ASSOCIATION OF HEALTH PROBLEMS WITH 50-HZ MAGNETIC FIELDS IN HUMAN ADULTS LIVING NEAR POWER TRANSMISSION LINES:

Ivan L. Beale, PhD, Department of Psychology, University of Auckland.

Neil. E. Pearce, PhD, Department of Medicine, Wellington Medical School.

Roger J. Booth, PhD, Department of Molecular Medicine, University of Auckland

Corresponding author:

Ivan L. Beale PhD
Department of Psychology
University of Auckland
PB 92019
AUCKLAND
NEW ZEALAND

ibeale@psych.auckland.ac.nz

Grant support: Health Research Council of New Zealand
University of Auckland Research Committee

Running head:
Health effects of residential magnetic fields.

ABSTRACT

BACKGROUND.
Although numerous studies of animals and cell cultures indicate effects of power-frequency magnetic fields on immune-system function, few studies have looked for evidence of association between environmental power-frequency magnetic field exposure and immune-related illnesses in humans. This study used a cross-sectional design to examine the dose-response relationship between magnetic-field exposure of adults in their homes and prevalence of immune-related and other chronic illnesses.

METHODS.
560 adults living near extra-high-voltage transmission lines completed questionnaires about demographics, health problems and other characteristics. 50-Hz magnetic field flux densities were measured in each room where each participant spent significant time, and individual time-integrated exposures were calculated.

RESULTS.
Trend analysis and multiple logistic regression procedures were used to relate derived health variables to individual estimates of time-integrated magnetic field exposure. Five of the eight health variables showed significant linear dose-response relationships with exposure. After adjustment for possible confounding, significantly elevated odds ratios were found both for asthma (odds ratio: 3.3) and combined chronic illnesses (odds ratio: 2.2) at higher exposure levels.

CONCLUSIONS.
The results indicate a possible adverse effect of environmental magnetic field exposure on immune-related and other illnesses.

Epidemiology; human adults; immune system; asthma; magnetic field exposure.

INTRODUCTION

The accumulating evidence that residential exposure to power-frequency magnetic fields is associated with elevated risk for childhood leukemia (e.g., 1,2) has led to concern that such field exposures may adversely affect immune-system function (3,4). Some laboratory studies both of live animals and human cell cultures have demonstrated effects of weak power-frequency fields on immune function at the cellular level (5-9) but extrapolation of such findings to residential exposure and human health is considered problematic (10).

To date there have been few studies of health effects on adults of residential exposure to power-frequency fields, these largely being confined to leukemia and central nervous system tumours (11-13) or mental health (14). Our study addresses the broader subject of a possible association between power-frequency magnetic field exposure and the incidence of immune-related diseases and other chronic health problems in adults.

Previous epidemiologic research has been examined for methodologic weaknesses that limit the power of studies to provide strong evidence for adverse effects of 50/60-Hz exposure. Three of the factors identified are poor exposure assessment of individuals, insufficient control of possible confounding variables, and inability to demonstrate a systematic dose-response relationship (e.g., 15). Our study attempted to address these problems in several ways: It employed a cross-sectional design intended to maximise the range of individual field exposures and therefore the possibility of finding a systematic dose-response relationship; it interviewed individual participants in an attempt to measure a wide range of possible confounders; and, direct measures were obtained of individual time-integrated exposures to 50-Hz magnetic fields, an index thought to be adequately representative of participants' overall history of residential exposure (16).

METHOD

Topographic maps of the Auckland Metropolitan area were used to locate streets running beneath or adjacent to overhead transmission lines connecting substations in the national grid. 50-Hz magnetic field flux densities were measured at the gateways of houses in these streets and letters were left in the mailboxes of all houses where gate readings exceeded 5 mG. For each such house, another house was selected in the same street with a gate reading less than 3 mG. This was to ensure that a wide range of magnetic field levels would found in the houses to be studied. The letter gave general information about the purpose of the study and invited residents between the ages of 15 and 72 years, who had resided at least six months at that address, to agree to participate by phoning the researcher or by returning a consent form by post. Participants were recruited at a follow-up visit when their status to participate was confirmed and written consent was obtained after any questions had been answered by the researcher. Consent included agreeing to have medical records checked by the participant's medical practitioner and to have blood samples taken. The informed consent procedure was approved by a university ethics committee.

