JOURNAL OF BIOELECTRICITY, 10(1&2), 241-256 (1991)

# ELECTROMAGNETIC FIELD SENSITIVITY

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## ABSTRACT

A multiphase study was performed to find an effective method to evaluate electromagnetic field (EMF) sensitivity of patients. The first phase developed criteria for controlled testing using an environment low in chemical, particulate, and EMF pollution. Monitoring devices were used in an effort to ensure that extraneous EMF would not interfere with the tests. A second phase involved a single-blind challenge of 100 patients who complained of EMF sensitivity to a series of fields ranging from 0 to 5 MHz in frequency, plus 5 blank challenges. Twenty-five patients were found who were sensitive to the fields, but did not react to the blanks. These were compared in the third phase to 25 healthy naive volunteer controls. None of the volunteers reacted to any challenge, active or blank, but 16 of the EMF-sensitive patients (64%) had positive signs and symptoms scores, plus autonomic nervous system changes. In the fourth phase, the 16 EMF-sensitive patients were rechallenged twice to the frequencies to which they were most sensitive during the previous challenge. The active frequency was found to



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be positive in 100% of the challenges, while all of the placebo tests were negative. We concluded that this study gives strong evidence that electromagnetic field sensitivity exists, and can be elicited under environmentally controlled conditions.

## INTRODUCTION:

Interaction mechanisms that underlie the health and biological effects of electromagnetic fields (EMF) on humans have been studied by many authors (1,2,3,4,5,6). This subject was reviewed recently at the 1990 Spring Meeting of the American Physical Society (7). Choy *et. al.* (8) investigated individuals with multiple sensitivities who reported reactions to various types of electrical equipment, including power lines, electronic office equipment such as typewriters and computer terminals, video display terminals, household appliances (such as hair dryers), and fluorescent lights.

This paper presents preliminary data on electromagnetic field tests using a square wave generator to evaluate the EMF sensitivity of patients reporting such sensitivities under environmentally controlled and monitored conditions.

## MATERIALS AND METHODS:

This study has been carried out in four phases.

I. The tests were carried out in an environmentally controlled area with porcelain-on-steel walls to minimize airborne chemical pollution which might interfere with the testing procedure. This type of construction also acted to decrease external electromagnetic fields. Portable EMF monitoring devices were used to find an area that would minimize background EMF which might disturb double-blind challenges and interfere with the testing process. The low-pollution room had a background of 0-100 V/m electric field and 20-200 nT (Tesla) magnetic field. The immediate test site of the patients had unmeasurable electrical fields and magnetic fields in the vicinity of 20 nT.

The major emphasis of this phase of the studies was the evaluation of the effects of the magnetic field generated by a coil fed from a sweep/function generator (Model 3030, B.K. Precision Dynascan Corp.). This equipment allowed us to test square wave frequencies from 0.1 Hz to 5 MHz.

The patients were tested while they were sitting comfortably upright in a chair with the generator on a desk at least 2 m away,

with its output connected to a coil 6 cm in diameter and 15 cm tall, made of 35 m of cable and positioned on the floor with its center approximately 0.3 m from the feet of the person tested. The mean values of the alternating magnetic field generated by this arrangement were approximately 2900 nT at floor level, approximately 350 nT at the level of the chair seat and patients' knees, and about 70 nT at hand level. The exposure period lasted approximately 3 minutes per challenge.

Before the EMF challenge, blood pressure, pulse rate, respiratory rate, temperature, sign and symptom scores, and autonomic nervous system functions were tested. The autonomic nervous system function was tested with a binocular iriscorder (Model C2515, Hamamatsu Photonics), which measured pupil area, time at which constriction and dilation occurred, and rate of constriction/dilation (9).

All patients had been previously evaluated and treated for biological inhalant, food and chemical sensitivities in order to minimize possible confusion from coexisting problems. The patients were stabilized on a healthy diet in a constant low-pollution environment. In addition, they had their overall body load reduced and stabilized in a controlled environment.

