American Journal of Epidemiology
Vol. 146, No. 12
Printed in U.S.A.

Magnetic Fields of Transmission Lines and Depression

Pia K. Verkasalo,[1] Jaakko Kaprio,[1] Jyrki Varjonen,[1] Kalle Romanov,[1] Kauko Heikkilä,[1] and Markku Koskenvuo[2]

Electromagnetic fields have been suggested to contribute to the risk of depression by causing pineal dysfunction. Some epidemiologic studies have supported this possibility but have generally reported crude methods of exposure assessment and nonsystematic evaluation of depression. Using two available nationwide data sets, the authors identified from the Finnish Twin Cohort Study 12,063 persons who had answered the 21-item Beck Depression Inventory of self-rated depressive symptoms in 1990. The personal 20-year histories of exposure (i.e., distance and calculated annual average magnetic fields) before 1990 to overhead 110- to 400-kv power lines were obtained from the Finnish Transmission Line Cohort Study. The adjusted mean Beck Depression Inventory scores did not differ by exposure, providing some assurance that proximity to high-voltage transmission lines is not associated with changes within the common range of depressive symptoms. However, the risk of severe depression was increased 4.7-fold (95% confidence interval 1.70–13.3) among subjects living within 100 m of a high-voltage power line. This finding was based on small numbers. The authors recommend that attempts be made to strive for a better understanding of the exposure characteristics in relation to the onset and course of depression. *Am J Epidemiol* 1997;146:1037–45.

depression; electromagnetic fields; epidemiologic factors

Depression results from a complicated interaction of biologic (1) and psychosocial factors (2, 3), possibly involving disruption of circadian rhythms (4). In 1988, Wilson (5) suggested that long-term exposure to extremely low-frequency magnetic fields, based on both experimental and epidemiologic observations, may cause pineal dysfunction in humans (including altered melatonin rhythms) that may, in turn, contribute to the onset of depression or exacerbate existing depressive disorders. The neurobehavioral effects of power-frequency magnetic fields have been reviewed in detail elsewhere (6).

The early epidemiologic studies on magnetic fields and depression and/or suicide (7–11), published in the 1980s, showed somewhat increased relative risks but shared a number of methodological problems including the lack of a standard measure for depressive symptoms, a lack of control for possible confounding, and a crude method for exposure assessment. The two more sophisticated studies (12, 13) employed a standardized measure for depressive symptoms and an improved control for confounding; the secondary exposure assessment in both studies was, however, based solely on proximity to power lines with no attempt for additional quantification of exposure. The first study (12) found an odds ratio (OR) of 2.8 (95 percent confidence interval (CI) 1.6–5.1) for depression, whereas the other (13) observed no significant difference in the depression scores between the exposed and nonexposed group. In one very recent study (14), living within 100 m of high-voltage power lines was linked to an increased risk of depression in mothers before and after giving birth. In another recent study (15), the risk for depression among electricians was increased twofold, whereas electrical workers in aggregate showed little evidence of an increase in risk.

We combined data from two nationwide studies that provided readily available information on depression, residential magnetic fields of transmission lines, and demographic characteristics. The purpose of our study was to investigate the hypothetical relation between 50-Hz magnetic fields of overhead 110- to 400-kv power lines and self-rated depression in Finland.

Received for publication November 12, 1996, and accepted for publication July 2, 1997.

Abbreviations: BDI, Beck Depression Inventory; CI, confidence interval; OR, odds ratio.

[1] Department of Public Health, University of Helsinki, Helsinki, Finland.
[2] Department of Public Health, University of Turku, Turku, Finland.
Reprint requests to Dr. Pia Verkasalo, Department of Public Health, P.O. Box 41, FIN-00014 University of Helsinki, Finland.

MATERIALS AND METHODS

Finnish Twin Cohort Study

The data for the present study were obtained from two nationwide, population-based studies: the Finnish Twin Cohort Study and the Finnish Transmission Line Study. The Finnish Twin Cohort Study is a genetic epidemiologic project for the study of genetic and environmental determinants of chronic disease. The older part of the cohort, used in this paper as a sample of individuals, was compiled from the Central Population Registry of Finnish citizens in 1974. It consists of all same-sex pairs born before 1958 with both members of a pair alive in 1967. The selection procedures, determination of twinship, and assessment of representativeness are described in detail elsewhere (16, 17). The twins were mailed a baseline questionnaire in 1975, and the response rate to the questionnaire was 89 percent. The social class, educational level, and marital status distributions of the twins were found to be very comparable with the Finnish population as a whole.

A follow-up study of these twins was carried out in 1990, when a questionnaire was mailed to the twins born between 1930 and 1957 belonging to pairs with both twins alive in 1987 (18). The questionnaire contained 102 health-related questions or scales, among them the 21-item Beck Depression Inventory (BDI) (19–21), which had an individual response rate of 77.5 percent (22). Those who completed fewer than 19 items on the BDI ($n = 400$) were excluded from the present study. For the remainder ($n = 12,063$), missing values were replaced by the mean value of the subjects' other items, and the final sums were calculated to be used in the present study. Subjects were aged 33–60 years at the time of testing.

