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Residential proximity to electromagnetic field sources and birth weight: Minimizing residual confounding using multiple imputation and propensity score matching☆

Frank de Vocht [a,*], Brian Lee [b]

[a] Centre for Occupational and Environmental Health, Institute of Population Health, Manchester Academic Health Sciences Centre, The University of Manchester, Oxford Road, Manchester M13 9PL, United Kingdom

[b] Department of Epidemiology and Biostatistics, Drexel University School of Public Health, 1505 Race St., Philadelphia, PA 19102, USA

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ABSTRACT

Studies have suggested that residential exposure to extremely low frequency (50 Hz) electromagnetic fields (ELF-EMF) from high voltage cables, overhead power lines, electricity substations or towers are associated with reduced birth weight and may be associated with adverse birth outcomes or even miscarriages. We previously conducted a study of 140,356 singleton live births between 2004 and 2008 in Northwest England, which suggested that close residential proximity (≤50 m) to ELF-EMF sources was associated with reduced average birth weight of 212 g (95%CI: −395 to −29 g) but not with statistically significant increased risks for other adverse perinatal outcomes. However, the cohort was limited by missing data for most potentially confounding variables including maternal smoking during pregnancy, which was only available for a small subgroup, while also residual confounding could not be excluded. This study, using the same cohort, was conducted to minimize the effects of these problems using multiple imputation to address missing data and propensity score matching to minimize residual confounding.

Missing data were imputed using multiple imputation using chained equations to generate five datasets. For each dataset 115 exposed women (residing ≤50 m from a residential ELF-EMF source) were propensity score matched to 1150 unexposed women. After doubly robust confounder adjustment, close proximity to a residential ELF-EMF source remained associated with a reduction in birth weight of −116 g (95% confidence interval: −224:−7 g). No effect was found for proximity ≤100 m compared to women living further away.

These results indicate that although the effect size was about half of the effect previously reported, close maternal residential proximity to sources of ELF-EMF remained associated with suboptimal fetal growth.

1. Introduction

Adverse pregnancy outcomes are a result of complex interactions between maternal, placental, fetal and environmental factors during pregnancy that are not always fully understood (de Boo and Harding, 2006; Silbergeld and Patrick, 2005). Although endogenous electric fields play a role in normal embryo development, for example in guiding cell orientation and migration, and disruption of these fields can result in developmental abnormalities (Saunders and McCaig, 2005) it is unclear whether maternal exogenous exposure to extremely low frequency electromagnetic fields (ELF-EMF) can have similar effects on the fetus (Feychting, 2005; Swanson and Kheifets, 2006).

Results from epidemiological studies have indicated that maternal ELF-EMF exposure from the use of electrical equipment such as televisions, terminals and electric blankets may be associated with increased risk of adverse perinatal outcomes, but only a limited number of studies have been conducted specifically addressing this question (Feychting, 2005; Shaw, 2001). Residential exposure to ELF-EMF from the electricity distribution network has been linked to increased risk of miscarriages (Auger et al., 2012; Juutilainen et al., 1993; Lee et al., 2002; Li et al., 2002), although there is debate on whether ELF-EMF is the causal agent (Mezei et al., 2006; Savitz, 2002; Savitz et al., 2006). The weight of evidence with respect to other adverse birth outcomes seems to be against ELF-EMF as a causal agent (Auger et al., 2011; Blaasaas et al., 2003; Malagoli et al., 2012), although this is based on relatively few studies with significant error in exposure estimation (Maslanyj et al., 2009), small numbers of high exposed women (residential address very close proximity to power lines) and missing information on important confounders (de Vocht et al., 2014).

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* Corresponding author at: Centre for Occupational and Environmental Health, The University of Manchester, Oxford Road, Manchester M13 9PL, United Kingdom. Tel.: +44 161 275 8500.

E-mail address: frank.devocht@manchester.ac.uk (F. de Vocht).

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Although it remains unclear whether an association between residential proximity to sources of ELF-EMF and risk of low birth weight exists (Auger et al., 2011; Savitz and Ananth, 1994), a recent study has shown an association between close maternal residential proximity to high voltage cables, overhead power lines, electricity substations or towers and reduced birth weight, but not preterm birth (de Vocht et al., 2014). This study of 140,356 live hospital singleton births in the Northwest of England reported an average decreased birth weight of 212 g (95%CI: −395 to −29) for close residential proximity (≤50 m) to sources of ELF-EMF, which was strongest in female newborns (−251 g (95%CI: −487 to −15)). Despite the large cohort however, the study lacked statistical power to reach firm conclusions on increased risk of clinically important birth outcomes because of the relatively few number of cases living in close residential proximity to these sources of ELF-EMF, while also residual confounding from especially socio-economic factors could not be excluded and it was further limited by missing data on important confounders (e.g., maternal smoking during pregnancy).

