PERSONAL MEASURES OF POWER-FREQUENCY MAGNETIC FIELD EXPOSURE AMONG MEN FROM AN INFERTILITY CLINIC: DISTRIBUTION, TEMPORAL VARIABILITY AND CORRELATION WITH THEIR FEMALE PARTNERS' EXPOSURE

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Received 29 September 2015; revised 29 September 2015; accepted 17 November 2015

Power-frequency magnetic field exposure science as it relates to men and couples have not been explored despite the advantage of this information in the design and interpretation of reproductive health epidemiology studies. This analysis examined the distribution and temporal variability of exposures in men, and the correlation of exposures within couples using data from a longitudinal study of 25 men and their female partners recruited from an infertility clinic. The average and 90th percentile demonstrated fair to good reproducibility, whereas the maximum showed poor reproducibility over repeated sampling days, each separated by a median of 4.6 weeks. Average magnetic field exposures were also strongly correlated within couples, suggesting that one partner's data could be used as a surrogate in the absence of data from the other for this metric. Environment was also an important effect modifier in these explored matters. These issues should be considered in future relevant epidemiology studies.

INTRODUCTION

Power-frequency magnetic fields (subsequently referred to as 'magnetic fields') are ubiquitous given the reliance on alternating current electricity in all aspects of life⁽¹⁾. Accordingly, exposures to magnetic fields are expected to be pervasive in most human populations as well⁽²⁾. For well over three decades, magnetic fields have been studied as a potential risk factor for infertility and adverse pregnancy outcomes⁽³⁾. Despite the large research effort, the epidemiology studies to date have generated inconsistent findings and, in most cases, were characterised by study designs that may include bias and/or exposure misclassification, which has generated debate and also motivated further research that has been published in the peer-reviewed literature^(3–7). Research in this area is also complicated by the lack of an established biophysical mechanism that could explain a relationship between exposure to low-level magnetic fields and biological effects leading to adverse reproductive health outcomes^(1, 8). Nevertheless,

there continues to be interest in studying the relationship of adverse reproductive health outcomes with magnetic field exposures in human populations^(9–15).

To date, the vast majority of epidemiologic research has focussed on exposures to magnetic fields among women (see, for example, the epidemiology studies by Lee *et al.*⁽¹⁶⁾ and Li *et al.*⁽¹⁷⁾) and how that may correlate with adverse pregnancy outcomes (e.g. miscarriage and birth defects). In comparison, similar studies that have been conducted among men are much more limited; the authors are only aware of one such study to date, a case-control study by Li *et al.*⁽¹⁸⁾ of men ($n = 148$) that were recruited at a sperm bank in China. In that study, participants provided two semen samples that were separated by 7–21 d, and, after outcome status was determined, wore a personal magnetic field exposure monitor that collected data every 4 s for a single, 24-h period on a day that the participant's considered representative of a typical day in the previous 3 months. Eligible cases were those men whose semen samples both met at

least one of the World Health Organization (WHO)'s criteria for low sperm motility, morphology or concentration. Eligible controls were those men whose semen quality parameters in both samples did not meet any of the WHO criteria. Li *et al.*⁽¹⁸⁾ reported that men with a 90th percentile magnetic field exposure of ≥ 1.6 mG had an increased risk of poor semen quality compared with men with a 90th percentile exposure of < 1.6 mG. They also reported that duration of exposure ≥ 1.6 mG increased the risk of poor semen quality in a dose-dependent manner. The analysis by Li *et al.*⁽¹⁸⁾ is a novel contribution to the literature, and is characterised by several strengths, such as use of objective exposure (personal exposure monitors) and outcome (semen analysis) assessment methodologies. However, the study design is not without its limitations. Notably, the study potentially suffers from temporal ambiguity as personal exposure data were collected after the outcome was determined. There may also be some degree of measurement error associated with the 90th percentile magnetic field exposures, as they were estimated using data across a single, 24-h period, which may not sufficiently capture the variability in exposures that can occur over the duration of spermatogenesis. Taken together, further research on the relationship between magnetic fields and male reproductive health may be warranted.

To help inform the design of these epidemiology studies, which will in turn reduce bias and lead to more valid effect estimates, exposure science studies are needed on the distribution and temporal variability of daily personal magnetic field exposures in men, especially as they relate to durations that are relevant to male reproduction (i.e. sampling days separated by weeks or months). These issues have primarily been explored using data sets in women that integrate exposures both inside and outside the home^(3, 7, 16), or in men and women that integrate exposures inside the home only and have been pooled together⁽⁵⁾. To date, it is unclear how generalisable these studies are to understanding patterns of daily personal magnetic field exposures that occur in men because, when compared with women, there may be important differences related to behaviour, time–activity patterns and resultant exposures.