The BDI instructions asked the subjects to describe themselves presently ("right now") on a scale that provided four alternatives. The 21 symptoms and attitudes were mood, pessimism, sense of failure, lack of satisfaction, guilt feelings, sense of punishment, self-dislike, self-accusation, suicidal wishes, crying, irritability, social withdrawal, indecisiveness, distortion of body image, work inhibition, sleep disturbance, fatigue, loss of appetite, weight loss, somatic preoccupation, and loss of libido. Each could be rated from 0 to 3 in terms of intensity, resulting in a total BDI score between 0 and 63. Although the mean BDI scores in a recent Finnish population study (also based on the Finnish Twin Cohort) (21) were 4.52 (95 percent CI 4.38–4.66) for men and 5.75 (95 percent CI 5.61–5.89) for women, the cutoff scores of 10, 19, and 30 have been recommended by the US Center for Cognitive Therapy (20) to distinguish between none or minimal (BDI < 10), mild to moderate (BDI 10–18), moderate to severe (BDI 19–29), and severe (BDI ≥ 30) forms of depression.

The Finnish Twin Cohort data from the 1990 health questionnaire was also used for the assessments of social support and stressful life events. First, social support was measured with five questions, three of which assessed the quantity of social support on a six-category scale (scale I), and two dichotomous questions assessed the quality of social support (scale II). The three quantitative questions asked the numbers of the subjects' weekly contacts, good friends possibly paying a visit without prior notice, and family members and others with whom they spoke openly. The two qualitative questions were based on the subjects' personal experience of their human relationships and asked whether the respondent possessed a good friend capable of giving support and whether he or she had anyone around for sharing deepest feelings and confidences. Both scales of social support were independently associated with BDI scores.

As for stressful life events, the subjects were asked whether the following life events had happened: death of a spouse, death of a friend, poor health of a family member, sexual problems, divorce or legal separation, troubles in other human relationships, considerable interpersonal conflicts at work, loss of a job, serious economic problems, serious personal health problems, considerable conflicts with spouse, and any other serious problem. The subjects were also asked to indicate when those life events had happened: during the last 6 months, during the last 5 years, earlier, or never. A sum variable of stressful life events was calculated with scores of 4, 2, 1, and 0 for the respective categories.

A nationwide hospital discharge registry has been kept in Finland by the National Board of Health since 1969. It covers all discharges of inpatients from hospitals in Finland. The doctors treating the respective patients have assigned the discharge diagnoses according to the Finnish version of the *International Classification of Diseases*, Eighth Revision, through 1986, and thereafter the Ninth Revision. Up to four different diagnoses are listed per patient at each discharge. The data on psychiatric diagnoses (ICD-9 rubrics 290–301) for 1972–1995 were linked to the twin cohort using the unique identification number assigned to each Finnish citizen. The reliability of the nationwide hospital discharge registry of Finland has been considered satisfactory for epidemiologic purposes (23, 24).

Finnish Transmission Line Cohort Study

The Finnish Transmission Line Cohort Study includes long-term information on residential magnetic field exposures of the 384,000 people (more than 6 percent of the total Finnish population) who have lived any period of time between 1970 and 1989 within 500 m of overhead power lines of 110–400 kv in magnetic fields calculated to be ≥0.01 μT (25). The cohort's coverage can be estimated to be close to 90 percent of all Finnish people. The compilation of personal exposure histories was based on the Central Population Register, which provided the dates of moving in and out of every residence in 1984–1989, along with a maximum of two addresses before 1984. The shortest distances between the center of each residential building and each overhead power line up to 500 m away were measured from topographical maps of Finland (scale 1:20,000) for each of the years from 1970 to 1989; the annual average magnetic fields (in μT) for each building were calculated, successively taking into account current, typical locations of phase conductors in power lines and distance. The exposure assessment and applications of the Transmission Line Cohort have been extensively described elsewhere (25–29).

The Transmission Line Cohort was combined with the Twin Cohort using the respondents' personal identification numbers, which are unique for every resident of Finland. The former provided the exposure data of the present study, and the latter, its outcome and covariate data. The members of the Twin Cohort who were not included in the nationwide Transmission Line Cohort (i.e., including everyone living in the vicinity of high-voltage power lines in Finland in 1970–1989) were presumed to have minimal exposure to the residential magnetic fields of high-voltage power lines.

Data analyses and statistical methods

Although the study population consisted of twins, the analyses disregarded their twinship and considered them as individuals drawn from the population. This procedure has been used in earlier analyses of individuals of the twin cohort (30, 31), and inferences from epidemiologic analysis of twins considered as individuals are comparable with those based on singletons from the general population. However, the lack of independence among observations involving some twin pairs would actually make the effective sample size slightly smaller than what is reported, thus making the actual variance slightly larger and CIs slightly wider than what is reported under the assumption of independence.