Interviewing and field measurement were done by senior psychology students under the supervision of qualified and experienced researchers. The interviewers were trained to a mastery criterion on all the skills relevant to data collection. This included making neutral responses to typical questions by participants about the effects of magnetic fields, questionnaire administration, and field measurement. Initial interviews were directly supervised by a researcher and subsequent interviews monitored on a random basis as a means of quality control. Interviews took about 90 minutes and took place in a quiet area in each participant's home at a time convenient to the participant. Interviewers worked in pairs for reasons of personal safety and to facilitate supervision of children during interview of a parent.

Questionnaires given, in order of administration, were as follows:

The Life Changes Questionnaire (17). This is a list of 38 life events. Subjects indicate which have occurred in their lives within the past 12 months. The score is the sum of marked events, weighted according to their typical effect on mental health.

The Powerlines Project Questionnaire. This was developed specifically for this study, to collect all relevant demographic, general behavioural and health information. Included were questions to determine age, gender, education, occupation, health problems, medication use, alcohol use, and years resident at current address. Also included at the end of the questionnaire was a question asking participants to rate their general health over the past six months on a 5-point scale from "terrible" to "excellent". Additional tests of cognitive functioning and mental health were also given at this time but are not analysed in this report.

Field measurements.

At the end of the interview, participants were asked to say in which rooms of the house they spent one hour or more per day on average. The estimated time spent in each room was noted.

Interviewers then used gaussmeters (MSI-50; Magnetic Sciences International) to record 50-Hz magnetic flux densities at three places in each nominated room. During this time, the normal pattern of appliance use was continued, but no readings were taken closer than 1 metre to appliances. In bedrooms, one reading was recorded at the head of the bed, one in the middle of the bed, and one away from the bed. The time of day when the readings were taken was also recorded. Because field measurements would be expected to vary to some extent according to variations in current loadings on the transmission lines at various times of the day, seasons of the year, etc., an assessment was made of the representativeness of the field measurements taken following the regular interviews. This was accomplished by a researcher re-visiting 38 participants chosen at random and repeating the field measurement protocol. The time, day and month were chosen to suit the participants, without reference to the previous measurement occasion. The local geomagnetic field was measured at six representative locations at the conclusion of the study, using an Elsec 820 proton precession magnetometer (Littlemore Scientific Engineering Co., Oxford, U.K.).

Scoring of questionnaires.

This was done by researchers from records that did not indicate the address of the participant nor the field measurements taken at the address. Thus the scorer was "blind" to the magnetic field exposure relevant to each record.

RESULTS

Magnetic field characteristics.

The 50-Hz magnetic field flux density measurements are summarised in Table 1(a). Two indexes of average exposure were derived for each participant. Average exposure was the arithmetic mean of all readings taken in the two or three rooms in which the participant spent one hour or more per day on average. Time-integrated exposure was derived by multiplying the average estimated hours spent in each room by the mean of the readings taken in the room, and summing across the rooms in which the participant spent one or more hours per day on average. The Pearson correlation between the two exposure indexes was .96.

Test-retest reliabilities were calculated as Pearson reliability coefficients for average exposure (r=.915, N=38) and time-integrated exposure (r=.90, N=38). The coefficients were calculated on the 38 pairs of values obtained from field measurements and time estimates taken at the first and second visits.

The mean flux density of the local geomagnetic field was 544 mG (range 543-547 mG). Table 1(b) shows values grouped according to quintiles, with 112 participants in each. The quintiles are based on the distribution of time-integrated exposure, however average exposure values for each quintile are also reported because this exposure measure has been widely used in previous studies and is easier to relate to current knowledge about typical environmental exposure levels.

Participants.

Fifty-five people consenting initially were not included in the study because subsequently they failed to keep appointments for administration of tests or questionnaires. Forty-nine people were excluded because they indicated that they would have difficulty being interviewed in the English language. Twenty-four were excluded because they had resided less than six months at that address and a further ten excluded because they were about to change address. Six were excluded for reasons of physical incapacity and twenty-five excluded because they were older than 72 years. Of the 704 households approached, 330 did not yield anyone willing to participate. The other 374 households yielded a total of 572 participants, 560 of whom met all the inclusion criteria and completed the relevant questionnaires. Table 2 shows demographic data for the whole sample and for each quintile.

