgroups (data not shown).

Our results are in line with previous studies that provided no evidence for increased risks of PD after occupational (Feychting et al. 2003; Hakansson et al. 2003; Johansen 2000; Noonan et al. 2002; Park et al. 2005; Roosli et al. 2007; Savitz et al. 1998a, b; Sorahan and Kheifets 2007) or residential (Frei et al. 2013; Huss et al. 2009) ELF-MF exposure. Odds ratios in our study were also very similar across groups with earlier or more recent exposures. Previous studies have also not provided clear evidence of an effect of timing of the exposure on PD risk: no effect on the risk estimates was observed in two studies when excluding most recent exposures (Roosli et al. 2007; Sorahan and Kheifets 2007), while studies reported either lower (Savitz et al. 1998a, b) or higher (Roosli et al. 2007) odd ratios when evaluating more recent exposure compared with lifetime exposure.

Of note, and although most results were not statistically significant, we observed quite consistently odds ratios below unity for both ELF-MF and electrical shocks exposures. Given the results of the previous studies and the absence of any postulated mechanism, this is unlikely to represent a true protective effect of ELF-MF or electrical shocks on the development of PD. If affected persons with first disease symptoms prior to diagnosis would change occupation to less-exposed jobs, this effect would result in decreased odds ratios. The extent of this reduction would, however, be relatively minor as manifestation of the disease is late in life. We adjusted our analyses for cigarette smoking and coffee consumption, for which in agreement with previous studies we observed inverse associations with PD risk (Van der Mark et al. 2014). However, adjusting for these factors had only a small effect on our reduced odds ratios.

The low odds ratios observed in our study might also relate to the fact that cases were more often highly educated than controls and may have been working more likely in high-skilled white-collar occupations, which represent more often lower-exposed jobs. Our analyses confirmed this and correspond well with literature showing that PD is positively associated with "white-collar jobs" such as teaching or legal professions in some studies (Goldman et al. 2005; Li et al. 2009). Possible explanations for this association include physical activity, more common in low-skilled jobs that may protect against PD (Xu et al. 2010), or a premorbid parkinsonian personality that might make affected persons preferentially select for white-collar jobs (Dagher and Robbins 2009; Menza 2000). Adjusting the ELF-MF and electrical shocks analyses for occupational skill and status increased the odds ratios and brought them closer to unity although this effect was not very strong.

In conclusion, our case–control study did not indicate an increase in risk of PD after exposure to ELF-MF or after experiencing electrical shocks. This in combination with the results of earlier studies and the lack of an established mechanism suggests that no relation exists between PD and exposures related to electricity.

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Conflict of interest The authors declare that they have no conflict of interest.

References

Andrews KW, Savitz DA (1999) Accuracy of industry and occupation on death certificates of electric utility workers: implications for epidemiologic studies of magnetic fields and cancer. Bioelectromagnetics 20:512–518

Bowman JD, Touchstone JA, Yost MG (2007) A population-based job exposure matrix for power-frequency magnetic fields. J Occup Environ Hyg 4:715–728. doi:10.1080/15459620701528001

Cannon JR, Greenamyre JT (2011) The role of environmental exposures in neurodegeneration and neurodegenerative diseases. Toxicol Sci 124:225–250. doi:10.1093/toxsci/kfr239

Dagher A, Robbins TW (2009) Personality, addiction, dopamine: insights from Parkinson's disease. Neuron 61:502–510. doi:10.1016/j.neuron.2009.01.031

Deapen DM, Henderson BE (1986) A case-control study of amyotrophic lateral sclerosis. Am J Epidemiol 123:790–799

Dumont M (2006) The reliability–or lack thereof–of data on skills. Econ Lett 93:348–353. doi:10.1016/j.econlet.2006.06.008

Feychting M, Jonsson F, Pedersen NL, Ahlbom A (2003) Occupational magnetic field exposure and neurodegenerative disease. Epidemiology 14:413–419. doi:10.1097/01.EDE.0000071409.23291.7b

Frei P, Poulsen AH, Mezei G, Pedersen C, Salem LC, Johansen C et al (2013) Residential distance to high-voltage power lines and risk of neurodegenerative diseases: a Danish population-based case-control study. Am J Epidemiol. doi:10.1093/aje/kws334

Goldman SM, Tanner CM, Olanow CW, Watts RL, Field RD, Langston JW (2005) Occupation and parkinsonism in three movement disorders clinics. Neurology 65:1430–1435. doi:10.1212/01.wnl.0000180361.74060.70

Grell K, Meersohn A, Schuz J, Johansen C (2012) Risk of neurological diseases among survivors of electric shocks: a nationwide cohort study, Denmark, 1968–2008. Bioelectromagnetics 33:459–465. doi:10.1002/bem.21705

Hakansson N, Gustavsson P, Johansen C, Floderus B (2003) Neurodegenerative diseases in welders and other workers exposed to high levels of magnetic fields. Epidemiology 14:420–426. doi:10.1097/01.EDE.0000078446.76859.c9

Huss A, Spoerri A, Egger M, Roosli M (2009) Residence near power lines and mortality from neurodegenerative diseases: longitudinal study of the Swiss population. Am J Epidemiol 169:167–175