Another exposure science issue that has yet to be reported on in the literature is the correlation of personal magnetic field exposures within male–female couples, despite the many advantages of this information to the design and interpretation of reproductive health epidemiology studies. Based on previous studies, the norm for assessing the potential association between exposure to magnetic fields and adverse pregnancy outcomes is to estimate maternal exposures as it is assumed that only maternal exposures are biologically relevant. However, fertilisation and embryo and foetal development are directly dependent on the father's health as well⁽¹⁹⁾. Thus, if

exposures within couples are correlated, then the observed associations could be related to the exposures that were experienced by the mother, the father or both. Despite this limitation, one advantage of such a scenario is that maternal exposure data could potentially be used as an exposure surrogate in the absence of paternal exposure data to examine associations with male reproductive health outcomes prior to fertilisation and vice versa. This could be especially valuable if there is differential recruitment between women and men based on their willingness to wear a personal magnetic field exposure monitor independent of their willingness to provide a biological measurement, or if there is availability of exposure data from one of the partners and also an opportunity to obtain outcome data from archived data or biological samples.

The aims of the present analysis were to (1) examine the distribution of personal magnetic field exposures in men, (2) assess the temporal variability of personal magnetic field exposures in men and (3) explore the correlation of personal magnetic field exposures within male–female couples. To study these aforementioned exposure science issues, longitudinal data were collected from men and their respective female partners recruited at an infertility clinic in Boston, MA. This analysis fills several data gaps in the literature, and is expected to inform the design and interpretation of future reproductive health epidemiology studies.

MATERIALS AND METHODS

Study participants

Men ($n = 25$) in this study were enrolled in the Environment and Reproductive Health (EARTH) Study, which is an ongoing collaboration between the Massachusetts General Hospital (MGH) Fertility Center and the Harvard School of Public Health (HSPH) studying how the environment potentially influences infertility^(20, 21). Male participants were partners in couples seeking infertility treatment at MGH due to a male factor, a female factor, or a combination of both male and female factors. Where applicable and available, data from the participant's respective female partners ($n = 19$) were also incorporated into the present analysis. Data were collected for up to three repeated, 24-h time periods separated by several weeks.

Time–activity diary

Participants were asked to complete a time–activity diary⁽⁷⁾, which was modelled after the one used in the U.S. National Children's Study (<http://www.nationalchildrensstudy.gov>) and consisted of describing their daily activities and locations at 30-min intervals.

Measurement of magnetic field exposure and physical activity

Participants were asked to wear at the hip level a small personal magnetic field exposure monitor (EMDEX LITE, EnerTech, Campbell, CA, USA). The EMDEX LITE was calibrated to measure the magnetic field level in milligauss ($1 \text{ mG} = 0.1 \mu\text{T}$) every 4 s within a frequency band ranging from 40 to 1000 Hz, a bandwidth that includes the power frequency of 60 Hz. The resultant magnetic field level of the X, Y and Z planes was used in the analysis.

Participants were also asked to wear at the hip level an ActiGraph accelerometer (Model Number GT3X, Pensacola, FL, USA). The ActiGraph is a triaxial accelerometer that reports movement as 'counts per epoch' (average counts every 2 s for this study) from the measured accelerations (g) in the X, Y and Z planes. Similar to the EMDEX LITE, physical activity level was defined as the resultant average counts every 2 s across these three axes. Average counts represented an indication of total movement, with higher counts representing higher overall physical activity.

Participants were instructed to wear the monitors throughout the entire monitoring period (i.e. inside and outside the home), except at bedtime and when bathing, showering or swimming. These personal exposure monitors, as well as similar monitors manufactured by the same company, have been used in numerous other studies conducted in adults^(3, 5–7, 16–18, 22).

Measurement of other variables

At enrolment, a research nurse administered a questionnaire to collect data on age, race/ethnicity and occupation, and measured the participants' height and weight. Participants also completed a more detailed questionnaire where information on other variables, including education level, was also collected.