There is no reason to believe that the residential history of adult twins is different from that of other adults in the population. Less than 10 percent of twins lived together in 1981 (32). The mean BDI scores did not differ by zygosity for either sex. Also, the mean scores of twins from pairs in which both responded did not differ from the mean scores of twins from pairs in which only one responded.

The exposure measures used in the statistical analyses included, in addition to the mean distance and average magnetic field of each calendar year, the mean distance over the entire period for which the subjects lived within 500 m of the lines as well as cumulative exposure to magnetic fields during 1970–1989 (in μT-years), the latter being calculated as the sum of the products of magnitude and duration of magnetic field exposure.

Two statistical approaches were applied to investigate the relation between depression and power lines. First, the mean BDI scores were calculated for each exposure category to assess the transmission line effects on depressiveness at levels commonly encountered in the general population. Second, the cutoff scores of 10, 19, and 30 were applied in the analyses to study power line effects on mild to severe forms of depression.

In the analyses of mean BDI scores, we used analysis of covariance models (SAS, PROC GLM) to take simultaneously into account exposure (cutoff points of 50, 100, 200, and 500 m for distance; 0.01, 0.10, and 0.20 μT for magnetic field; and 0.01, 0.25, 0.50, and 1.00 μT-years for cumulative exposure to magnetic fields), BDI score, and confounding variables. The covariate-adjusted means and standard deviations of the BDI score in each exposure category were estimated from models with exposure, sex (men, women), age (continuous), social class (white collar, blue collar, farmer, unknown), education (primary, secondary, tertiary), marital status (unmarried, married, divorced, widowed), working outside the home (yes, no), regular day work (yes, no), engaged in salaried work (yes, no), current smoking status (never smoked, occasional smoking, former smoker, current smoker), presence of heavy drinking (i.e., a bottle of wine or its equivalent during a single occasion at least once a month or more often: yes, no), number of alcohol-related pass-outs during the past year (never, once, more often), life events scale (very low: <2 points, low: 2–4 points, high: 5–7 points, very high: ≥8 points), social support scale I (very low: <9 points, low : 9–10 points, high: 11–13 points, very high: ≥14 points), and social support scale II (low: <2 points, intermediate: 3 points, high: 4 points). Respective models were also fitted separately for men and women. The significance of a variable was assessed by a partial sum of squares F test; the criterion of statistical significance was set at the 5 percent level. Differences in the two-dimensional contingency tables were tested for statistical significance using the Pearson chi-square test.

In the analyses of a series of BDI strata ("no depression" (BDI < 10), "mild depression" (BDI 10–18), "moderate depression" (BDI 19–29),"severe depression" (BDI ≥ 30)), we obtained the relative risk estimates by calculating the odds ratios (ORs) of depression using exposure estimates with previously shown exposure cutoff points. The random variability was assessed by exact 95 percent CIs.

RESULTS

A sample of 5,512 men and 6,551 women were included in the present study. The proportion of study subjects included in the original transmission line cohort was 4.4 percent (i.e., (42 + 127 +362)/12,063)) (table 1). In 1989, 1.4 percent (n = 169) of the subjects compared with 1.5 percent (n = 58,000) of all Finnish people (n = 5 million) lived closer than 100 m from the lines; 0.3 percent (n = 33) of the subjects compared with a similar 0.3 percent (n = 15,600) of all Finnish people had an annual average magnetic field of ≥0.10 μT. (These estimates are based on previously published figures on transmission-line exposures in all of Finland (29).)

The response rates to the 1990 health questionnaire were somewhat higher among those living closer to the lines, the actual rates being 77, 74, 79, 80, and 83 percent for distances of ≥500, 200–500, 100–199, 50–99, and <50 m from the nearest high-voltage power line, respectively. As for the characteristics of the study subjects, those living within the 500-m corridor around the transmission lines appear to be relatively similar to those living outside the corridor (table 1). The two-dimensional contingency tables reveal neither major nor statistically significant (α = 0.05) differences by distance, the only exception being the slightly higher proportion of salaried workers among those living within 100 m of the lines (p = 0.03).

As for self-rated depressiveness, the covariate-adjusted means of BDI were 5.30, 5.27, 4.95, 5.08, and 4.20 in all study subjects by increasing cumulative exposure (nonsignificant) (table 2). The corresponding mean BDIs were lower for men (4.61, 4.91, 4.68, 4.04, and 4.53) than for women (5.86, 5.50, 5.19, 6.03, and 3.47). The results for distance and magnetic field in 1989 and mean distance in 1970–1989 were essentially the same as the results for cumulative exposure.

Of all the subjects, 10,043 (83 percent) experienced hardly any symptoms of depression (BDI < 10), 1,623 (13 percent) were mildly depressed (BDI 10–18), 338 (3 percent) moderately depressed (BDI 19–29), and 59 (0.5 percent) severely depressed (BDI ≥ 30) (table 3).