[insert tables 1 & 2 here]

Data analysis.

Participants' responses to questions about their health were sorted into eight variables which were analysed to test hypotheses about association between magnetic field exposure and health problems. Four of these variables reflected either general health or particular types of health problem. *Self-rated health* was measured from responses to a question that required participants to rate their general health during the past six months by circling the appropriate word on a five-point scale from "terrible" to "excellent". Responses were dichotomised (1,2 vs. 4,5) for analysis. Incidence of *chronic illnesses* was measured by asking participants to name any chronic illnesses they suffered from for at least the past six months and for which medication was prescribed by a medical practitioner. Participants were scored as having an *Allergy-related illness* (hay fever, food allergies, asthma, excema, uticaria, dermatitis, psoriasis) or an *autoimmune-related illness* (rheumatoid arthritis, thyroiditis, Graves' disease, Sjogren's syndrome, ulcerative colitis, Crohn's disease, systemic lupus erythematosis, pernicious anaemia, autoimmune chronic active hepatitis, myasthenia gravis, multiple sclerosis, Goodpasture's syndrome, type-I diabetes) if they reported having been diagnosed with diseases in either category.

The other four variables reflected specific diseases. *Colds and 'flu* were measured by asking participants to indicate the number they had suffered in the past six months. Responses were dichotomised (any vs. none) for analysis. *Type-II diabetes, asthma* and *rheumatoid arthritis* were scored if a participant reported both being diagnosed and prescribed medication. No other specific illnesses were analysed because the numbers were too small to permit detection of an association with exposure.

All health measures were analysed using the same procedure. First, the number of people classified as cases and controls were calculated for each exposure quintile, and a χ^2 test for linear trend conducted to test for a significant linear dose-response pattern (18). These results are shown in Table 3.

Next, time-integrated exposure was dichotomised (quintile 1&2 = less-exposed, quintile 4&5 = more-exposed). Participants in quintile 3 were excluded to avoid possible misclassification into upper and lower exposure categories. For each health measure, the proportions of cases and controls falling into the two exposure categories were examined using the Mantel-Haenszel procedure to obtain crude estimates of prevalence odds ratios (OR) and their associated 95% confidence limits. These are shown in Table 4.

Variables considered to be possible confounders were tested to see whether they were significantly associated with caseness for each health measure. This was done by entering them simultaneously with the dichotomised exposure classification in a multiple logistic regression with the health measure as dependent variable (19). Possible confounders selected were age (dichotomised by median split), gender, SES (median split), ethnicity (Caucasian vs. other), smoking (yes or no), alcohol (none or occasional vs. heavy), years resident at address (median split), educational qualification (secondary vs. tertiary) and life changes (median split of score on Life Changes questionnaire). Also included as a possible confounder was a variable reflecting participants' beliefs about whether living near powerlines had any effect on their health. Belief was indicated on a 5-point scale from “definitely improved it” to “definitely made it worse”, but for analysis scores were dichotomised according to whether participants scored either “possibly made it worse” or “definitely made it worse” or whether they scored another category. Variables were identified for further consideration if they were significant predictors in the regression equation , based on a liberal criterion ($p<.20$). Estimates of prevalence odds ratios were then re-calculated, simultaneously adjusting for the influence of those variables by using the Mantel-Haenszel procedure for weighted OR . The adjusted ORs are shown in Table 4.

[Tables 3 & 4 about here]

Table 3 shows that for self-rated health, chronic illnesses, asthma and type-II diabetes, there was a significant linear association between the proportion of cases and exposure level. Colds and ‘flu and allergy-related diseases were not systematically related to exposure level. Autoimmune-related illnesses showed a significant linear trend between quintiles 2 and 5 (χ^2=6.04, p=.01) but the reversal of direction of trend between quintiles 1 and 2 results in the overall trend being non-significant. It is notable that this same reversal of trend between quintiles 1 and 2 is shown in 5 of the 8 variables. The analysis of proportions of cases across dichotomously classified exposure categories (Table 4) shows significant elevation of risk at the higher exposure category only for self-rated health (OR=2.1), chronic illnesses (OR=2.2), asthma (OR=3.1) and type-II diabetes (RR=8.3). When the OR was adjusted for possible confounders, there was some reduction of ORs for all variables except asthma. In particular, the adjusted ORs for self-rated health and type-II diabetes fell to non-significant levels, with lower 95% CIs below unity. For self-rated health, the strongest confounder was ethnicity, which on its own reduced the OR by 14%. For diabetes, the strongest confounding was with the interaction between ethnicity and age, affecting OR by 23%. It was noted that although participants’ beliefs about the effects of powerlines of their health did influence the relation between exposure and 5 of the 8 health variables, its effect on OR estimates was important only for self-rated health (6.3%).

