HEALTH EFFECTS OF ELECTROMAGNETIC RADIATION ON WORKERS: EPIDEMIOLOGIC STUDIES

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This paper was prepared for a plenary session of the NIOSH scientific workshop on the health effects of electromagnetic radiation on workers. It reviews the epidemiological evidence on cancer, reproduction, and neuropsychological effects with respect to the risk resulting from occupational exposure to 60/50 Hz electromagnetic fields (EMF). Childhood and adult cancers resulting from residential exposure to EMF are not included in this review, nor are studies dealing with direct current energy. With a few exceptions, this review is limited to published studies in peer reviewed journals.

CANCER

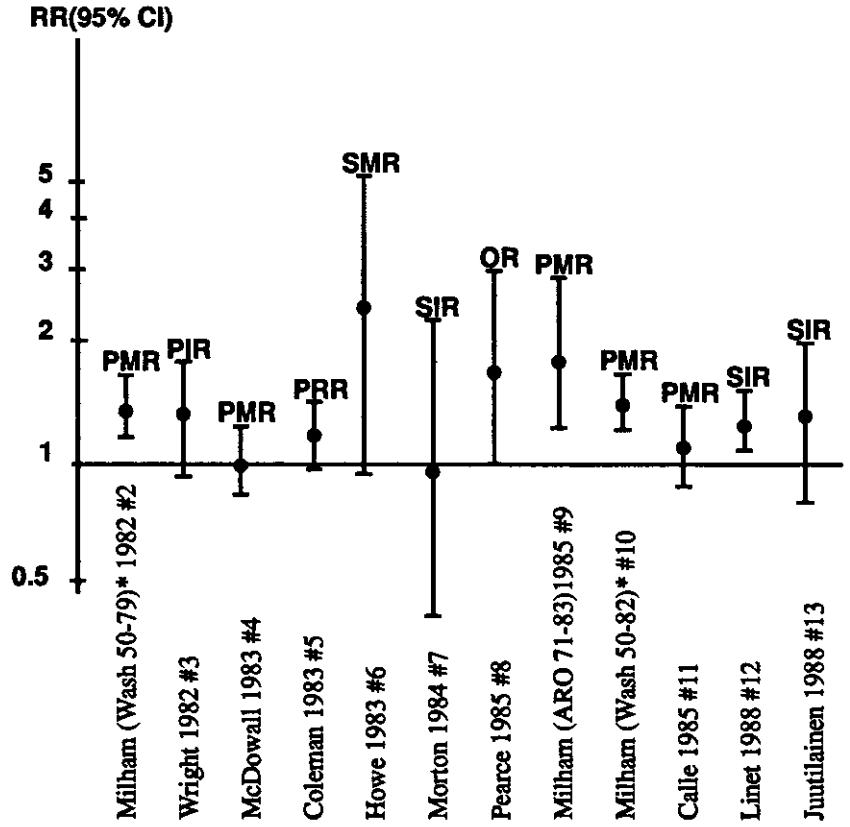
Cancer was first associated epidemiologically with exposure to EMF in 1979, when Wertheimer and Leeper (1) reported that children dying from cancer resided more often in homes with high current configuration than did healthy control children. Wire configuration around houses was used as a surrogate for EMF exposure.

Soon after this study, epidemiologists from many countries looking at occupational cohorts, reported what seemed to be a confirmation of the putative association, EMF-cancer, as proposed by Wertheimer.

Since 1982, scores of occupational epidemiologic studies have been published. To discuss the evolution of knowledge gained through those studies, it is convenient to regroup them under subtitles: (1) cancer hypotheses generating studies, (2) leukemia case control studies, (3) brain cancer case control studies, (4) cohort studies of electrical workers, (5) skin melanoma case control studies, (6) welding and exposure to EMF, (7) male breast cancer.

Cancer hypotheses generating studies

To test Wertheimer's hypothesis, occupational epidemiologists first examined existing mortality and morbidity registries of several countries. Within six years, from 1982 to 1988, no less than 12 communications had been published, most of them as short papers or letters to editors. As seen from figure 1, the majority of these reports observed an excess of leukemia among broadly defined "electrical occupations" and this excess seemed to be higher for acute myeloid leukemia (Figure 2). Pooled analyses of these results have established a significant excess of all leukemias with a risk estimate of 1.18 (1.09 - 1.29) and a significant excess of acute myeloid leukemia with risk estimate of 1.46 (1.27 - 1.65) (14). Results presented in figures



* some overlapping

Figure 1. Leukemia Risks among Electrical Workers—All Leukemia

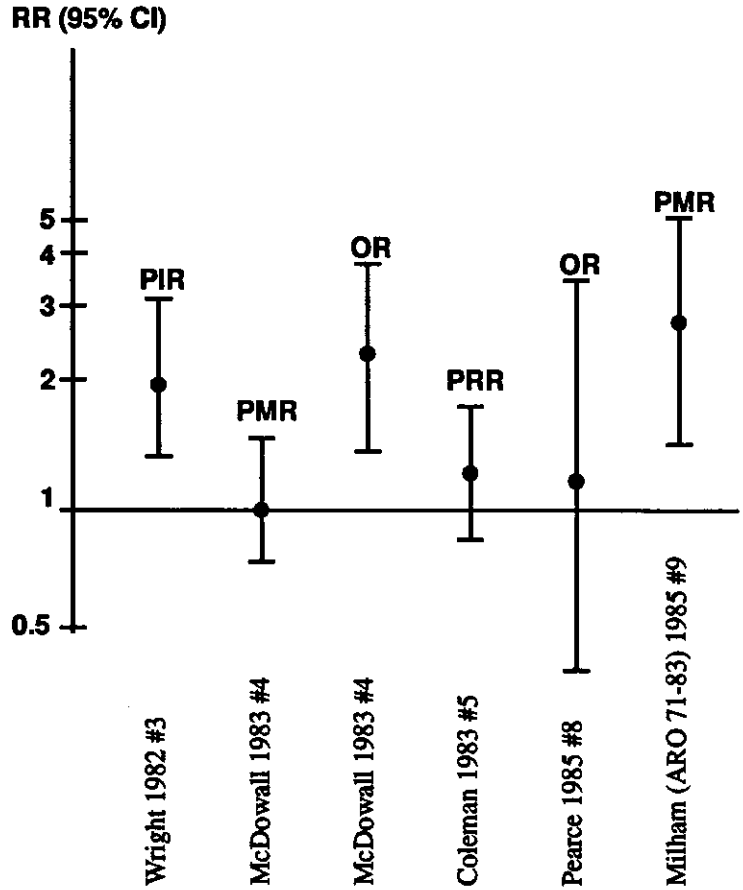


Figure 2. Leukemia Risks among Electrical Workers—Acute Myeloid Leukemia

1 and 2 are for all leukemias and for all workers. More spectacular excesses were noted for specific leukemia types and/or specific occupational groups but these excesses varied between studies and no consistent finding can be pinpointed.