In table 4, the crude ORs by exposure and degree of depression are presented. The ORs for depression among those living within 100 m of a transmission line were 0.62 (95 percent CI 0.37–1.07), 0.60 (0.19–1.89), and 4.74 (1.70–13.3) by increasing severity of depressive symptoms, when compared with those living outside the 500-m corridor. The corresponding OR for severe depression was 3.17 (95 percent CI 0.76–13) for those living in the distance of 50–99 m of a line and 9.42 (95 percent CI 2.22–40) for those living within 50 m. The OR for severe depression in those with a magnetic field of ≥0.10 μT was 15.3 (95 percent CI 3.52–66.5). When applying the higher cutoff point of 0.2 μT, no cases of depression (i.e., with BDI ≥ 10) appeared in the highest exposure category.

The increased ORs for severe depression were due to only four women: 1) a 36-year-old dizygous twin woman who had lived since 1983 within 47 m of a 110-kv power line with a magnetic field in 1989 of 0.17 μT and who had a BDI score of 31; 2) a 40-year-old dizygous woman who had lived since 1987 within 66 m of a 110-kv power line with a magnetic field in 1989 of 0.01 μT and who also had a BDI score of 31; 3) a 49-year-old dizygous woman who had lived since 1983 within 91 m of a 110-kv power line with a magnetic field in 1989 of 0.01 μT and who also had a BDI score of 31; and 4) a 60-year-old monozygous twin woman who had lived since 1970 within 43 m of a 110-kv power line with a magnetic field in 1989 of 0.11 μT and who had a BDI score of 32. None of these women nor their twin sisters had been hospitalized for a mental disorder, according to the hospital discharge register.

In addition, we attempted to analyze the risk of severe depression using each of the exposure estimates for 1970–1989 separately. The crude ORs were between 5.49 (in 1981) and 43 (in 1970–1971) for distances within 50 m. However, these findings were mostly due to only one 60-year-old woman.

DISCUSSION

The present study is the only nationwide, population-based study on the association of depression and power lines/magnetic fields. In contrast to the first generation of relevant studies (7–11), we employed a systematic measure for depression, controlled for several potential confounders, and estimated the average residential magnetic field level in addition to the distance from the nearest power line.

The rationale of the present study is based on the presumption that high-voltage power lines provide a relatively stable and, in some cases, a dominating exposure source. One exposure-related limitation of the present study is, however, the relatively low levels of power line-generated magnetic field exposures. Although the baseline levels at typical Finnish homes rarely exceed 0.1 μT (33), the 50th percentile of the

TABLE 1. Characteristics of study subjects by distance to the nearest high voltage power line in 1989, based on data from the Finnish Twin Cohort Study and the Finnish Transmission Line Cohort Study

Characteristic	Distance (m)							
	<50 (*n* = 42)		50–99 (*n* = 127)		100–500 (*n* = 362)		≥500 (*n* = 11,532)	
	No.	%	No.	%	No.	%	No.	%
Sex								
Men	20	47.62	56	44.09	188	51.93	5,248	45.5
Women	22	52.38	71	55.91	174	48.07	6,284	54.4
Age (years)								
33–39	13	30.95	47	37.01	145	40.06	4,158	36.0
40–44	7	16.67	26	20.47	72	19.89	2,548	22.1
45–49	7	16.67	24	18.90	63	17.40	1,893	16.4
50–54	9	21.43	17	13.39	47	12.98	1,459	12.6
55–60	6	14.29	13	10.24	35	9.67	1,474	12.7
Social class (missing = 455)								
White collar	18	46.2	43	35.0	117	34.1	3,869	34.8
Blue collar	19	48.7	62	50.4	169	49.1	5,414	48.8
Farmer			4	3.3	15	4.4	627	5.7
Unknown	2	5.1	14	11.4	43	12.5	1,192	10.7
Education (missing = 18)								
Primary	26	61.9	81	63.8	238	65.9	7,590	65.9
Secondary	9	21.4	27	21.3	69	19.1	2,111	18.3
Tertiary	7	16.7	19	15.0	54	15.0	1,814	15.8
Marital status (missing = 22)								
Unmarried	4	11.9	12	9.5	57	15.8	1,610	14.0
Married	35	81.0	103	81.8	283	78.2	8,863	77.0
Divorced	2	4.8	9	7.1	16	4.4	803	7.0
Widowed	1	2.4	2	1.6	6	1.7	235	2.0
Working outside home (missing = 300)								
Yes	34	81.0	109	87.9	275	77.3	8,658	77.0
No*	8	19.1	15	12.1	81	22.8	2,583	23.0
Regular daywork (missing = 246)								
Yes	30	73.2	96	76.8	275	77.9	9,23	81.6
No†	11	26.8	29	23.2	78	22.1	2,075	18.4
Engaged in salaried work (missing = 223)								
Yes	30	71.4	95	75.4	220	61.6	7,566	66.9
No‡	12	28.6	31	24.6	137	38.4	3,749	33.1
Current smoking status (missing = 331)								
Never smoked	15	37.5	59	46.8	167	47.4	5,341	47.6
Occasional smoking	1	2.5	3	2.4	15	4.3	385	3.4
Former smoker	9	22.5	34	27.0	78	22.2	2,572	22.9
Current smoker	15	37.5	30	23.8	92	26.1	2,916	26.0
Presence of heavy drinking (missing = 153)								
No	28	68.3	90	70.9	257	71.6	8,278	72.7
Yes	13	31.7	37	29.1	102	28.4	3,105	27.3
Number of alcohol pass-outs during the past year (missing = 157)								
Never	38	92.7	111	87.4	308	86.0	9,825	86.3
Once	2	4.9	9	7.1	25	7.0	716	6.3
More often	1	2.4	7	5.5	25	7.0	839	7.4
Life events scale (missing = 1,208)								
Low	2	5.3	7	6.1	18	5.6	746	7.2
II	18	47.4	34	29.6	140	43.2	3,835	37.0
III	7	18.4	31	27.0	70	21.6	2,194	21.1
Most	11	29.0	43	37.4	96	29.6	3,603	34.7
Social support scale I (missing = 14)								
Low	10	23.8	38	29.9	93	25.8	3,303	28.6
II	9	21.4	38	29.9	85	23.6	3,114	27.0
III	15	35.7	36	28.3	121	33.5	3,559	30.9
High	8	19.1	15	11.8	62	17.2	1,543	13.4
Social support scale II (missing = 24)								
Low			3	2.4	16	4.5	729	6.3
Intermediate	4	9.5	10	7.9	36	10.0	1,137	9.9
High	38	90.5	113	89.7	307	85.5	9,646	93.8