Huss A, Vermeulen R, Bowman JD, Kheifets L, Kromhout H (2013) Electric shocks at work in Europe: development of a job exposure matrix. Occup Environ Med 70:261–267. doi:10.1136/oemed-2012-100732

Johansen C (2000) Exposure to electromagnetic fields and risk of central nervous system disease in utility workers. Epidemiology 11:539–543

Koeman T, Slottje P, Kromhout H, Schouten LJ, Goldbohm RA, van den Brandt PA et al (2013) Occupational exposure to extremely low-frequency magnetic fields and cardiovascular disease mortality in a prospective cohort study. Occup Environ Med 70:402–407. doi:10.1136/oemed-2012-100889

Li CY, Sung FC (2003) Association between occupational exposure to power frequency electromagnetic fields and amyotrophic lateral sclerosis: a review. Am J Ind Med 43:212–220. doi:10.1002/ajim.10148

Li X, Sundquist J, Sundquist K (2009) Socioeconomic and occupational groups and Parkinson's disease: a nationwide study based on hospitalizations in Sweden. Int Arch Occup Environ Health 82:235–241. doi:10.1007/s00420-008-0327-z

Menza M (2000) The personality associated with Parkinson's disease. Curr Psychiatry Rep 2:421–426

Nath U, Thomson R, Wood R, Ben-Shlomo Y, Lees A, Rooney C et al (2005) Population based mortality and quality of death certification in progressive supranuclear palsy (Steele-Richardson-Olszewski syndrome). J Neurol Neurosurg Psychiatr 76:498–502. doi:10.1136/jnnp.2004.039370

Noonan CW, Reif JS, Yost M, Touchstone J (2002) Occupational exposure to magnetic fields in case-referent studies of neurodegenerative diseases. Scand J Work Environ Health 28:42–48

Oostenbrink JB, Rutten FF (2006) Cost assessment and price setting of inpatient care in the Netherlands. The DBC case-mix system. Health Care Manag Sci 9:287–294

Palmer KT, Harris EC, Coggon D (2007) Carpal tunnel syndrome and its relation to occupation: a systematic literature review. Occup Med (Lond) 57:57–66. doi:10.1093/occmed/kql125

Park RM, Schulte PA, Bowman JD, Walker JT, Bondy SC, Yost MG et al (2005) Potential occupational risks for neurodegenerative diseases. Am J Ind Med 48:63–77. doi:10.1002/ajim.20178

Pennington S, Snell K, Lee M, Walker R (2010) The cause of death in idiopathic Parkinson's disease. Parkinsonism Relat Disord 16:434–437. doi:10.1016/j.parkreldis.2010.04.010

Pressley JC, Tang MX, Marder K, Cote LJ, Mayeux R (2005) Disparities in the recording of Parkinson's disease on death certificates. Mov Disord 20:315–321. doi:10.1002/mds.20339

Roosli M, Lortscher M, Egger M, Pfluger D, Schreier N, Lortscher E et al (2007) Mortality from neurodegenerative disease and exposure to extremely low-frequency magnetic fields: 31 years of observations on Swiss railway employees. Neuroepidemiology 28:197–206. doi:10.1159/000108111

Savitz DA, Checkoway H, Loomis DP (1998a) Magnetic field exposure and neurodegenerative disease mortality among electric utility workers. Epidemiology 9:398–404

Savitz DA, Loomis DP, Tse CK (1998b) Electrical occupations and neurodegenerative disease: analysis of US mortality data. Arch Environ Health 53:71–74. doi:10.1080/00039899809605691

Schrag A, Wenning GK, Quinn N, Ben-Shlomo Y (2008) Survival in multiple system atrophy. Mov Disord 23:294–296. doi:10.1002/mds.21839

Sorahan T, Kheifets L (2007) Mortality from Alzheimer's, motor neuron and Parkinson's disease in relation to magnetic field exposure: findings from the study of UK electricity generation and transmission workers, 1973–2004. Occup Environ Med 64:820–826. doi:10.1136/oem.2006.031559

Van der Mark M, Nijssen PCG, Vlaanderen J, Huss A, Mulleners WM, Sas AMG, et al (2014) A case-control study of the protective effect of alcohol, coffee, and cigarette consumption on parkinson disease risk: time-since-cessation modifies the effect of tobacco smoking. PLoS One 9(4):e95297. doi:10.1371/journal.pone.0095297

Vergara X, Kheifets L, Greenland S, Oksuzyan S, Cho YS, Mezei G (2013) Occupational exposure to extremely low-frequency magnetic fields and neurodegenerative disease: a meta-analysis. J Occup Environ Med 55:135–146. doi:10.1097/JOM.0b013e31827f37f8

World Health Organization (WHO) (2007) Environmental health criteria 238: extremely low frequency (ELF) fields

Xu Q, Park Y, Huang X, Hollenbeck A, Blair A, Schatzkin A et al (2010) Physical activities and future risk of Parkinson disease. Neurology 75:341–348. doi:10.1212/WNL.0b013e3181ea1597