Everybody, including the authors, have recognized that these exploratory studies were gross, that numbers were small, that exposure was ill defined, that statistical analyses very often were weak, that there may exist at the workplace carcinogenic agents other than EMF responsible for the excesses observed, that no confounders have been controlled for and consequently that the results can only be indicative and need to be reassessed by more powerful and better designed studies

Leukemia case control studies

Five case control studies bearing on the issue of leukemia among workers occupationally exposed to EMF have been published since 1985 (see Table 1). These studies are impressive: they are well

Table 1

LEUKEMIA AMONG WORKERS OCCUPATIONALLY EXPOSED TO EMF

	CASES / CONTROLS	EXPOSURE ASSESSMENT		OR (CONF. INT.)
Gilman#15	underground coal miners	time spent	all L	2.53*
1985	40 leukemia deaths	\underground	acute L	2.85
	160 non cancer deaths		chronic L	8.22*
			CLL	6.33*
			Myelogenous L	4.74*
			AML	3.80
Stern#16	naval shipyard workers	job histories	for electricians	
1986	53 leukemia deaths		+ years of employment	
all L	3.00 (1.29 - 6.98)			
	212 members of cohort		ML	2.33 (0.77 - 7.06)
	alive at dx of cases		LL	6.00 (1.47 - 24.45)
			for welders	
			all L	2.25 (0.92 - 5.53)
			ML	3.83 (1.28 - 11.46)
			LL	0 (----)
Flodin#17	population based search	postal	for electrical workers (elec.	
1986	for association with gamma	questionnaire	technicians, elec. welders,	
	rad in houses		computer telephone mechanics)	
	59 AML alive		AML	3.8 (1.5 - 9.5)
	354 general population controls			
Coggon#18	male cancers in	occupational hist.	AML a cluster of 5 electrical	
1986	3 UK counties	through postal	workers in these 29 cases	
	29 acute myeloid leukemia	questionnaires		
	2913 other cancers			
Pearce#19	New Zealand cancer	occupation on	for all electical workers	
1989	reg. 80 - 84	registry forms	all L	1.62 (1.04 - 2.52)
	534 male leukemia		acute L	1.25 (0.62 - 2.54)
	all other cancers		chronic L	2.12 (1.19 - 3.76)
			ML	1.22 (0.60 - 2.48)
			LL	1.73 (0.89 - 3.37)
			AML	1.16 (0.48 - 2.84)

* $p < 0.05$

designed, with reasonably large numbers of leukemia cases. On two occasions, the association of leukemia with EMF was an incidental observation by authors whose objective was to test a different hypothesis. Odd ratios are higher than

those observed in the exploratory studies. In general, excesses are seen for all leukemias and acute myeloid leukemia; chronic lymphoid leukemia is also reported with elevated odds ratios. These five studies, however, are plagued with one weakness: exposure assessment. Exposure is estimated based usually on occupational history secured through postal questionnaire or transcribed from registration forms. Gilman (15) used time spent underground as a surrogate of EMF exposure for coal miners.

These case control studies seem to support and even strengthen the possible association between leukemia and working in 'electrical occupations,' but because of the gross estimates of exposure, they say little about its association with EMF.

Brain cancer case control studies

Brain is the second cancer site that has caught the attention of occupational epidemiologists. Since 1985, at least seven case control studies of brain cancer and occupational exposure to EMF have been published (Table 2).

Most of these studies have shown elevated odd ratios for electrical related occupations. Some odd ratios were high (Speers (22) observed an OR of 13.10 among Texas utility employees). At least 3 studies indicated the presence of a dose response relationship between EMF exposure and brain cancer.

As with the leukemia studies, these case control studies of brain cancer are impressive. There are reasonably large numbers of cases among exposed workers. Many elevated odd ratios are statistically significant and dose response relationships were observed more than once. However exposure has been estimated based on remote information, usually through occupations reported on registry files or secured through postal questionnaires.

Table 2

BRAIN CANCER AMONG WORKERS OCCUPATIONALLY EXPOSED TO EMF

	CASES / CONTROLS	EXPOSURE ASSESSMENT	OR (CONF. INT.)
Lin#20			
1985	Maryland residents 519 glioma/ astrocytoma deaths 519 rand. non cancer deaths	occupation on death certif. panel rating based on occupations	EMF exposure determined from occupation A (definite) 2.15 (1.1 - 4.1) B (probable) 1.95 (0.9 - 3.9) C (possible) 1.44 (1.1 - 2.0) D (no) 1.00 (- - - -)
Coggon#18			
1986	male cancer in 3 UK counties 97 brain cancers 2845 other cancers	occupational hist. through postal quest.	elec. eng. 1.9 (0.4 - 5.6) elec. & electron. workers 2.0 (0.8 - 4.1)
Thomas#21			
1987	Louisiana, N. Jersey, Penn. residents 435 brain cancer deaths 386 non-brain cancer	occupational history from next of kin panel rating based on occ.	MW/RF rad. 1.6 (1.0 - 2.4) MW/RF manf. repair of elec. equipment 2.3 (1.3 - 4.2) electron. wkr 3.9 (1.6 - 9.9)
Speers#22			
1988	East Texas res. 202 glioma deaths 238 ran. non-brain tumor deaths	occ. hist. on death certif.	utility emp. 13.10 (1.3-128.9) elec. occ. 2.11 (0.8 - 5.8)
Pearce#19			
1989	New Zealand cancer Registry 80 - 84 452 male brain can. all other cancers	occ. on reg. forms	all elec. workers 1.01 (0.56 - 1.82) elec. eng. 4.74 (1.65-13.63) electric. 1.91 (0.84 - 4.33)
Savitz#23			
1989	1095 brain cancer deaths in 16 US states		elec. wrkrs 1.5 (1.01 - 2.1) elec. & electron. technicians 3.1 electric power repairmen 2.4
Brownson#24			
1990	Missouri Cancer Registry 84 - 88 312 wh male brain cancers 1248 other cancers	occ. frm hosp. rcrd (usl or lngst)	communication workers 1.4 (0.5 - 4.1) utilities & sanitary services 0.5 (0.1 - 1.7)

Cohort studies of electrical workers

In a search for further clues on the possible association of cancer with occupational exposure to EMF, studies of cohorts of workers exposed to EMF are worth looking into. Such studies should provide us with additional information on the risks for leukemia and brain cancer as well as other cancer types.