Statistical analysis

Statistical analyses were performed using SAS version 9.3 for Windows (SAS Institute, Cary, NC, USA). Prior to conducting any statistical analyses, two data sets were created. In the first data set, non-wear time intervals as reported in the time–activity diaries were removed^(3, 6, 7). In the second data set, non-wear time intervals were not removed. Statistical analyses were performed using both of these data sets to explore if the approach taken to handle non-wear time modified the results. Previous studies by the authors that use data from a subset of women from the EARTH Study⁽⁷⁾ and a cohort of women from North Carolina⁽³⁾ do not suggest that this approach biases the results^(3, 7). Furthermore, the authors have demonstrated in these women from the EARTH Study⁽⁷⁾ that personal magnetic field exposures may differ

between settings. To further explore this matter, statistical analyses were also performed using data for the entire sampling day (total) and stratified by environment (inside and outside the home). Statistical significance was defined as a p -value of ≤ 0.05 .

Descriptive statistics were first calculated for the following variables: age, race/ethnicity, body mass index [BMI, $\text{weight (kg)} \div \text{height (m)}^2$], education and occupation. Distributions were then calculated for the following participant-level variables: daily average, 90th percentile and maximum personal magnetic field exposures; daily average physical activity counts; daily monitor wear durations; daily 90th percentile personal exposures $\geq 1.6 \text{ mG}$; daily duration of personal exposures $\geq 1.6 \text{ mG}$; and per cent of total time where personal exposures $\geq 1.6 \text{ mG}$.

To assess both between- and within-person variabilities in daily personal magnetic field exposure metrics (average, 90th percentile and maximum) over the course of repeated measurement days (separated by several weeks in this case), intraclass correlation coefficients (ICCs) were calculated using the variance components from linear mixed models with log-transformed outcome variables (magnetic field exposure metric) and only one random effect as the random intercept for each subject. The magnitudes of the ICCs were evaluated using the following criteria: poor reproducibility ($\text{ICC} < 0.40$), fair to good reproducibility ($0.40 \leq \text{ICC} < 0.75$) and excellent reproducibility ($\text{ICC} \geq 0.75$)⁽²³⁾. ICCs were calculated using data from men that had data available for 2–3 sampling days.

Lastly, Spearman's correlation coefficients were calculated to assess the correlation of the daily average, 90th percentile and maximum magnetic field exposures within male–female couples. Correlations were estimated for these daily personal exposure metrics for each measurement day separately. These measurement-day correlation coefficients were subsequently combined to derive an overall average across all three time points. Correlation coefficients were only calculated using data from couples that were measured on the same day.

RESULTS

As shown in Table 1, 25 men were recruited into the present study. The participants had a median age of 34 y [interquartile range (IQR): 32, 41 y] and median BMI of 26 kg m^{-2} (IQR: 24, 30 kg m^{-2}). They were mainly Caucasian (88 %), highly educated (90 % were at least college graduates) and professionally employed (96 %). The monitors were worn by the participants for a median of 15.0 h (IQR: 14.0, 16.0 h) per day on repeated sampling days that were separated by a median of 4.6 weeks (IQR: 3.3, 5.7 weeks) within the participants.

Table 2 shows the distribution of the daily personal magnetic field exposure metrics for the entire cohort. The geometric mean (GM) values for the average, 90th percentile and maximum were 1.2, 2.2 and 28.9 mG, respectively. When stratifying by environment, the averages (difference in GMs: 0.2 mG) and 90th percentiles (difference in GMs: 0.1 mG) were similar, whereas maximums varied greatly (difference in GMs: 9.9 mG); maximum exposures experienced outside the home were higher than those experienced

inside the home on average. On average, the men in the present study were also approximately twice as active outside the home (median of average counts: 26.2, IQR: 19.4, 39.0) relative to inside the home (median of average counts: 13.1, IQR: 9.5, 18.9).

Table 3 displays the distribution of select metrics among the men in the present study, which were derived based on the 1.6 mG threshold used in the Li *et al.*⁽¹⁸⁾ study. Most of the men (80 %) had experienced a 90th percentile personal magnetic field exposure of ≥ 1.6 mG and, on average, experienced exposures ≥ 1.6 mG for ~ 20 % of the measurement day. When stratifying by environment, while a greater fraction of men experienced 90th percentile exposures ≥ 1.6 mG outside the home (92 %) compared with inside the home (64 %), the per cent of time ≥ 1.6 mG was greater inside the home (25 %) relative to outside the home (16 %).