DISCUSSION

The results indicate that, for adults living near transmission lines, the prevalence of chronic illness is linearly related to the level of 50-Hz magnetic field exposure. The same is true for self-rated health status and for some specific illnesses, particularly asthma and type-II diabetes. Autoimmune-related illnesses collectively were significantly linearly related to exposure over most of the exposure range (quintiles 2 through 5). Linear dose-response functions are considered to be evidence for existence of a health hazard (20), and are regarded as giving a much better description of the relation between exposure and health than the more-usual contrasting of extremes or dichotomies such as exposed vs. unexposed (21). The range of average exposure levels of participants in our study extended from .01 mG to 75.8 mG. This is in contrast to the smaller range (.2 - 3.5 mG) over which dose-response patterns have been reported in studies of cancer (21).

The process of risk estimation is simplified by the contrasting of health problems in exposed and unexposed populations. Despite the limited power of our study design to detect ORs as small as 2, the analysis of health problems in the less-exposed vs. more-exposed participants showed that the crude estimate of prevalence ORs for health problems on those variables showing linear dose-response patterns ranged from 1.7 (arthritis) to 8.3 (type-II diabetes). After adjustment for the confounding influence of other variables, however, significant elevations of risk associated with higher exposure were confined to two health variables, chronic illnesses (210% elevation) and asthma (330% elevation). These elevations are large compared to those reported in most other studies of health effects of residential magnetic-field exposure, including those on childhood leukemia (2).

The exposure-level threshold for increased risk can only be crudely estimated from our data. The lower boundary of time-integrated exposure for the high-exposure category was 71.0 mG-hour and the mean was 206.65 mG-hour. The upper boundary of the low exposure category was 38.93 mG-hour and the mean was 16.98 mG-hour. The distributions of mean exposure levels (without time integration) in the two exposure categories overlap somewhat, the minimum for the high-exposure category being 3.22 mG and the maximum for the lower exposure category being 4.93 mG. This threshold region for increased risk in this study is more than two orders of magnitude lower than the maximum permissable exposure limit (1000 mG) for the general public recommended in the relevant international guideline (22).

It is possible that the associations between exposure level and health measures found in this study are due to some factor other than the possible confounders identified and controlled for. However, such factors would have to be correlated with field exposure over a wide range to yield the dose-response pattern found in this study. Because scoring of illnesses was based entirely on self-report of diagnosis and medication, it is also possible that our findings are a direct result of biased reporting of health problems, with a bias for reporting health problems being positively correlated with level of field exposure. This would arise if more-exposed participants were more likely to associate health problems with exposure and therefore more likely to report them in the context of an investigation of effects of exposure. It was precisely to eliminate this possibility that “perceived effect” was included in the analysis as a possible confounder. Also, the fact that some outcomes were not associated with exposure indicates that there was not a general tendency for more-exposed participants to over-report health problems.

A major focus of this study was the possibility that immune-related illnesses would be affected by magnetic-field exposure. Significant ORs were not found for colds and ‘flu, nor for the collective categories of allergy-related or autoimmune-related illnesses. For the latter, however, there was evidence of a linear dose-response pattern. One immune-related illness, asthma, was strongly associated with exposure level. Also, many of the chronic illnesses reported were immune-related, although there were too few cases of most specific diseases to permit useful analysis. The results may therefore be interpreted as consistent with the idea that the immune system is influenced by exposure, but the influence is not uniformly expressed in all immune-related diseases. Further study of magnetic-field exposure and immune-related illnesses is clearly warranted, including investigation of specific immune variables.