II. This was a single-blind screening of 100 patients who complained of being EMF-sensitive. They were challenged under low-pollution conditions using the sweep/function generator at 0.1, 0.5, 1, 2.5, 5, 10, 20, 40, 50, 60, and 100 Hz; then at 1, 5, 10, 20, 35, 50, 75, and 100 KHz; and finally at 1 and 5 MHz. There were twenty-one active challenges and five blanks (placebos) per person, giving a total of 2600 challenges. When the number and/or intensity of symptoms were 20% over baseline, the result was considered positive, and were recorded as such under the various criteria used. A change in the iriscorder readings more than two standard deviations from baseline was also recorded as a positive result.

III. Twenty-five patients, who were found to be positive in phase II challenges, and who had no more than one placebo reaction were then selected for a third phase of the study. In addition, 25 healthy naive volunteers were challenged. Double-blind EMF challenges and placebos using the aforementioned parameters were performed. There were 1300 total challenges, of which 1050 were

Table 1

Phase II -- Single-blind Challenge of 100 Patients

| No. of Patients | No. of Active Challenges | No. of Blank Challenges | Pos. Reactions to Active Challenges | Pos. Reactions to Blanks |
|---|---|---|---|---|
| 50 | 1050 | 250 | 750 | 150 |
| 25 | 525 | 125 | 0 | 0 |
| 25 | 525 | 125 | 325 | 0 |

active and 250 were blanks. The tests averaged 21 active frequencies and 5 blanks per subject.

IV. Sixteen patients who reacted in phase III were then rechallenged on two separate occasions in a double-blind manner, using only the frequencies to which they had responded most strongly. For each subject, the frequency of maximum sensitivity was inserted randomly into a series of 5 placebo challenges. Thus, there were a total of 32 active challenges and 160 blanks.

RESULTS:

Phase I. The EMF measurements were quite reproducible. We found that the lights and air handling equipment had to be off during the tests because of their electromagnetic field output. Baseline studies on patients were completed without remarkable result.

Phase II. Of the total of 100 patients tested in the single-blind study, 50 reacted to several of the placebos in addition to the active challenges, and were excluded from further study. Twenty-five subjects who did not react to any active challenges were also excluded. A final 25 subjects who did react to active challenges, but not to blanks, were selected for the third phase of the study (Table 1).

Phase III. The 25 subjects selected from phase II were rechallenged, and 16 (64%) reacted positively to the active challenges

(Table 2). The total number of positive reactions to the 336 active challenges in the 16 patients was 179 (53%), as compared to 6 positive reactions out of 80 blanks (7.5%). There were no reactions to any challenge, active or placebo, in the volunteer group of naive subjects (Table 2).

When evaluating frequency response, 75% of the 16 patients reacted to 1 Hz, 75% to 2.5 Hz, 69% to 5 Hz, 69 % to 10 Hz, 69% to 20 Hz, and 69% to 10 KHz (Table 3). No patient reacted to all 21 of the active frequencies in the challenges. The average was 11 reactive frequencies per patient, with a range of 1 to 19 positive responses.

The principal signs and symptoms produced were neurological (tingling, sleepiness, headache, dizziness, unconsciousness), musculoskeletal (pain, tightness, spasm, fibrillation), cardiovascular (palpitation, flushing, tachycardia, edema), oral/respiratory (pressure in ears, tooth pain, tightness in chest, dyspnea), gastrointestinal (nausea, belching), ocular (burning), and dermal (itching, burning, prickling pain) (Table 4). Most reactions were neurological.

Phase IV. In the 16 patients again rechallenged in a double-blind manner, using only the single frequency to which they were most sensitive, all reported reactions to the active frequencies when challenged. None reacted to the placebos (Table 5). Signs and symptoms in all 16 patients were positive as was the autonomic nervous system dysfunction, as measured by the iriscorder (Table 6, Figure 1). Examples of changes were a 20% decrease in pulmonary function and a 40% increase in heart rate. In the 16 patients with positive reactions to EMF challenges, two had delayed reactions; gradually became depressed and finally became unconscious. Eventually, they awoke without treatment. Symptoms lasted from 5 hours to 3 days.