ICCs, presented in Table 4, varied widely depending on the exposure metric and the environment. When considering total exposures experienced throughout the day, the average and 90th percentile demonstrated fair to good reproducibility, whereas the maximum showed poor reproducibility; similar conclusions were met when isolating exposures that occurred inside the home only. However, the average, 90th percentile and maximum all were characterised by poor reproducibility when considering only exposures that were experienced outside the home.

As demonstrated in Table 5, the within-couple correlation for the average was consistently statistically significant, positive and strong across all three measurement days for exposures inside the home only (average correlation: 0.90). All remaining personal magnetic field exposure metric–environment combinations did not generate consistent correlations across all three measurement days.

Table 1. Characteristics of male participants ($n = 25$).

Characteristic	Median (IQR)	n (%) ^a
Age (years)	34 (32, 41)	
BMI (kg m^{-2})	26 (24, 30)	
Asian		2 (8)
Black/African-American		0 (0)
Caucasian		22 (88)
Native American/Alaska Native		0 (0)
Pacific Islander		0 (0)
Other		1 (4)
Did not graduate from high school		0 (0)
High school graduate		1 (5)
1 or 2 y of college		1 (5)
3 or 4 y of college		0 (0)
College graduate		8 (40)
Graduate degree		10 (50)
Professional (e.g. engineer), manager (e.g. marketing manager) or executive (e.g. chief financial officer)		24 (96)
Graduate student		1 (4)

IQR, interquartile range.

^aMissing data on education for 5 participants, total $n = 20$.

Table 2. Distribution of daily personal magnetic field exposure metrics (mG) and daily magnetic field exposure monitor and accelerometer wear time (hours) by environment among male participants.

Environment	Daily wear time Median (IQR)	Metric	GM	Percentiles		
				25th	50th	75th
Total ^a	15.0 (14.0, 16.0)	Average	1.2	0.8	1.2	1.6
		90th percentile	2.2	1.6	2.2	3.1
		Maximum	28.9	19.6	28.8	40.4
Inside the home ^a	7.5 (4.5, 11.0)	Average	1.3	1.0	1.3	2.0
		90th percentile	2.0	1.3	2.2	3.2
		Maximum	14.3	8.7	13.4	23.7
Outside the home ^b	8.0 (3.5, 10.5)	Average	1.1	0.7	1.1	1.8
		90th percentile	2.1	1.3	2.3	3.2
		Maximum	24.2	17.2	26.3	35.0

GM, geometric mean; IQR, interquartile range.

^aFifty-seven sampling days from 25 men.

^bFifty-five sampling days from 25 men.

Table 3. Distribution of select metrics (derived with the 1.6 mG cut point used in the Li *et al.*⁽¹⁸⁾ study) by environment among male participants.

Environment	Metric	n (%)	Percentiles		
			25th	50th	75th
Total ^a	Data sets with 90th percentile ≥ 1.6 mG	41 (72)			
	Participants with 90th percentile ≥ 1.6 mG	20 (80)			
	Duration (hours) ≥ 1.6 mG		1.4	2.8	5.0
	Per cent of total time ≥ 1.6 mG		9.2	20.1	34.3
Inside the home ^a	Data sets with 90th percentile ≥ 1.6 mG	34 (60)			
	Participants with 90th percentile ≥ 1.6 mG	16 (64)			
	Duration (hours) ≥ 1.6 mG		0.4	1.6	3.5
	Per cent of total time ≥ 1.6 mG		5.5	24.7	57.9
Outside the home ^b	Data sets with 90th percentile ≥ 1.6 mG	37 (67)			
	Participants with 90th percentile ≥ 1.6 mG	23 (92)			
	Duration (hours) ≥ 1.6 mG		0.6	0.9	1.7
	Per cent of total time ≥ 1.6 mG		8.1	15.7	34.1

Table 4. Between- and within-subject variance apportionments and ICCs for log-transformed daily personal magnetic field exposure metrics by environment among male participants.

Environment	Metric	Variance estimate		ICC
		Between subject	Within subject	
Total ^a	Average	0.13	0.08	0.61
	90th percentile	0.18	0.08	0.69
	Maximum	0.03	0.31	0.08
Inside the home ^a	Average	0.17	0.07	0.71
	90th percentile	0.28	0.09	0.75
	Maximum	0.32	0.50	0.39
Outside the home ^b	Average	0.10	0.21	0.32
	90th percentile	0.13	0.29	0.30
	Maximum	0.05	0.32	0.13

ICC, intraclass correlation coefficient.