* Includes homemakers, persons on disability annuity or old age pension, students, unemployed, and other respondents.
† Includes nightwork, two shifts without nightwork, two shifts including nightwork, three-shift work, and not working.
‡ Includes persons doing piecework pay, entrepreneurs, farmers, and persons not working temporarily or ever.

TABLE 2. Depressiveness according to Beck Depression Inventory (BDI) in the vicinity of high voltage power lines in Finland in 1990 by sex and exposure, based on data from the Finnish Twin Cohort Study and the Finnish Transmission Line Cohort Study

Exposure	BDI in men		BDI in women		BDI in all adults	
	No.	Mean* ± SE	No.	Mean* ± SE	No.	Mean* ± SE
Distance in 1989 (m)						
Reference	5,248	4.62 ± 0.07	6,284	5.85 ± 0.07	11,532	5.30 ± 0.05
200–500	78	5.22 ± 0.61	69	4.82 ± 0.67	147	5.06 ± -0.46
100–199	110	4.82 ± 0.47	105	6.26 ± 0.55	215	5.62 ± 0.37
50–99	56	4.74 ± 0.64	71	4.93 ± 0.66	127	4.92 ± 0.46
<50	20	3.74 ± 1.15	22	5.43 ± 1.23	42	4.66 ± 0.85
Magnetic field in 1989 (μT)						
Reference	5,312	4.63 ± 0.07	6,334	5.84 ± 0.07	11,646	5.30 ± 0.05
0.01–0.09	190	4.77 ± 0.36	199	5.40 ± 0.40	389	5.16 ± 0.27
0.10–0.19	3	2.10 ± 3.16	15	7.28 ± 1.35	18	6.25 ± 1.20
≥0.20	7	5.34 ± 2.00	3	1.26 ± 3.57	10	4.64 ± 1.82
Mean distance in 1970–1989‡ (m)						
Reference	5,075	4.61 ± 0.07	6,108	5.86 ± 0.07	11,183	5.30 ± 0.05
200–500	124	5.43 ± 0.46	115	5.24 ± 0.51	239	5.40 ± 0.35
100–199	180	4.70 ± 0.37	182	5.54 ± 0.41	362	5.20 ± 0.28
50–99	108	4.72 ± 0.48	10-5	5.29 ± 0.55	213	5.10 ± 0.37
<50	25	3.67 ± 0.97	41	6.12 ± 0.88	66	5.07 ± 0.65
Cumulative exposure in 1970–1989 (μT years)						
Reference	5,079	4.61 ± 0.07	6,110	5.86 ± 0.07	11,189	5.30 ± 0.05
0.01–0.25	352	4.91 ± 0.27	363	5.50 ± 0.29	715	5.27 ± 0.20
0.25–0.49	39	4.68 0.89	43	5.19 ± 0.85	82	4.95 ± 0.62
0.50–0.99	24	4.04 ± 0.95	18	6.03 ± 1.23	42	5.08 ± 0.77
≥1.00	18	4.53 ± 1.15	17	3.47 ± 1.40	35	4.20 ± 0.91

* Adjusted for all the characteristics shown in table 1.
† SE, standard error.
‡ Mean of distance over the period of living within 500 m of the lines.

workday average magnetic field exposure has been found to be 0.17 μT, and the 75th percentile is 0.27 μT (34).