ACKNOWLEDGMENTS

Thanks to the participants who willingly gave their time, and to the research assistants who assisted with data collection, scoring and data entry, especially Denise Conroy, Marcus Henning, Sandra Heriot and Kath Murrell. Funded by the Health Research Council of New Zealand and the University of Auckland Research Committee.

REFERENCES

1. Feychting M, Ahlbom A. Childhood leukemia and residential exposure to weak extremely low frequency magnetic fields. Environ Health Perspect 1995; 103 Suppl 2: 59-62.

2. Miller MA, Murphy JR, Miller TI, et al. Variation in cancer risk estimates for exposure to powerline frequency electromagnetic fields: A meta-analysis comparing EMF measurement methods. Risk Analysis 1995; 15: 281-287.

3. Nair I, Morgan MG, & Florig HK. Biological effects of power frequency electric and magnetic fields. Technical report: Congress of the United States Office of Technology Assessment. OTA-BP-E-53. Washington, D.C.: US Government Printing Office, 1989.

4. Loscher W & Mevissen M. Animal studies on the role of 50/60 -Hertz magnetic fields in carcinogenesis. Life Sci 1994; 54: 1531-43.

5. Adey WR. Evidence for tissue interactions with microwave and other nonionizing electromagnetic fields in cancer promotion. In Fiala J & Pokorny J (Eds), Biophysical aspects of cancer. Prague: Charles University, 1987.

6. Cadossi R, Zucchini P, Emilia G, et al. In vitro and in vivo effects of low frequency low energy pulsed electromagnetic fields in hematology and immunology. In Frey AH (Ed), On the nature of electromagnetic field interactions with biological systems. New York: Springer, 1995.

7. Mevissen M, Lerchl A, Szamel, et al. Exposure of DMBA-treated female rats in a 50-Hz, 50 microTesla magnetic field: Effects on mammary tumor growth, melatonin levels, and T lymphocyte activation. Carcinogenesis 1996; 17: 903-10.

8. Ramoni C, Dupuis ML, Vecchia P, et al. Human natural killer cytotoxic activity is not affected by in vitro exposure to 50-Hz sinusoidal magnetic fields. Int J Radiat Biol 1995; 68: 693-705.

9. Walleczek J. Immune cell interactions with extremely low frequency magnetic fields: Experimental verification and free-radical mechanisms. In Frey AH (Ed), On the nature of electromagnetic field interactions with biological systems. New York: Springer-Verlag, 1995.

10. Cleary SF. A review of in vitro studies: Low frequency electromagnetic fields. Am Ind Hyg Assoc J 1993; 54: 178-85.

11. Coleman MP, Bell CMJ, Taylor H, et al. Leukemia and residence near electricity transmission equipment: A case control study. Br J Cancer 1989; 60: 793-98.

12. Feychting M & Ahlbom A. Magnetic fields, leukemia, and central nervous system tumors in Swedish adults residing near high-voltage lines. Epidemiology 1994; 5: 501-9.

13. Wertheimer N & Leeper E. Adult cancer related to electrical wires near the home. Int J Epidemiol 1982; 11: 345-55.

14. Poole C, Kavet R, Funch DP, et al. Depressive symptoms and headaches in relation to proximity of residence to an alternating-current transmission line right-of-way. Am J Epidemiol 1993; 137: 318-30.

15. Savitz DA, Pearce NE, Poole C. Update on methodological issues in the epidemiology of electromagnetic fields and cancer. Epidemiol Rev 1993; 15: 558-66.

16. Morgan MG, Nair I. Alternative functional relationships between ELF field exposure and possible health effects: Report on an expert workshop. Bioelectromagnetics 1992; 13: 335-350.

17. Holmes TH, Rahe RH. The Social Readjustment Rating Scale. J Psychometric Res 1967; 11: 213-18.

18. Schlesselman JJ. Case control studies. New York: Oxford University Press, 1982.

19. SPSS. SPSS for Windows, 1995. Chicago: SSPS Inc., 1995.

20. Wilson R. Risk assessment of EMF on health. IEEE Engineering in Medicine and Biology 1996; 15: 77-86.

21. Poole C, Ozonoff D. Magnetic fields and childhood cancers. IEEE Engineering in Medicine and Biology 1996; 15: 41-49.

22. International Radiation Protection Association. Interim guidelines on limits of exposure to 50/60 Hz electric and magnetic fields. Health Physics 1990; 58: 113-122.