Several cohort studies of electrical workers exist in the literature. The occupational cohorts that have been studied are: telephone operators, electronic industry workers, electrical engineers, telecommunications industry workers, linemen, station operators, electricians, amateur radio operators, telephone company workers, electrical utility workers, and radiomen. In most of them, sample sizes are large and observation periods extend over many years.

Two trends are noticeable (see Table 3). Up until 1990, although several risk ratios for leukemia and brain cancer were over 1.0, few excesses were statistically significant. Only one study observed a significant excess of acute myeloid leukemia (AML) (31), and only one, an excess of all leukemias (35). No brain cancers were significantly in excess. Since 1990, care has been given to defining exposed groups with more homogeneity. As a consequence, more significant excesses for leukemia and brain cancer have been observed.

Since exposure in large cohort studies is usually 'diluted,' the observation made concerning leukemia and brain cancer in these cohorts supports the possibility of an association between these cancers and exposure to EMF (as suggested by case control studies). Moreover, while cohort studies have not been very powerful in showing an excess of leukemia and brain cancer among exposed workers, they have revealed a fairly constant excess of skin melanoma(skin melanoma is in excess in 5/7 cohorts).

Table 3

COHORT STUDIES OF ELECTRICAL WORKERS

	all cancer	skin melanoma	brain	leukemia	acute myeloid leukemia
Wiklund 1981, RR #25					
Telephone operators	NR	NR	NR	1.03 (12)	NR
Vagero 1983, RR #26					
Electronics industry	1.15* (1855)	1.35* (59)	< 1.0	< 1.0	< 1.0
Olin 1985, SMR #27					
Electrical engineers	0.5* (24)	3.2 (3)	1.0 (2)	0.9 (2)	0
Vagero 1985, SMR #28					
Telecommunication industry	1.03 (102)	2.5* (8)	1.0 (5)	0	0
Tornqvist 1986, RR #29					
Linemen	1.10 (236)	NR	1.5 (13)	1.3 (10)	NR
Station operators	1.00 (463)	NR	1.0 (17)	1.0 (16)	NR
McLaughlin 1987, SIR #30					
Electricians		NR	NR	0.8 (42)	NR
NR					
Powerline workers	NR	NR	1.0 (13)	NR	NR
Telecommunications	NR	NR	1.1 (13)	NR	NR
Milham 1988, SMR #31					
Amateur radio operators	0.89* (741)	NR	1.39 (29)	1.24(36)	1.76*(15)
Guberan 1989, SMR #32					
Electricians	1.14 (52)	0.91 (1)+	1.54 (2)	1.43 (2)	0
De Guire 1988, SIR #33					
Telecommunication industry	NR	2.7* (10)	NR	NR	NR
Lin 1989, SMR #34					
Telecommunication industry	1.01 (129)	NR	2.4 (5)	NR	NR
Matanoski 1989, SIR #35					
all telephone employees	0.81* (391)	NR	1.0 (13)	0.77 (12)	0.85 (7)
all line workers	0.83* (265)	NR	0.7 (6)	0.88 (9)	0.74 (4)
cable splicers	1.81* (40)	NR	1.79 (2)	7.00*(3)	2.31 (1)
Koifman 1989, PMR #36					
Electrical utility workers	1.60* (347)	0.82 (1)	1.44 (8)	0.89 (4)	NR

Table 3 cont'd

	all cancer	skin melanoma	brain	leukemia	acute myeloid leukemia
Garland 1990, SIR #37					
Young males in navy					
electrician's mate	NR	NR	NR	2.4* (7)	NR
electronics technician	NR	NR	NR	1.1 (5)	NR
radioman	NR	NR	NR	1.1 (4)	NR
Juutilainen 1990, SIR #13					
probably exposed to EMF	NR	NR	1.31 (13)	1.85* (10)	1.47 (3)
possibly exposed to EMF	NR	NR	1.29*(149)	1.42* (94)	1.37(34)
electricians (indoor installers)	NR	NR	0.75 (10)	0.95 (7)	0.74 (2)
telephone installers & repairmen	NR	NR	2.37 (9)	1.43 (3)	1.23 (1)
linemen and cable jointers	NR	NR	0.91 (2)	3.08 (4)	2.08 (1)
Vagero 1990, PRR/SRR #38					
electrical, electronic	NR	0.98 (63)	NR	NR	NR
	NR	1.18 (16)	NR	NR	NR
telephone operators	NR	12.03* (2)	NR	NR	NR
electrical engineers	NR	6.92 (2)	NR	NR	NR

\+ all skin
* statistically significant
NR not reported
Numbers in parentheses indicate the number of cases for each cause.

Skin melanoma case control studies

Two case control studies of eye melanoma with mention of electrical workers, were traced (see table 4). In 1983, Swerdlow (39), observed elevated odd ratios of eye melanoma for electrical and electronics workers. However, in another case control study of eye melanoma in 4 Canadian western provinces, Gallagher (40) did not find an excess of electrical or electronics workers among his cases.

So reports of excess of skin (and eye) melanoma among electrical and electronics workers should not be overlooked. It is however, commonly argued that the excess of skin melanoma in this group of workers reflects more the higher socio-economic status of these people rather than the consequence of exposure to EMF. This deserves further attention.

Table 4

EYE MELANOMA AMONG WORKERS OCCUPATIONALLY EXPOSED TO EMF

	CASE / CONTROLS	EXPOSURE ASSESSMENT	OR (PRR)
Swerdlow 1983(#39)	England and Wales Cancer registry 2159 m. incident cases 2125 f. incident cases other registrants	occupation in registry	for electrical and electronics workers 1968 - 78 1.26 1971 1.67 1972 7.14* 1973 2.63 1974 4.44* 1975 5.71*
Gallagher 1985 (#40)	Cancer registry of 4 provinces in west Canada (79 - 81) age 20 - 79 65 ocular melanoma 65 random controls	occupation secured through interviews	no elevated risk found for electrical or electronics workers

* $p < 0.05$
PRR = Proportional Registration Ratios

Welding and EMF

Welders are exposed to intense electric and magnetic fields. Theoretically, they are among the workers most exposed to EMF. In 1987, Stern (41) included an extensive review of 15 cancer studies in welders (Table 5). He observed that excess lung cancer was reported in most studies but not leukemia. He proposed that this observation goes against the hypothesis of an association of EMF - leukemia. However, at approximately the same time, in a case control study of chronic myeloid leukemia, Preston-Martin (42) reported a highly elevated odd ratio (OR adjusted 25.4 (22) 2.78-232.54) for welders. This last finding is remarkable in view of the negative studies previously cited.