^aDerived from linear mixed models with only one random effect as the random intercept for each subject using 52 sampling days from 20 men.

^bDerived from linear mixed models with only one random effect as the random intercept for each subject using 50 sampling days from 20 men.

All statistical analyses were repeated without removing non-wear time data, which generated comparable results (data not shown).

DISCUSSION

In this study, personal magnetic field exposures were measured longitudinally in a sample of male volunteers as well as their respective female partners who together attended a fertility clinic located in Boston, MA. Among the men, the daily average and 90th percentile of these magnetic field exposures were much more stable over time relative to the maximum.

In addition, average magnetic field exposures at home were strongly correlated within couples.

To date, the authors are aware of no other study that has characterised personal magnetic field exposures among men that are members of subfertile couples, which may be differentially susceptible to exposure to environmental agents. The propensity to experience elevated maximum exposures was greater outside the home relative to inside the home. These men also had a greater physical activity level outside the home, which is consistent with a previous analysis among a subset of women from the EARTH cohort⁽⁷⁾. It is plausible that when physical activity level, shown to be positively associated with maximum magnetic field

Table 5. Within-couple correlation of same-day personal magnetic field exposure metrics by environment.

Environment	Metric	Spearman's correlation coefficient			
		Day 1 ^{a,b}	Day 2 ^{c,d}	Day 3 ^{c,d}	Average
Total	Average	0.77*	0.52*	0.80*	0.70
	90th percentile	0.86*	0.38	0.55*	0.60
	Maximum	-0.22	0.71*	-0.30	0.06
Inside the home	Average	0.96*	0.81*	0.93*	0.90
	90th percentile	0.92*	0.53*	0.57*	0.67
	Maximum	0.12	-0.19	-0.04	-0.04
Outside the home	Average	0.77*	0.25	0.33	0.45
	90th percentile	0.65*	0.22	0.09	0.32
	Maximum	-0.13	0.68*	0.29	0.28

^aTotal and inside the home: correlations calculated using data from 19 couples.

^bOutside the home: correlations calculated using data from 18 couples.

^cTotal and inside the home: correlations calculated using data from 15 couples.

^dOutside the home: correlations calculated using data from 14 couples.

* $p \leq 0.05$.

exposure⁽⁵⁻⁷⁾, was increased outside the home, the probability of encountering elevated field sources also increased, leading to elevated maximum exposures outside the home among the men in the present study. Given that the average and 90th percentile magnetic field exposures were each similar for inside and outside the home, the results suggest that exposures to sources of elevated magnetic fields occur intermittently over the course of the day (otherwise, the average and 90th percentiles would have differed by environment as well).

Li *et al.*⁽¹⁸⁾ reported that ~50 % of the men in their study experienced a daily 90th percentile of ≥ 1.6 mG, which is much lower than what was observed among the men in the present; ~80 % of the men in the present study experienced a 90th percentile of ≥ 1.6 mG during at least one of the sampling days. However, because Li *et al.*⁽¹⁸⁾ only collected personal exposure data during a single day, they may have underestimated the true distribution of 90th percentile exposures in their study population (i.e. if they collected more than 1 sampling day within participants, they may have observed that the percentage of men with 90th percentile ≥ 1.6 mG was > 50 %). In addition, the authors⁽⁷⁾ recently published an analysis of a subset of women ($n = 40$) from the same cohort and found that the GMs for the average and maximum were 1.2 and 34.4 mG, respectively, which are comparable with those observed among the men in the present study. Several additional studies have reported on the distribution of personal magnetic field exposures among cohorts of women from both California ($n = 960$)^(17, 24) and North Carolina ($n = 100$)⁽³⁾, which have been described elsewhere⁽⁷⁾. However, to date, relevant magnetic field exposure data among adults are limited.