However, if such a link exists it is important to study this further since suboptimal growth in utero has been linked not only to increased neonatal morbidity and mortality (Barker, 2006) including cardiovascular disease, insulin resistance, diabetes mellitus type 2, dyslipidemia, and end-stage renal disease in adulthood, but also to decreased levels of intelligence and cognition (de Bie et al., 2010). Therefore, this work aims to alleviate, or minimize the impact of missing data and residual confounding in the initial study (de Vocht et al., 2014) by imputing missing data using multiple-imputation methodology and subsequently apply a causal-modeling analysis framework using propensity score matching.

2. Materials and methods

2.1. Data

The details of the North West Perinatal Survey Unit (NWPSU) data, coding of data and linkage to proximity measures of ELF-EMF exposure have been described in detail elsewhere (Khashan et al., 2010). For this study, the same dataset was used as in the original study by de Vocht et al. (2014). In short, maternal and perinatal information collected at the time of delivery by the responsible midwife of all hospital births in 21 maternity units in North Western England between 2004 and 2008 from was included. The data were cleaned based on rules developed by expert obstetric opinion; implausible entries were set to missing (birth weight < 500 g and >5500 g (n = 336) and gestational age < 24 weeks and >44 weeks (n = 274)).

Latitude and longitude grid references of maternal residence at the time of delivery were obtained and linked to geolocations of cables, lines, substation sites and electricity towers (sources) freely available on the British National Grid website (Nationalgrid, 2013). The nearest linear distance from each maternal location to each source was calculated using ArcGIS (Environmental System Research Institute (ESRI), Redlands, CA, USA) and categorized in closest proximity to a source of 50 m or less (yes/no) based on UK data indicating that the magnetic field from 275 to 400 kV transmission lines will typically fall to 0.2 μT around 70–80 m or within 30–50 m for 132 kV lines (Maslanyj et al., 2009) and 100 m or less based on data indicating that 91% of addresses with estimated fields of >0.1 μT are located within 99 m of a power line (Kroll et al., 2010).

Variables that were determined as likely confounders, because *a priori* it was thought they may correlate with distance to EMF sources because cheaper housing and more deprived communities may exist in closest proximity to especially power lines and towers (Sims and Dent, 2005), included: maternal age (5-year groups), ethnicity (White/non-White), mother's body mass index (BMI), socio-economic status using the Index of Multiple Deprivation (IMD) (Directgov, 2007), parity and self-reported smoking during pregnancy (recorded as "yes/no" at the time of delivery). These may not be direct confounders but rather additional SES indicators to complement IMD and minimize the likelihood of residual confounding. Additionally, gender of the newborn was included as an effect modifier. The IMD score comprises of seven indices of deprivation assigned on a neighborhood level (income, employment, health and disability, education, living environment, crime and barriers to housing and services) and were categorized into quintiles of deprivation based on English National Standards.

For this study, permission was obtained for secondary analysis of the anonymized data from the data custodian.

2.2. Multiple imputation strategy

Missing data, especially on an important confounder, can result in biased effect estimates, since sample restriction to only those with complete data may not be representative of the full sample. In this dataset self-reported maternal smoking during pregnancy was missing for 62% of the cohort and mother's BMI for 45% of the cohort, while data were also missing for other confounders (Table 1), which restricted analyses in de Vocht et al. (2014). Missing data on maternal smoking during pregnancy and on mother's BMI was proportionally more often missing in lower socio-economic groups, which will have let to differential deletion of births prior to the original analyses and in turn may have influenced representativeness of the results with respect to the source population. To handle missing data multiple imputation is often used, with the goal not to obtain "correct" predictions of missing values, but to obtain accurate estimates of the parameter of interest (i.e., the relationship of residential distance to sources of ELF-EMF and low birth weight in this study). A recently developed algorithm for multiple imputation using chained equations (MICE) has advantages over traditional methods of multiple imputation, including more accurate modeling of covariate distributions. In brief, MICE uses regression models to predict the missing values of variables, conditional on other variables. The algorithm does so in an iterative fashion, cycling through each variable with

Table 1
Characteristics original NWPSU dataset and average imputed datasets (n = 5).

Original dataset	N = 264,695[1]	Imputed datasets (n = 5)
Birth weight mean (SD)	3328 g (581)	3327 g (581)
Missing (%)	0%	
Gender (male)	51%	51%
Missing	<1%	
Ethnicity (Caucasian)	79%	79%
Missing	14%	
Previous pregnancies (none)	28%	28%
Missing	34%	
Body mass index (BMI)		
<20	9%	9%
20–29	72%	72%
30+	20%	20%
Missing	45%	
2007 Index of Multiple Deprivation		
Quintile 1	44%	44%
Quintile 2	20%	21%
Quintile 3	15%	15%
Quintile 4	13%	13%
Quintile 5	8%	8%
Missing	23%	
Maternal age (years)		
<20	8%	9%
20–34	75%	75%
35+	17%	17%
Missing	18%	
Maternal smoking during pregnancy		
Yes	20%	20%
Missing	62%	

[1] Percentages are calculated after subtraction of missing data from denominator.