DISCUSSION:

Since it has been found that electromagnetic fields can affect health, researchers have investigated these phenomena *in vivo* and *in vitro*, in animals (10,11,12) and humans (1,2,3,4,5,6,7).

No individual had been specifically challenged in an attempt to reproduce acute symptoms until Smith and Monro (5) followed by

Table 2

Phase III - 25 Patients Previously Positive Rechallenged And Twenty-Five Controls Tested Double-blind

| No. of Persons | No. of Active Challenges | No. of Blank Challenges | Positive Reactions to Challenges | Positive Reactions to Blanks |
|---|---|---|---|---|
| 16 patients (out of 25 reacting positively) | 336 | 80 | 179 | 6 |
| 25 controls (none of them reacting positively) | 525 | 125 | 0 | 0 |

Table 3

PERCENTAGE OF 16 PATIENTS WITH POSITIVE REACTION TO DIFFERENT FREQUENCIES

| Frequency (Hz) | Patients with Positive Reaction % |
|---|---|
| 0.1 | 31 |
| 0.5 | 44 |
| 1 | 75 |
| 2.5 | 75 |
| 5 | 69 |
| 10 | 69 |
| 20 | 69 |
| 40 | 50 |
| 50 | 50 |
| 60 | 63 |
| 100 | 56 |
| 1K | 56 |
| 5K | 38 |
| 10K | 69 |
| 20K | 56 |
| 35K | 31 |
| 50K | 50 |
| 75K | 50 |
| 100K | 38 |
| 1M | 50 |
| 5M | 31 |

Table 4
Comparison of Symptoms and Signs Induced by Frequencies

| Hz. | No. patients w/pos.reaction | Neurological No.of Pts. | % | Musculoskeletal No.of Pts. | % | Cardiovascular No.of Pts. | % | Respiratory No.of Pts. | % | Gastrointestinal No.of Pts. | % | Eyes No.of Pts. | % | Skin No.of Pts. | % |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 0.1 | 5 | 3 | 60 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 20 | 0 | 0 | 0 | 0 |
| 0.5 | 7 | 4 | 57 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 1 | 12 | 4 | 33 | 3 | 25 | 0 | 0 | 1 | 8 | 1 | 8 | 0 | 0 | 0 | 0 |
| 2.5 | 12 | 5 | 42 | 2 | 17 | 0 | 0 | 1 | 8 | 1 | 8 | 0 | 0 | 0 | 0 |
| 5 | 11 | 5 | 46 | 0 | 0 | 1 | 9 | 2 | 18 | 1 | 9 | 0 | 0 | 0 | 0 |
| 10 | 11 | 7 | 64 | 1 | 9 | 0 | 0 | 2 | 18 | 0 | 0 | 0 | 0 | 0 | 0 |
| 20 | 11 | 4 | 36 | 0 | 0 | 1 | 9 | 1 | 9 | 1 | 9 | 0 | 0 | 0 | 0 |
| 40 | 8 | 4 | 50 | 0 | 0 | 0 | 0 | 2 | 25 | 0 | 0 | 0 | 0 | 1 | 13 |
| 50 | 8 | 5 | 63 | 0 | 0 | 2 | 25 | 1 | 13 | 0 | 0 | 0 | 0 | 0 | 0 |
| 60 | 10 | 5 | 50 | 0 | 0 | 1 | 10 | 3 | 30 | 0 | 0 | 0 | 0 | 0 | 0 |
| 100 | 9 | 4 | 44 | 0 | 0 | 1 | 11 | 2 | 22 | 1 | 11 | 0 | 0 | 0 | 0 |
| 1K | 9 | 6 | 67 | 0 | 0 | 1 | 11 | 0 | 0 | 0 | 0 | 1 | 11 | 0 | 0 |
| 5K | 6 | 2 | 33 | 1 | 17 | 0 | 0 | 1 | 17 | 0 | 0 | 0 | 0 | 0 | 0 |
| 10K | 11 | 4 | 36 | 1 | 9 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 20K | 9 | 5 | 56 | 0 | 0 | 2 | 22 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 11 |
| 35K | 5 | 2 | 40 | 0 | 0 | 0 | 0 | 1 | 20 | 0 | 0 | 0 | 0 | 1 | 20 |
| 50K | 8 | 2 | 25 | 0 | 0 | 1 | 13 | 2 | 25 | 0 | 0 | 0 | 0 | 1 | 13 |
| 75K | 8 | 1 | 13 | 0 | 0 | 1 | 13 | 3 | 38 | 0 | 0 | 1 | 13 | 0 | 0 |
| 100K | 6 | 2 | 33 | 2 | 33 | 0 | 0 | 2 | 33 | 0 | 0 | 0 | 0 | 0 | 0 |
| 1M | 8 | 4 | 50 | 1 | 13 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 5M | 5 | 2 | 40 | 1 | 20 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