Another limitation of the present study relates to exposure misclassification, which has been a major issue in all epidemiologic studies on the adverse health effects of magnetic fields. Magnetic field is a time-dependent vector quantity with magnitude and direction. Since there is a variety of magnetic field sources, assessments of exposures to magnetic fields should, ideally, take into account the numerous components of magnetic fields from all sources affecting the observation point at that particular instant in time. Exposure assessment is further complicated by the fact that the truly hazardous characteristics of magnetic fields (if any) remain unknown.

The potential effects of exposure misclassification due to measurement error and other sources of magnetic fields (whether at home or in an occupational setting, at night or during the day) are also important. Nondifferential exposure misclassification would likely have the effect of biasing the observed risk estimates toward unity. In practice, this would increase the possibility of false-negative results (given that there is an effect) and encourage careful considerations as to the strength of "negative" evidence. Regarding more detailed discussions on our exposure assessment method, we refer to our previous publications using the Finnish Transmission Line Cohort Study data (25–27, 29).

The BDI has been widely used in epidemiologic studies and has good psychometric properties (20). It is not, however, an instrument for the clinical diagnosis of depression. Nonetheless, one study has given quite similar estimates for the prevalence of depression using both BDI and DSM-III criteria (35). A recent Finnish study (21) found that the mean BDI scores of those who had a history of hospitalization for depression had scores that were twice as high as the scores of subjects with no such history. More skepticism has been addressed toward the validity of BDI in the case of severe depression, suggesting that high scores might simply represent diffuse maladaptive functioning in a subclinical population (20).

Our results of mean BDI scores controlled for several important determinants of depression, all of which (except for regular day work (shift work)) were statistically significant (here $\alpha = 0.10$) but had at most minor effects on the risk estimates. Although Kendler et al. (36) suggested the strongest determinants of

TABLE 3. Number of study subjects by exposure, degree of depression, and sex, based on data from the Finnish Twin Cohort Study and the Finnish Transmission Line Cohort Study

Exposure	Unaffected (BDI <10) (*n* = 10,043)		Mildly depressed (BDI 10–18) (*n* = 1,623)		Moderately depressed (BDI 19–29) (*n* = 338)		Severely depressed (BDI ≥30) (*n* = 59)		Total (*n* = 12,063)
	Men	Women	Men	Women	Men	Women	Men	Women	
Distance in 1989 (m)									
Reference (>500)	4,541	5,043	571	995	116	211	20	35	11,532
200–500	68	59	8	9	2	1			147
100–199	97	88	11	14	2	3			215
50–99	50	60	6	6		3		2	127
<50	20	17		3				2	42
Magnetic field in 1989 (μT)									
Reference (<0.01)	4,597	5,083	577	1,004	118	212	20	35	11,646
0.01–0.09	169	171	19	21	2	5		2	389
0.10–0.19	3	10		2		1		2	18
≥0.20	7	3							10
Mean distance in 1970–1989† (m)									
Reference (>500)	4,392	4,903	551	962	112	208	20	35	11,183
200–500	105	97	15	15	4	3			239
100–199	160	150	17	30	3	2			362
50–99	95	87	12	12	1	4		2	213
<50	24	30	1	8		1		2	66
Cumulative exposure in 1970–1989 (μT years)									
Reference (<0.01)	4,395	4,903	552	964	112	208	20	35	11,189
0.01–0.24	306	296	40	58	6	7		2	715
0.25–0.49	35	38	2	3	2	2			82
0.50–0.99	23	15	1	2				1	42
≥1.00	17	15	1		1	1		1	35

* BDI, Beck Depression Inventory.
† Mean of distance over the period of living within 500 m of the lines.

major depression to be stressful life events, genetic factors, a previous history of major depression, and the personality trait of neuroticism, the first three provide no readily available explanation for our results. In addition, a recall bias is unlikely since there had been no public concern about the possible adverse health effects of power lines in Finland at the time of the questionnaire in 1990. The possibility of residual confounding (e.g., by somatic diseases, medicines, or visible light) cannot, however, be fully excluded.

Our study results of comparable mean BDI scores by exposure provide some assurance that the proximity to high-voltage power lines is not associated with changes in the common range of self-rated depression in the general population. Disregarding the results of the first generation epidemiologic studies with totally unadjusted risk estimates, the earlier results of McMahan et al. (13) are in agreement with our results, whereas those of Poole et al. (12) are contradictory. Although McMahan's study population of white, upper class women was very homogenous, our population is more representative of the entire adult population.

As for the more severe forms of depression, the overall picture is far less clear. We found an almost fivefold, statistically significant increase in the risk of severe depression among subjects living within 100 m of a high-voltage power line. The respective increase among the subjects with a magnetic field of ≥0.1 μT was even higher. The number of cases was small, however. The only previous study on severe depression in relation to magnetic field levels has been conducted by Savitz et al. (15), who found a pattern of increased risk for depression among electricians.