Male breast cancer

In a recent study of telephone workers, Matanowski (35) found an elevated risk of male breast cancer among central office technicians. This is an extremely rare disease. Two cases were found among the 9,561 workers; ordinarily, none would be expected. The work environment of central office technicians is typified by a pattern of "spikes" in magnetic field intensity.

Table 5

STUDIES OF LEUKEMIA INCIDENCE IN WELDING POPULATIONS (FROM STERN #41):

	ALL LEUKEMIA		ACUTE LEUKEMIA		LUNG CANCER	
	O	RR	O	RR	O	RR
1)	6	0.96	4(m)	1.71		
2)	—	—	0(1)	—		
3)	20	0.83	13(a)	1.04		
4)	7	2.25				
5)			—(m)	(3.8)		
6)	19	0.89	6(a)	0.67		
7)	0	—			6	0.95
8)	0	—			17	1.5
9)	4	4.2			10	2.2
10)	4	0.35			50	1.32
11)	1	2.5			7	1.38
12)			6(a)	1.81	27	0.99
13)	43	0.99			193	1.42
14)	15	1.14			12	1.60
15)	27	0.85	7(m)	0.76	381	1.46
			4(1)	0.63	305	1.27
Pooled data RR	146	0.92	40	0.92	1008	1.34

(m)acute myeloid
(l)acute lymphoid
(a)all acute leukemia
—number not given

To test Matanowski's hypothesis, Demers (43) carried out a case control study of 227 male breast cancers drawn from 10 registries from the Surveillance Epidemiology and End Results (SEER) program of the National Cancer Institute. Controls were selected (300) through random digit dialing or from medicare eligibility lists. Exposure was based on work history. An elevated risk was found for any exposed job (OR = 1.8, CI 1.0 - 3.2) and was highest among electricians, telephone linemen, and electric power workers (OR = 6.0, CI 1.7 - 21.5), and radio or communication workers (OR = 2.9, CI 0.8 - 10.2).

The observation of an excess of male breast cancer among exposed workers may carry a particular significance in view of the proposed mechanism by which EMF could cause cancer through interfering with the melatonin hormonal system.

Conclusions on cancer evidence

Even if epidemiologic studies, so far, have raised more questions than they have answered and have yielded little convincing evidence, they should not be over looked. They were blamed to be plagued with methodologic weaknesses and above all, with crude estimates of exposure. Even with such weaknesses and estimates of exposure, they nevertheless, have observed increased risks which may mean methodologic improvements and more accurate measurements of exposure may confirm previous findings. It is disappointing to realize that since 1979, not much progress has been made. Things go at a snail's pace. Much hope is being put on the "mega research" projects that are now being conducted in several places in the world.

REPRODUCTION

Reproductive health is a concept that encompasses many concerns including genotoxicity, teratogenicity, infertility, effects on the child to be born or even cancer at a young age. Few studies have addressed these questions in the context of exposure to EMF.

It is convenient to regroup the traced studies under headings such as (1) outcomes of pregnancy and use of electric blanket, (2) outcomes of pregnancy in wives of exposed workers, (3) infertility of exposed male workers, (4) central nervous system cancer in children of exposed fathers, (5) childhood cancer and prenatal exposure to electric appliances.

Outcomes of pregnancy and use of electric blanket

Use of electric blanket and heated waterbed is probably the most intense domestic exposure to EMF that one can get. This may carry some impact on pregnancy outcomes by acting either directly on the fetus or on the gametes through some genotoxicity. Surprisingly, only two studies so far have addressed this question and they are both from the same authors, Wertheimer and Leeper (44, 45) (see Table 6).

Table 6

OUTCOMES OF PREGNANCY AND USE OF ELECTRIC BLANKETS

		prolonged gestation period	low birth weight	congenital malform.	early fetal loss
Wertheimer 1986 #44					
Population:	1784 Colorado births 102 fetal losses				
Exposure:	electric blankets heated waterbeds (determined by telephone)	+	+	N/A	+
Outcome:	extracted from birth records				
Wertheimer 1989 #45					
Population:	1879 Oregon births 142 fetal losses				
Exposure:	cable ceiling heating electric blankets heated waterbeds (determined from gov't records)	N/A	N/A	N/A	+
Outcome:	< 20 weeks gestation from birth records of sibling				

-	negative results
+	positive results
N/A	not applicable

In their first study, based on 1,784 Colorado births and 102 fetal losses, the authors observed a seasonal variation in prolonged gestational periods among users of electric blankets and heated waterbeds. They show that this variation paralleled the use of these electrical devices at the time of conception (Figure 3). Similarly, they observed an association between abortion rates and use of electrically heated beds (Figure 4). Even low birth weights were associated with the use of electrical devices, although this association existed only in combination with prolonged gestational periods in what the authors call "slow growing" infants.

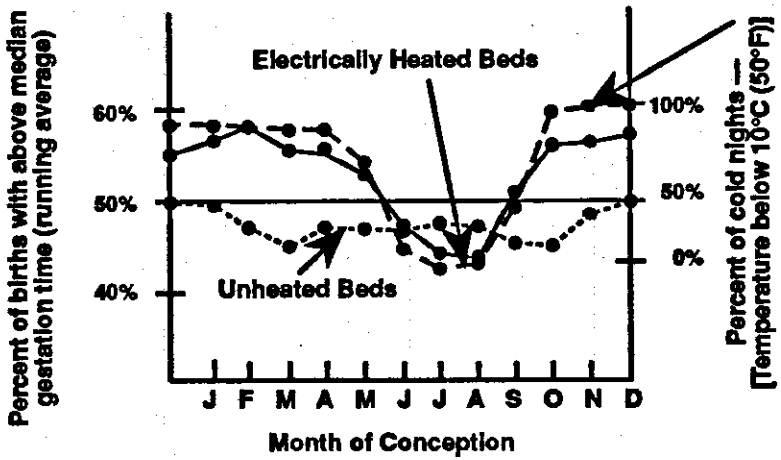


Figure 3. Seasonal pattern of cold nights (Denver, 1976-1982) and of gestation period, for users and nonusers of electrically heated beds. Gestation periods were generally longer for infants of users of electrically heated beds when those infants were conceived in the season when the need for electrical bed heating is greatest. *Based on Wertheimer (44)*

In their second study, the authors examined the relationship between early fetal losses and exposure to heating cables in private houses (as well as use of electric blankets and heated waterbeds). They observed a monthly variation in the ratio of abortions occurring among those exposed to EMF over the abortions occurring in unexposed controls. These variations paralleled the changes in heating degree days (Figure 5). Based on these two studies, the authors pposed that an association may exist between EMF exposure and unfavorable outcomes of pregnancy.