179 positive reactions out of 336 individual challenges

Table 5

Phase IV --Sixteen Patients Rechallenged to One Active Frequency on Two Separate Episoded and in Addition to Five Blank Challenges on Each Episodes -- Double-blind

First Episode of Challenge

| No. of patients | Total No. of frequencies | Total No. of blanks | No. of patients reacting to active challenge | No. of patients reacting to blanks |
|---|---|---|---|---|
| 16 | 16 | 80 | 16 | 0 |

Second Episode of Challenge

| No.4 of patients | Total No. of frequencies | Total No. of blanks | No. of patients reacting to active challenge | No. of patients reacting to blanks |
|---|---|---|---|---|
| 16 | 16 | 80 | 16 | 0 |

Choy, Monro, and Smith (8), who used a series of oscillators of varying frequency to trigger symptoms in electrically sensitive patients. We modified this procedure by developing controlled environmental areas where baselines were constantly monitored for particulates, pollutants, and extraneous fields. Here, controlled EMF output was applied so that data would be more reproducible.

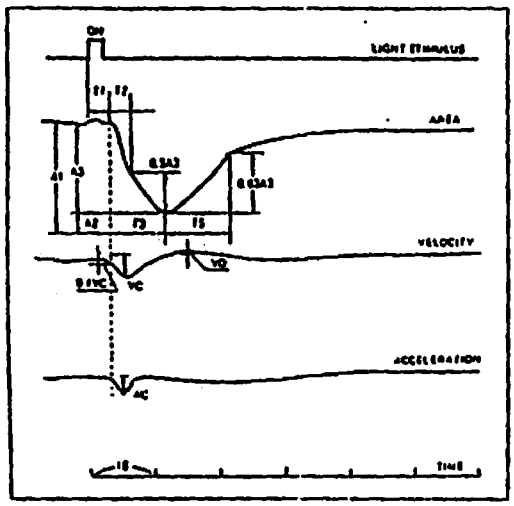
Several factors have led us to believe that we have reproducible results. Meticulous construction of environmental rooms made a great difference in the reproducibility of test results. Prior to the use of such facilities and careful monitoring, a variety of factors, such as diet, exposure to chemicals, EMF, or dust gave rise to symptoms which would have been mistaken for placebo reactions. Such effects were minimized here, as evidenced by the small number of placebo reactions. A few patients reacted to the fields generated by the monitoring devices (Iriscorder, EKG, and computers) and had to be dropped from the study as too fragile for accurate analysis. Some patients reacted to the fields generated by the fluorescent lights, and others did not present the same

Table 6

Parameters of 25 normal control's pupillary light reflex - Iriscorder - EHC-Dallas (Right and Left Eyes Combined)

| Parameter | x ± SD | Percent Variation |
|---|---|---|
| A1 | 5.70 ± 3.58 | 10.0 |
| CR | 0.46 ± 0.048 | 10.4 |
| T2 | 190.74 ± 18.36 | 9.5 |
| VC | 49.67 ± 5.86 | 11.8 |
| AC | 503.20 ± 75.80 | 15.1 |
| T5 | 1520.04 ± 285.86 | 18.7 |
| VD | 13.65 ± 2.44 | 17.9 |

**Factors of Measured Value**




The C2515 Iriscordor uses some or all of the following twelve factors to measure Light Reflex, Alternate-Stimulus Reflex, and Near Reflex.