As for a theoretical link between electromagnetic fields and depression (5), it remains unclear whether the observations of low nighttime melatonin levels in depressed patients (37) are the true cause or a mere consequence of depression. Nonetheless, the impact of biologic factors has been suggested to be more prominent in severe depression (1). Our findings suggest that particular attention should be given to the identification of depression subgroups that would theoretically be the most prone to the effects of electromagnetic fields.

In conclusion, the nearby high-voltage power lines and their magnetic fields of 50 Hz do not appear to be associated with changes within the common range of depressive symptoms; however, the results are less clear in the case of more severe depression. We observed a clear risk increase in severe depression, i.e., the very subgroup that might according to the study hypothesis be considered to be the most vulnerable to the effects of electromagnetic fields. However, we hesitate to draw strong conclusions about risk increase

TABLE 4. Depression in the vicinity of high voltage power lines in Finland in 1990, by exposure index and degree of depression, based on data from the Finnish Twin Cohort Study and the Finnish Transmission Line Cohort Study

Exposure index	Mildly depressed (BDI† 10–18)		Moderately depressed (BDI 19–29)		Severely depressed (BDI ≥ 30)	
	OR†	95% CI†	OR	95% CI	OR	95% CI
Distance in 1989 (m)						
Reference (>500)	1.00		1.00		1.00	
200–500	0.82	0.49–1.36	0.69	0.22–2.19		
100–199	0.83	0.54–1.26	0.79	0.32–1.94		
<100	0.62	0.37–1.07	0.60	0.19–1.89	4.74	1.70–13.3
Magnetic field in 1989 (μT)						
Reference (<0.01)	1.00		1.00		1.00	
0.01–0.09	0.72	0.52–1.00	0.60	0.28–1.29	1.04	0.25–4.26
≥0.10	0.53	0.13–2.26	1.28	0.17–9.47	15.3	3.52–66.5
Mean distance in 1970–1989‡ (m)						
Reference (≥500)	1.00		1.00		1.00	
200–500	0.91	0.62–1.34	1.01	0.47–2.16		
100–199	0.93	0.68–1.27	0.47	0.19–1.14		
≤100	0.86	0.59–1.24	0.74	0.33–1.67	2.86	1.03–7.97
Cumulative exposure in 1970–1989 (μT years)						
Reference (<0.01)	1.00		1.00		1.00	
0.01–0.24	1.00	0.80–1.24	0.63	0.36–1.10	0.56	0.14–2.31
0.25–0.49	0.42	0.17–1.04	1.59	058–4.38		
≥0.50	0.35	0.13–0.96	0.42	0.06–3.00	4.83	1.16–20.2

* Unadjusted odds ratios are shown in comparison to the unaffected study subjects (BDI < 10).
† BDI, Beck Depression Inventory; OR, odds ratio; CI, confidence interval.
‡ Mean distance over the period of living within 500 m of the lines

because of 1) the very small number of depressed cases, 2) the scarcely increased magnetic field levels, and 3) the small number of epidemiologic studies testing the "electromagnetic fields and depression" hypothesis. Nevertheless, our results suggest that this issue requires more investigation. In addition to improving the techniques for magnetic field assessment, we recommend that attempts be made to strive for a better understanding of the exposure characteristics, particularly in relation to the onset and course of depression.

ACKNOWLEDGMENTS

The Yrjö Jahnsson's Foundation and the Academy of Finland supported this study.

REFERENCES

1. Syvälahti EKG. Biological aspects of depression. Acta Psychiatr Scand 1994;89(suppl 377):11–15.
2. Lehtinen V, Joukamaa M. Epidemiology of depression: prevalence, risk factors and treatment situation. Acta Psychiatr Scand 1089;(suppl 377):7–10.
3. Weissman MM, Bland RC, Canino GJ, et al. Cross-national epidemiology of major depression and bipolar disorder. JAMA 1996;276:293–9.
4. Healy D. Rhythm and blues: neurochemical, neuropharmacological and neuropsychological implications of a hypothesis of circadian rhythm dysfunction in the affective disorders. Psychopharmacology 1987;93:271–85.
5. Wilson BW. Chronic exposure to ELF fields may induce depression. Bioelectromagnetics 1988;9:195–205.
6. Paneth N. Neurobehavioral effects of power-frequency electromagnetic fields. Environ Health Perspect Suppl 1993; 101(suppl 4):101–6.
7. Reichmanis M, Perry FS, Marino AA, et al. Relation between suicide and the electro-magnetic field of overhead power lines. Physiol Chem Phys 1979;11:395–403.
8. Perry FS, Reichmanis M, Marino A, et al. Environmental power-frequency magnetic fields and suicide. Health Physics 1981;41:267–77.
9. Perry FS, Pearl L. Health effects of ELF fields and illness in multistory blocks. Public Health 1988;102:11–18.
10. Perry FS, Pearl L, Binns R. Power frequency magnetic fields: depressive illness and myocardial infarction. Public Health 1989;103:177–80.
11. Baris D, Armstrong B. Suicide among electric utility workers in England and Wales. Br J Ind Med 1990;47:788–9.
12. 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.
13. McMahan S, Ericson J, Meyer J. Depressive symptomatology in women and residential proximity to high-voltage transmission lines. Am J Epidemiol 1994;139:58–63.
14. Preece AW, Iwi G, Grainger P, et al. Pre and post natal depression in proximity to high-voltage power lines. Presented at the Bioelectromagnetics Society Conference, Victoria, Canada, June 1996.
15. Savitz D, Boyle CA, Holmgreen P. Prevalence of depression among electrical workers. Am J Indust Med 1994;25:165–76.
16. Kaprio J, Sarna S, Koskenvuo M, et al. The Finnish Twin Registry: baseline characteristics. Section II. History of symp-