Outcomes of pregnancy in wives of exposed workers

Only one study has addressed this question. In 1983, Nordstrom (46) tried to assess the impact of fathers' exposure at work on the outcome of their wives' pregnancies (Table 7). Exposure was assessed based on the occupational history reported in questionnaires distributed to active and former employees of a Swedish electrical plant (Table 7).

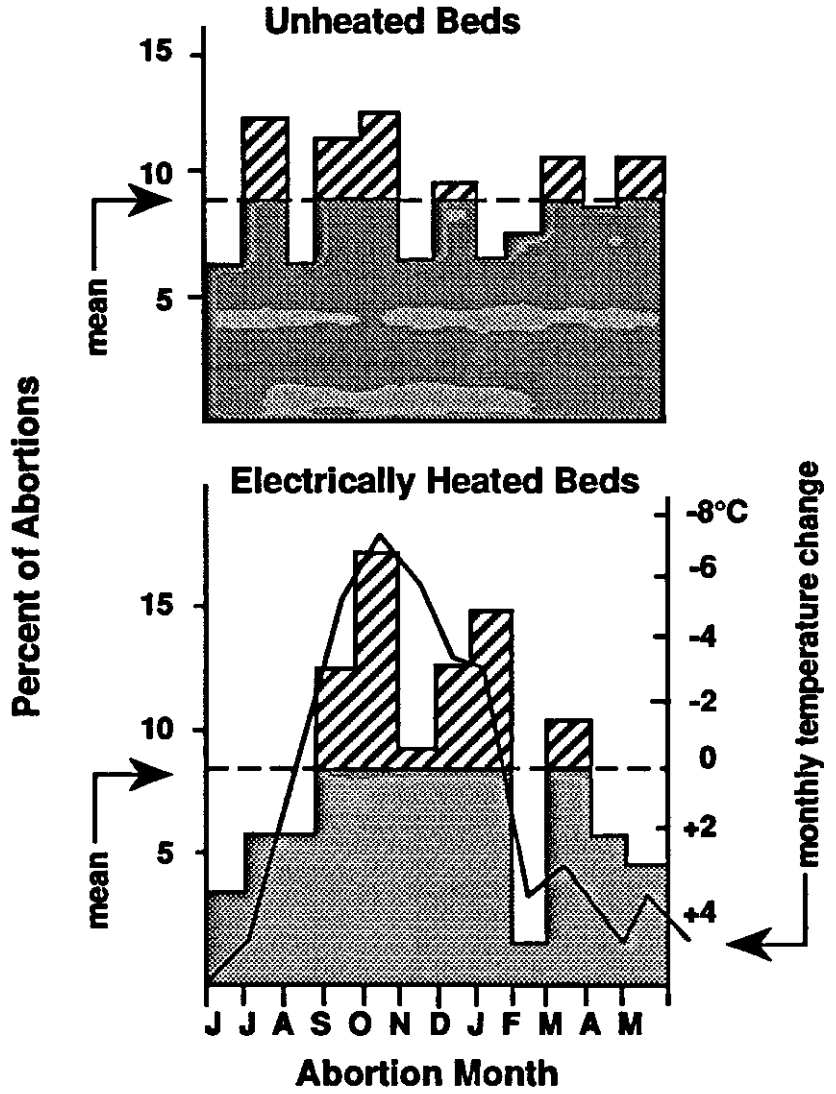


Figure 4. Season of abortion related to monthly changes in mean minimum temperature (Denver, 1976-1982). For users of electrically heated beds, an excess of reported abortions occurs in the winter months, especially in those months when the mean minimum temperature is colder than it was during the preceding month.

Based on Wertheimer (44)

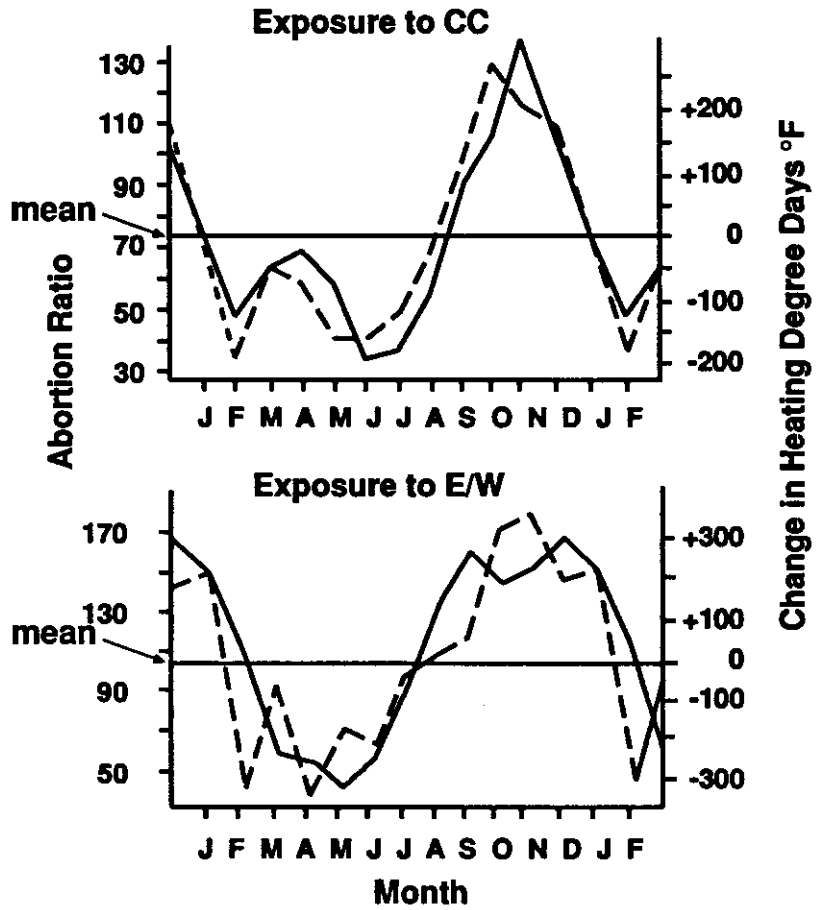


Figure 5. Abortions related to change in temperature. A monthly running ratio of abortions occurring among those exposed to electromagnetic field sources, divided by abortions occurring in unexposed controls, is represented by the solid line. The monthly change in heating degree days (compared with the preceding month) is represented by the broken line. (Note: heating degree days F can be converted to heating degree days C by multiplying by 0.55.) In the top graph, the source of electromagnetic fields is ceiling cable electric heat (CC); in the bottom graph, the exposure source is electric blankets and heated waterbeds (E/W). Increased abortion in each exposed group is highly correlated with months when cold weather is increasing (with a consequent increase of electromagnetic field exposure in the exposed group). *Based on Wertheimer (44)*