A1 : Initial pupil area ($mm^2$)
A2 : Minimum pupil area after light stimulus ($mm^2$)
A3 : Pupil area change after light stimulus ($mm^2$)
CR: Contraction ratio (A3/A1)
D1 : Initial diameter ❶ (mm)
T1 : Time from light stimulus to start of contraction ❷ (msec)
T2 : Time to half contraction (msec)
T3 : Time to total contraction (msec)
T5 : Time to recover to 63% of A3 after dilation from minimum state (msec)
VC: Maximum velocity of contraction ($mm^2$/sec)
VD: Maximum velocity of dilation ($mm^2$/sec)
AC: Maximum acceleration of contraction ($mm^2/sec^2$)

❶ D1 is calculated from the pupil area, assuming that the pupil is circular.

❷ T1 is measured as the time from the light stimulus until the velocity of pupil contraction VC reaches 10% of the maximum velocity VCmax.

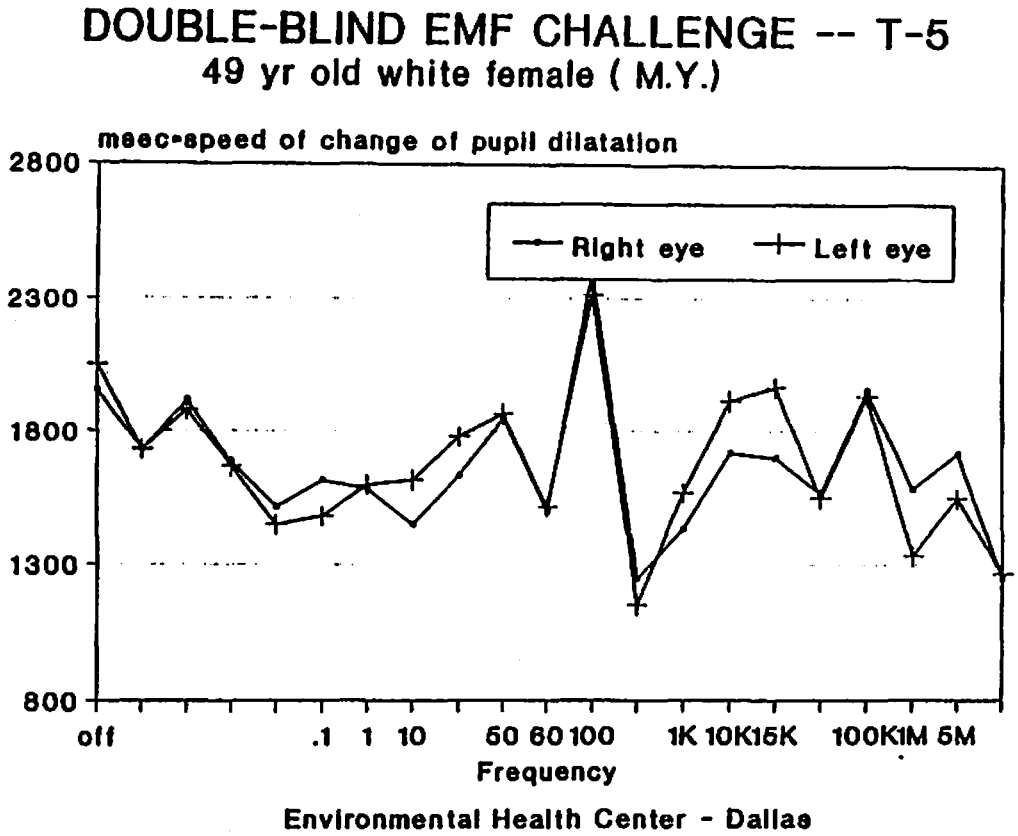



Figure 1. Speed of dilation of the pupil following EMF stimulation at various frequencies as measured by iriscorder. Note that right and left eyes respond simultaneously and to the same relative degrees at a given frequency. These results are quite reproducible (viz. text).

signs and symptoms at each challenge, even though the reactions were significant when contrasted with the blank responses. The Iriscorder data were objective, however, and were always reproducible (Figure 1).