To the authors' knowledge, this is the first analysis to report on the intra-individual temporal variability

of personal magnetic field exposures in men over durations that are relevant to male reproductive health and that integrate exposures from magnetic field sources inside and outside the home, including the workplace. If there is interest in characterising personal magnetic field exposures in male reproductive health epidemiology studies and the average or 90th percentile modelled as continuous variables are the metrics of interest, then collecting 1 d of sampling may be appropriate. However, if there is interest in the maximum, then collecting more than 1 day of sampling is necessary to reduce measurement error. The same is true when focussing on magnetic field exposures inside the home only. However, if investigators are interested in exposures occurring outside the home only, then more 1 d of sampling would be required to adequately capture the intra-individual variability in exposures that are experienced over time regardless of the selected exposure metric. Others^(3, 5, 7, 16, 25) have also examined the temporal variability of personal magnetic field exposure metrics in adults and have reported similar findings for the exposure metrics assessed in the present study. Thus, there appears to be consensus across several cohorts that exposure measurement error due to temporal variability is much more problematic for those exposure metrics towards the upper tail of the exposure distribution. This is expected as what drives peak exposures is intermittent interactions with high magnetic field sources, which can vary from day to day, especially if one's mobility patterns are highly variable.

This study presented evidence that average personal magnetic field exposures collected in men at home could be used as a surrogate for average exposures of their respective female partners at home, and vice versa. In a residential study of exposures among

adults at 217 houses across the contiguous USA, Rankin *et al.*⁽²⁵⁾ reported that average personal magnetic field exposures and long-term fixed site measurements inside the home were strongly correlated (Pearson's: 0.74, Spearman's: 0.78). Based on these results, one may argue that investigators could rely on an area measurement inside the home instead of personal data if there is interest in average exposures among adult men or women. However, for the other correlation scenarios examined, there appears to be too much variability in magnetic field exposures within couples to justify surrogacy. If there is interest in average exposures inside the home, this information is useful, especially if it is feasible to recruit one partner to provide a biological sample, but challenging to recruit that individual to wear a personal magnetic field exposure monitor relative to their partner. The findings of the present study also have application retrospectively among fertility cohorts that primarily focussed on women, but also have corresponding semen samples from their male partners who never had their exposures characterised. However, highly correlated average exposures inside the home within couples may make it difficult to disentangle any post-fertilisation associations as the any potential relationship identified could be related to the magnetic field exposures that were experienced by the mother, the father or both.

Unique strengths of this study include thousands of data points per day within each individual, and the novelty of the exposure science issues that were explored. Despite the limited sample size, the results were largely consistent with similar data sets gathered from other adult populations. In addition, it is possible that this study had some degree of differential participation in the magnetic field exposure component of the EARTH study, but this is expected to be limited as the subjects were similar to the participants of the overall EARTH cohort on demographic factors. Bias due to missing data is also limited as the missing data were from participants that already contributed data to the available data set. Therefore, the missing data should be comparable with the data used in the analysis assuming that there were no major variations in participant behaviour and resultant magnetic field exposure during these missing time periods.

CONCLUSIONS

In conclusion, the authors explored several magnetic field exposure science issues in men and in relation to their female partners that are of relevance to reproductive health epidemiology studies. The daily average and 90th percentile personal magnetic field exposures were relatively stable over a time period of several weeks in contrast to the maximum, which was highly unstable. When modelled as a continuous variable, one day's worth of sampling may adequately

characterise personal magnetic field exposures in men over durations relevant to male reproductive health if there is interest in the average or 90th percentile. However, more than 1 d of sampling is necessary to minimise exposure measurement error in such studies if there is interest in the maximum. Nevertheless, caution should be used when analysing the temporal reliability data in the present study, because when magnetic field exposure is modelled as a categorical variable instead (e.g. using a threshold to differentiate 'exposed' vs. 'unexposed' persons), the reliability can be different. In particular, the reliability is dictated by the selected threshold, with decreasing reliability over time with increasing threshold^(3, 7). The number of sampling days per participant is study specific and should be balanced by the realistic financial and participant burden constraints often associated with large-scale epidemiology studies. The authors found that the average was correlated within male–female couples at home, which may assist with the design and interpretation of future reproductive health epidemiology studies concerning exposures to magnetic fields. Similar to previous studies, one's environment was observed to be an important determinant of personal magnetic field exposure and, as a result, affects the temporal variability of exposures in men and exposure patterns within couples.

FUNDING

This work was supported by project 1-SP0239 from the Electric Power Research Institute and grants R01 ES009718 and R01 ES016099 from the National Institute of Environmental Health Sciences, National Institutes of Health. R.C.L. was also supported by the Rackham Predoctoral Fellowship Award from the University of Michigan.

ACKNOWLEDGEMENTS

The authors also acknowledge all other members of the EARTH study team, specifically Ramace Dadd and Myra Keller at the Harvard T. H. Chan School of Public Health and physicians and staff at MGH Fertility Center, and especially thank all of the study participants.

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