Table 7

OUTCOMES OF PREGNANCY IN WIVES OF EXPOSED WORKERS

		low birth weight	spontaneous abortion	perinatal death	congenital malform.
Nordstrom 1983 #46					
Population:	483 electrical utility employees 880 pregnancies				
Exposure:	male employment (determined through questionnaire)	-	-	-	+
Outcome:	answers to questionnaire checked against hospital records				

\- negative results
\+ positive results

Pregnancy outcomes were checked against hospital records. The outcomes studied were: spontaneous abortions, perinatal deaths, stillbirths and congenital malformations. The authors reported an excess of abnormal pregnancies due mainly to an increase in congenital malformations among couples whose male partner worked in high voltage switch yards . No effects were observed for the other outcomes that were studied.

Infertility of exposed male workers

To look into the potential influence of occupational EMF exposure on workers' fertility, authors have studied several end points such as: number of children, children's sex ratios male/female, difficulty in attaining pregnancy, and azoo and oligo spermia.

Number of children and their sex ratios

In an unpublished report, Roberge (47) reported that in a group of 56 utility workers exposed to 735 kV transmission lines, the children's sex ratio male/female was 1.1 (27/25) before starting work and changed to a ratio of 5.7 (17/3) 4.5 years later (Table 8). In 1979, Knave (48) observed that 53 substations (400 kV) workers had fewer children (mostly boys) than a group of non exposed utility workers, but he attributed this difference to confounding due to higher education

Table 8

INFERTILITY OF EXPOSED MALE WORKERS

Roberge 1976 #47	children sex ratio modified by exposure	
	before	1.1 (27/25)
	after	5.7 (17/3)
Knave 1979 #48	less children among exposed workers (mostly boys)	
Nordstrom 1983 #46	children sex ratio varies somewhat with exposure	
	exposed	0.92 (67/73)
	moderately exposed	1.23 (190/154)
	non exposed	1.16 (167/144)
	exposed workers had more difficulty attaining pregnancy	
Buiatti 1984 #50	azoospermia / oligospermia	
	for radio electric workers	OR 5.89(5) 0.86 - 40.18
Baronocelli 1986 #49	no trend in number of children by exposure categories	

of the exposed men. In 1983, Nordstrom (46) reported that the children's sex ratio male / female in 3 groups of utility workers was as follows: switchyard workers 0.92 (67/73), other exposed workers 1.23 (190/154), non exposed workers 1.16 (167/144). In 1986, Baroncelli (49) studied the number of children among several exposure categories of utility workers and did not observe any difference.

These issues of number of children among exposed utility workers and the sex ratio male/female of these children, have been rather controversial and have contributed little to the question of infertility among exposed workers.

Difficulty in attaining pregnancy

In his study of reproductive hazards among workers at high voltage substations in Sweden, Nordstrom (46) attempted to estimate male infertility by inquiring about the difficulty in attaining pregnancy in couples where the male was exposed during the fertility age. The reported rates of difficulty were as follows: 400 kV switchyard workers 20% (32/164), 380-220 V transmission line workers 19% (12/62), and those exposed to a maximum of 130 kV 6% (2/33). In further analyses, the difficulties in the first group were concentrated among high voltage switchyard workers.

Azoo spermia/oligo spermia

In 1984, in a well structured case control study, Buiatti (50) reported an elevated although not significant azoo spermia and oligo spermia odd ratio of 5.89 (5) CI = 0.86 - 40.18, for radio electric workers. The authors considered this observation very unusual and recommended further investigations. In general, it is reasonable to say that male infertility remains an issue that has not been sufficiently studied so far and should be pursued.

CNS cancers and paternal occupational exposure before birth

Paternal exposure before birth on the development of brain cancer in childhood has been addressed in at least 4 population based case control studies, 2 from Texas by the same research team, 1 from New York State and 1 from Philadelphia (Table 9).

Table 9

CNS CANCER IN CHILDREN AND PARENTAL OCCUPATIONAL EXPOSURE TO EMF / CASE-CONTROL STUDIES

	CASES / CONTROLS	EXPOSURE ASSESSMENT		OR (CASES) CONF. INT.
Spitz, 1985 #51				
157 neuroblastoma, < age 15, 1964-78	father's occupation on birth certificate	group I: electricians electric & electronics workers, linemen, utility employees,		
314 rand. controls from general population				
Texas		welders		2.14 (13) 0.95-4.82
		group II: group I +		
	elec. equipment salesmen and repairmen electron. wrkrs			2.13 (17) 1.05-4.35 11.75 (6) 1.40-98.55
Nasca, 1988 #52				
338 CNS primry cancers < age 15, 1968-77	father's occ. at birth and dx/mother's	group I: elec., electron. wrkrs,	brth	1.70 (15) 0.80-3.59
678 rand. cntrls from gen. population	interview	linemen, welders	dx	1.28 (11) 0.56-2.91
NY state		group II: group I +		
		electric equipment	birth	1.61 (19) 0.83-3.11
		repairmen,	dx	1.14 (12) 0.53-2.46
		utility workers		

Table 9—CNS cancer and parental occupational exposure to EMF / case-control(cont'd)

	CASES / CONTROLS	EXPOSURE ASSESSMENT	OR (CASES) CONF. INT.
Johnson, 1989 #53			
499 CNS cancers	father's occ. on	all ind. with potential	
<age 15, 1964-80	birth certificate	EMF exposure	1.64 (25) 0.96-2.82
998 rand. cntrls frm		- electron. manuf.	3.56 (7) 1.04-12.24
gen. population		- elec. and electron.s	
Texas		apparatus manuf.	1.42 (7) 0.54-3.77
		- telephone comm.	
		industry	1.22 (3) 0.29-5.14
		radio & TV ind.	0.68 (1) 0.07-6.54
		- elec. utilities	2.71 (4) 0.60-12.18
		- elec. repair servcs	1.63 (4) 0.44-6.10
		- comp. & off. mach.	
		manufacturing	4.07 (4) 0.74-22.32
		- elec., electron.	
		engineers	0.50 (1) 0.06-4.51
		- radio operators	2.01 (2) 0.28-14.32
		- electrical, electronic	
		apparatus assemblers and	
		mechanics	2.01 (4) 0.50-8.08
		- electron. apparatus	
		assmblrs	
		& mechanics	3.01 (3) 0.50-18.11
		- elec. & electron.	
		assmblrs, installers	
		& mechanics	1.34 (10) 0.60-3.01
		- electricians	3.52 (7) 1.02-12.08
		- const. elec.	10.05 (5) 1.17-86.29
Bunin 1990 #54	occupation history	group I: as Spitz	1.3 (-) 0.4-4.1
104 neuroblastoma	of both parents	group II: as Spitz	1.0 (-) 0.4-2.3
104 random controls	telephone interview		
		electrical and electronics	
		products workers	1.6 (-) 0.5-6.2
		products assemblers	4.0 (-) 0.4-195.0
		elec. and electron.	
		prod. assmbly wrkrs	
		(both mother &	6 cases / 1 control
		father exposures)	