toms and illnesses, use of drugs, physical characteristics, smoking, alcohol and physical activity. Helsinki, Finland: Department of Public Health, University of Helsinki, 1978. (Department of Public Health publication no. M37).
17. Kaprio J, Sarna S, Koskenvuo M, et al. The Finnish Twin Registry: formation and compilation, questionnaire study, zygosity determination procedures and research program. Prog Clin Biol Res 1978;24B:179–84.
18. Kaprio J, Koskenvuo M, Rose RJ. Population-based twin registries: illustrative applications in genetic epidemiology and behavioral genetics from the Finnish twin cohort study. Acta Genet Med Gemellol 1990;39:427–39.
19. Beck AT, Ward CH, Mendelson M, et al. An inventory for measuring depression. Arch Gen Psychiatry 1961;4:561–71.
20. Beck AT, Steer RA, Garbin MG. Psychometric properties of the Beck Depression Inventory: twenty-five years of evaluation. Clin Psychol Rev 1988;8:77–100.
21. Varjonen J, Romanov K, Kaprio J, et al. Self-rated depression in 12,063 middle-aged adults. Nord J Psychiatr. (In press).
22. Hublin C, Kaprio J, Partinen M, et al. The prevalence of narcolepsy: an epidemiological study of the Finnish Twin Cohort. Ann Neurol 1994;35:709–16.
23. Heliövaara M, Reunanen A, Aromaa A, et al. Validity of hospital discharge data in a prospective study on stroke and myocardial infarction. Acta Med Scand 1984;216:309–16.
24. Poikolainen K. Accuracy of hospital discharge data: five alcohol-related diseases. Drug Alcohol Depend 1983;12: 315–22.
25. Verkasalo PK, Pukkala E, Kaprio J, et al. Magnetic fields of high-voltage power lines and cancer risk in Finnish adults: nationwide cohort study. BMJ 1996;313:1047–51.
26. Verkasalo PK, Pukkala E, Hongisto MY, et al. Risk of cancer in Finnish children living close to power lines. BMJ 1993; 307:895–9.
27. Hongisto M, Valjus J. Magnetic field exposure in the vicinity of the national grid of Finland. Conference paper no. 36–104. Conférence Internationale des Grands Réseaux Électriques à Haute Tension (CIGRÉ), Paris, France, 1994:28.8.-3.9.
28. Verkasalo PK. Magnetic fields and leukaemia: risk for adults living close to power lines. Scand J Work Environ Health 1996;22(suppl. 2):1–56.
29. Valjus J, Hongisto M, Verkasalo P, et al. Residential exposure to magnetic fields generated by 110–400 kv power lines in Finland. Bioelectromagnetics 1995;16:365–76.
30. Kaprio J, Koskenvuo M. A prospective study of psychological and socio-economic characteristics, health behavior, and morbidity in cigarette smokers prior to quitting compared to persistent smokers and non-smokers. J Clin Epidemiol 1988; 41:139-50.
31. Romanov K, Hatakka M, Keskinen E, et al. Self-reported hostility and suicidal acts, accidents and accidental deaths: a prospective study of 21,443 adults aged 25–59. Psychosom Med 1994;56:328–36.
32. Kaprio J, Koskenvuo M, Langinvainio H, et al. Genetic influences on use and abuse of alcohol: a study of 5,638 adult Finnish twin brothers. Alcohol Clin Exp Res 1987;11:349–56.
33. Juutilainen J, Saali K, Eskelinen J, et al. Measurements of 50 Hz magnetic fields in Finnish homes. Helsinki: Imatran Voima Oy, 1989. (Imatran Voima Oy research report IVO-A-02/89).
34. Floderus B, Persson T, Stenlund C. Magnetic field exposure in the work place: reference distribution and exposure in occupational groups. Int J Occup Environ Health. (In press).
35. Oliver JM, Simmons ME. Affective disorders and depression as measured by the diagnostic interview schedule and the Beck Depression Inventory in an unselected adult population. J Clin Psychol 1985;41:469–77.
36. Kendler KS, Kessler RC, Neale MC, et al. The prediction of major depression in women: toward an integrated etiologic model. Am J Psychiatry 1993;150:1139–48.
37. Wetterberg L. Light and melatonin in humans. In: Stevens RG, Eilson BW, Anderson LE, eds. The melatonin hypothesis. Columbus, OH: Battelle Press, 1997:233–65.