TABLE 1 (a). Magnetic flux density at 50-Hz.

	N	Mean	Min	Max	S.D.
Individual reading (mG)	4557	6.92	0.01	194.30	9.02
Room mean (mG)	1519	6.92	0.01	141.2	9.02
Average exposure (mG)	560	6.74	0.01	75.80	8.08
Time-integrated exposure (mG-hour)	560	100.14	0.03	974.33	125.61

TABLE 1(b). Exposure values for quintiles based on time-integrated exposure.

	Quintiles				
	1	2	3	4	5
N	112	112	112	112	112
Mean average exposure (mG)	0.57	2.09	3.92	7.66	19.44
S.D.	(0.44)	(0.77)	(1.03)	(2.55)	(9.42)
Min.	0.01	.80	1.83	3.22	7.71
Max.	2.14	4.93	6.80	18.80	75.80
Mean time-integrated exposure (mG-hour)	6.40	27.56	53.33	105.79	307.61
S.D.	(4.18)	(6.93)	(9.37)	(22.46)	(137.6)
Min.	0.03	14.89	39.26	71.00	151.10
Max.	13.93	38.93	70.80	150.60	974.33

TABLE 2. Characteristics of participants in whole sample and separate quintiles.

	Whole sample	Quintiles				
		1	2	3	4	5
N	560	112	112	112	112	112
Female (%)	53.9	58.0	51.8	45.5	55.4	58.9
Age (mean years)	40.5	42.0	38.3	40.4	41.7	40.0
SES (mean level)	3.64	3.32	3.52	3.72	3.74	3.87
Ethnic identity						
% European	75.4	82.2	75.0	85.6	75.0	58.9
% NZ Maori	10.0	6.2	7.2	7.2	11.6	17.9
% Pacific Island	10.2	9.8	8.0	3.6	10.7	18.7
% Other	4.5	1.8	9.8	3.6	2.7	4.5
Mean duration of residence (years)	10.85	10.6	9.9	9.3	13.1	11.4
Educational level (mean)	1.45	1.59	1.59	1.41	1.37	1.31

Table 3. Percent in each quintile classified as "case" on each health measure. χ^2 statistics for linear association with exposure are also shown for each measure.

	Exposure quintiles					χ^2	*p*
	1	2	3	4	5		
N	112	112	112	112	112		
self-rated health	8.2	9	5.6	14.6	18.2	5.78	.016
chronic illnesses	12.5	7.1	11.6	18.8	20.5	7.06	.008
allergy-related	8.9	5.4	9.8	5.4	8.0	0.05	.82
autoimmune-related	8.0	3.6	4.5	9.8	10.7	2.22	.13
colds and 'flu	17	22.3	15.2	16.1	20.2	0.00	.994
asthma	1.8	2.7	6.2	5.4	8.0	5.61	.017
type-II diabetes	0.9	0	0.9	4.5	2.7	4.12	.042
arthritis	5.4	2.7	4.5	6.3	7.1	1.16	.28

Table 4. Numbers of people classified as "cases" and "non-cases" on each health variable. Crude and adjusted prevalence Odds Ratios (OR) and their associated 95% confidence intervals (CI) are also shown.

	Less exposed		More exposed						
	cases	non-cases	cases	non-cases	Crude OR	95% CI	Adj OR	95% CI	*p*
self-rated health	15	159	29	148	2.1	1.1, 4.3	1.4	0.6, 3.5	.48
chronic illnesses	22	202	43	180	2.2	1.2, 4.0	2.1	1.1, 4.0	.02
allergy-related	16	208	15	209	0.9	0.4, 2.1	.89	.44, 1.8	.88
autoimmune-related	13	211	23	201	1.9	0.9, 4.0	1.8	0.7, 4.4	.24
colds and 'flu	44	180	40	181	0.9	0.6, 1.5	0.9	0.6, 1.3	.45
asthma	5	219	15	209	3.1	1.1, 10.1	3.3	1.1, 10.5	.04
type-II diabetes	1	223	8	216	8.3	1.0, 177	6.5	0.7, 137	.15
arthritis	9	215	15	209	1.7	0.7, 4.3	1.2	0.4, 3.7	.87