The number of cases in these studies was fairly large (from 157 to 499); the children were from 0 to 14 years of age. Fathers' occupations were assessed from birth certificates in two studies and from interviews with the mother or father in the other two. Exposure was estimated from fathers' occupation and no direct measurements were carried out.

Most odd ratios in these studies are elevated, several of them reaching statistical significance. The most striking results concern occupations that involve use, repair or manufacture of electrical and electronics equipment; electronics workers; and electricians.

In view of previous studies that have observed an excess of brain cancer among workers exposed to EMF, these studies of the potential relationship between childhood brain cancer and paternal exposure at birth deserve to be repeated and this issue needs to be investigated further.

Childhood cancer and use of electric appliances

Alongside the study of the association between residential exposure and childhood cancer, Savitz (23) interviewed mothers of children about their use of electric appliances before and after the child's birth. His results were published in 1990 (Table 10). After adjustment for income, prenatal electric blanket exposure was associated with a small increase in the incidence of childhood cancer (OR 1.3, CI 0.7 - 2.2) that was more pronounced for leukemia (OR 1.7, CI 0.8 - 3.6) and brain cancer (OR 2.5, CI 1.1 - 5.5).

Table 10

CHILDHOOD CANCER AND PRENATAL EXPOSURE TO ELECTRIC APPLIANCES

		all cancers	leukemia	brain
Savitz 1990 #23				
252 cancers aged 0-14 222 random controls				
exposure by questionnaire	electric blankets	1.3 (0.7-2.2)*	1.7 (0.8-3.6)*	2.5 (1.1-5.5)*
	water beds	0.7 (0.4-1.4)	0.3 (0.1-1.2)	0.5 (0.2-2.0)
	electric clocks	0.8 (0.5-1.2)	0.9 (0.5-1.6)	0.8 (0.4-1.7)
multiple controlled analysis	heating pads	1.1 (0.6-1.9)	0.9 (0.4-2.2)	0.9 (0.4-2.7)

* after adjustment for income

Conclusions on reproduction

The findings on reproduction can be summarized as follows: association between EMF exposure from electric blanket or through exposed spouse on pregnancy outcomes (prolonged gestation period, low birth weight, congenital malformation, spontaneous abortion) has been proposed by some authors, but so few studies have been conducted that this concern remains to be explored further. With regard to male infertility, studies on the number of children and sex ratio of children of exposed workers are probably not worth pursuing. Four studies have addressed this concern and they are either contradictory or totally negative. The issue of difficulty in attaining pregnancy among couples whose men are switchyard workers and the issue of azoo spermia/aligo spermia among workers exposed to elevated fields may be worth pursuing in the context of observations made by Nordstrom (46) and Buiatti (50). The most worrisome observation and the one that deserves careful scrutiny is brain cancer in children of exposed workers or/and children whose parents used electric blankets anteceding their birth.

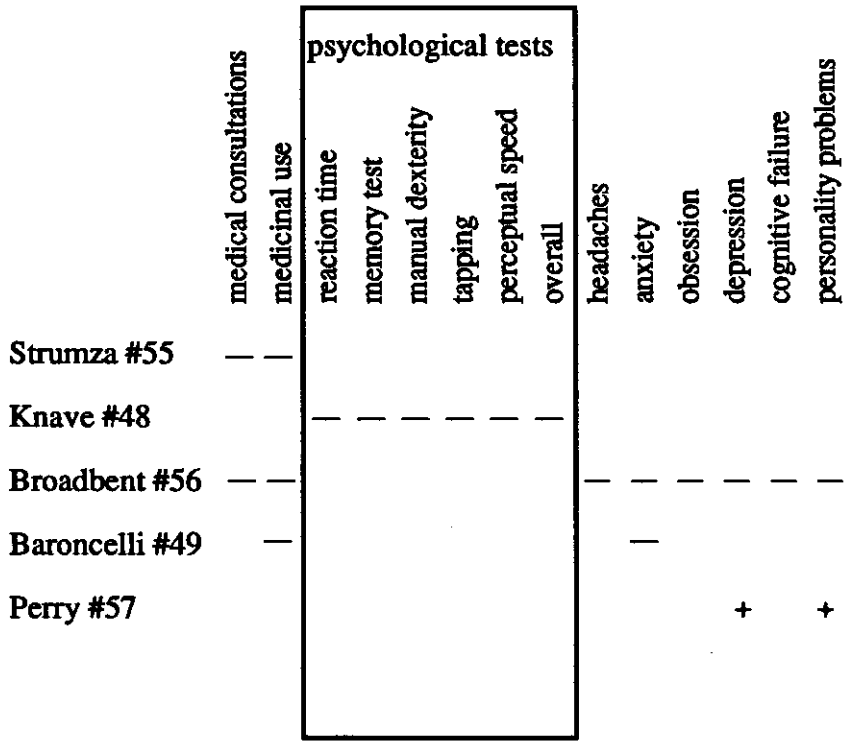
NEUROPSYCHOLOGICAL EFFECTS

Several epidemiological studies have tried to test the hypothesis raised many years ago by Russian authors of a potential effect of EMF exposure on the nervous system. Most of them are cross sectional studies of workers or residents working or living near and away from electrical sources.

Numerous effects, symptoms and performances in psychological tests have been investigated. Neurasthenic and depressive symptoms, schizophrenic diseases, psychological tests including reaction time, memory, manual dexterity, perceptual speed, medical visits, medicinal consumption, headache, etc. are but a few examples of this myriad of end points observed. A schematic summary of the most important studies is given in Tables 11a and 11b.

Table 11a

PSYCHOLOGICAL AND NEUROLOGICAL EFFECTS OF EXPOSURE TO EMF



— negative results
+ positive results

Except for depression and personality abnormalities among high rise building dwellers reported in one study (57), no differences in psychiatric diseases or psychological abnormalities were observed between exposed and non exposed people. Results are remarkably negative. Knave (48) even reported that performance to psychological tests was better among exposed than non exposed workers, attributing these differences to higher socio-economic and educational levels of men working in high voltage substations. It is

Table 11b

PSYCHOLOGICAL AND NEUROLOGICAL EFFECTS OF EXPOSURE TO EMF

	neurasthenic symptoms	psychological tests: reaction time	memory	manual dexterity	perceptual speed	overall	medical visits	medicine use	headaches
Strumza 1970 #55 267 persons living or working within 25 meters of high tension power lines 258 p. liv. or work. > 125 meters of high tension power lines	N/A	N/A	N/A	N/A	N/A	N/A	no	no	N/A
Knave 1979 #48 volunteer workers, cross sectional 53 exposed to 400 kV substations - 53 non exposed from same co.	no	no	better	better	no	better	N/A	N/A	N/A
Broadbent 1985 #56 questionnaire to 390 electric utility workers	no	N/A	N/A	N/A	N/A	N/A	no	no	no
Baroncelli 1986 #49 railway high voltage substation workers / cross sectional exp. # 0 133 1 117 10 153 20 224	no	no	N/A	N/A	no	no	N/A	N/A	N/A
Perry 1988 #57 high rise building dwelling 75 cases (37 near, 38 distant)	yes (depression)								

surprising however, to realize that no study has investigated alteration in sleep patterns among EMF exposed workers. Knowing that EMF may alter the circadian rhythm and may interact with the secretion of melatonine (58), it would seem reasonable to conduct studies on the relationship between sleep pattern and exposure to EMF.

One concern related to the nervous system that has been studied with more attention was suicide (Table 12). Reichmanis (59) examined the association between the act of suicide and estimated EMF field exposure arising from 50 hertz overhead high voltage transmission lines at the residence of 598 suicide victims and controls in the Midlands, England. The addresses of cases and controls were plotted on planemetric maps together with transmission lines. The total electric and magnetic fields attributable to electric lines were estimated from this information for each case and control. There were differences in exposure between cases and controls but no clear association with intensity of exposure.

Table 12

SUICIDE AND EXPOSURE TO EMF

		Exposure Assessment	RR
Reichmanis 1979 #59	598 suicides (69-76) 598 rand. cntrls stratified by map areas West Midlands, UK	MF est. from maps of electrical equipment	suicide victims more exposed no clear association with MF intensity
Perry 1981 #60	second analysis of same material	MF measured at 0.5 meter from front door of the residence	cases exp. 305/590))p < .05 controls exp. 257/594)
			cases X 0.087 μT))p < .05 controls X 0.071 μT)
McDowall 1986 #61	8000 prsns residing within 30 mf of source in 1971 followed up to 1983	exp. est. from maps	SMR 75 (8)
Baris 1990 #62	British occ. mortality data	elec. occ.	for radio/radar mechanics PMR 1.53 (19) .92-2.39
			for telegraph/radio operators PMR 2.56 (10) 1.23-4.71

Later, Perry (60), conducted a similar study on the same 598 cases and controls. Measurements of magnetic fields (MF) were carried out at suicide and control addresses. More suicide than control measurements were above the median (278 suicides, 232 controls, $p < 0.01$) and the mean value of measured MF for the suicide address (0.087 μT) was significantly higher than that of the controls (0.071 μT) ($p < 0.05$). Socio-economic factors did not seem to account for this difference.

McDowall (61) followed up 8000 persons in England who were living within 30 meters of electric transmission facilities in 1971. The subjects were traced to 1983 and death certificates were obtained from national records. He found an SMR of 75 (8 observed, CI 32-147) for suicide (5) and "undetermined" deaths (3) combined. For those cases residing within 15 meters of the lines, the SMR was 143 (2 observed, CI 16-516). This study does not provide support for an association between EMF and suicide.

Baris (62) examined mortality from suicide in men with occupations likely to have resulted in exposure to electric and magnetic fields, using the British occupational mortality data from 2 independent decennial supplements (1970-72 and 1979-83). Except for an excessive PMR of 256 (CI 123-471) for telegraph radio operators and 153 (CI 92-239) for radio and radar mechanics in the 1970-72 supplement, no other excess was noted in potentially exposed occupations, even the most exposed ones.

In summary, the evidence linking suicide to EMF exposure is thin. It stems mostly from Reichmanis (59) and Perry's (60) studies. However, the counter evidence from McDowall (61) and Baris (62) is not convincing either. In light of recent experimental studies supporting a plausible biological mechanism through hormonal (melatonine) system, depression and suicide resulting from exposure to EMF remain timely issues.

CONCLUSIONS

With regard to health consequences from exposure to EMF in the working environment, three concerns have been addressed with some consistency by epidemiologists: cancer, reproduction and neuropsychological effects. Of the three, cancer is the one that has

raised the most interest. Leukemia, brain cancer and recently breast cancer are three sites where excess risks have been reported among workers engaged in "electrical occupations." Skin melanoma has also been in excess but it is believed to be reflective of a higher socio-economic status of electrical workers. Almost all "electrical occupations" have shown excesses of one cancer or another but no consistent observation has allowed firm conclusions. The size of the excess risk noted so far may seem small but it is to be regarded seriously in view of the poor estimates of exposure used. The real agent responsible for the excesses of cancer observed in "electrical occupations" may be something other than EMF (referred to as confounders by many authors), such as chemical exposures, but this has yet to be demonstrated.

Suspicion was raised of a potential effect of EMF on reproduction. Myriads of end points have been looked at. They encompassed outcomes of pregnancy, male infertility, and childhood cancer resulting from parental exposure. Many observations have yielded positive results. Unfortunately, they stemmed from few and most often from a unique observation and they still need to be confirmed. One of the most disturbing observation is a potential excess of brain cancer among children of parents exposed to EMF during pregnancy.

No neuropsychological effects have been reported among exposed workers. It even was observed that electrical workers performed better on psychological tests. The issues of depression and suicide remain open to more investigation. Sleep pattern should be studied in relation to EMF exposure.

In his critical review of the evidence on low frequency electromagnetic fields and leukemia, Cartwright (63) has referred to it as the "saga so far" and has predicted that the whole issue of adverse health effects of EMF with respect to leukemia, will end, after "many more years of speculation" as having been a dreadful scarecrow. He may be right, with respect to EMF being the causal agent of the cancer excess noted, but one cannot help from recognizing that the evidence points toward the existence of one carcinogenic factor in "electrical occupations and/or environment."

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