We also noted that patients sometimes had delayed or prolonged responses. Therefore, care had to be taken to be certain that the patient had returned to baseline before the next challenge. This carry-over was first noted when evaluating responses to placebo

challenges. Such a response could usually be explained and eliminated by use of longer intervals between challenges.

In this study, of the 100 patients who expressed suspicion of EMF sensitivity, 75 actually responded to fields, whereas none of the controls did. Of the 75, 25 had no reactions to blanks, whereas 50 did, and thus were discarded from the study; even though we felt that some of the reactions to blanks might be evidence of delayed reaction to previous frequencies, or prolonged response to the previous positive challenge, as well as true placebo reactions.

We learned that challenge with 21 frequencies was impossible on many sensitive patients. They were often unwell for several hours or days, which confused the data from repeat challenges on subsequent days. Hence, we selected the one frequency of maximum sensitivity for repeat challenges in the phase IV studies.

When one compares the various groups to controls, it is clear that there is a group of patients who have unstable response systems which appear different from those of the individuals who acted as controls. These studies show that EMF sensitivity could be elicited under environmentally controlled conditions. As a result of the weak field levels and short exposure time, the responses were mild except in two patients whose symptoms were so severe (e.g. drop attack, severe itching) that they received intravenous vitamin C, magnesium, and oxygen as a result of the prolonged and delayed reactions.

Signs and symptoms appeared similar to those seen in food or chemically sensitive patients at the Environmental Health Center/ Dallas, and included neurological, musculoskeletal, cardiovascular, respiratory, gastrointestinal, dermal, and ocular changes. The neurological symptoms were most common. Similar responses have been recorded by others in the literature (5,6,7,8,13,14). In 1972, after the Soviets reported that electrical utility workers were suffering from listlessness, fatigue, and nausea, Subrohmangam and coworkers (13) investigated and reported decisive changes in cardiac function and bioamine levels when pulses of 0.01 and 0.1 Hz were used. They found significant changes in the hypothalamus in response to the EMF fields.

In these studies, the preponderance of reactions occurred at one to 10 Hz, which accords well with their observations. However, many reactions also occurred at 50 and 60 Hz, as well a some up to

5 MHz. We conclude that in any given individual, susceptibility may develop to any frequency, and produce reactions.

Static magnetic fields are known to cause increased blood pressure on some individuals (14). Choy and coworkers (8) found that EMF reactions in EMF sensitive patients were not limited to the nervous system, but occurred in the same systems as in these studies, which basically corroborate theirs, though neurological symptoms predominated in our experiments.

Over the past 30 years, numerous investigations with animals and a few epidemiological studies of human populations have been devoted to assessing the relationship of microwave exposure to cataract development. The severity and speed of formation depends not only on intensity, but also on wavelength and duration of exposure (16-21). McCally *et. al.* (22) reported damage to corneal epithelium in *Cynomolgus* monkeys after 2.45 GHz irradiation for several hours at only 20-30 $mW/cm^2$ (CW) or even 10-15 $mW/cm^2$ with pulsed fields. Therefore the results of Paz (23) strongly suggests that the potential for eye injury exists in surgery where EMF fields are present.

In our experience, the patients' clinical responses could not always be reproduced completely, but the objective Iriscorder, EKG, and respirometer could be. However, the responses were definitely different from controls or placebo challenges, In our experience over the years, we have found partial reproduction of symptoms on repeat challenge to be as significant as total reproduction. Therefore, significant differences from controls in objective measurements were deemed valid.

There are several explanations for lack of exact reproducibility. These are: a) the patients' total body loads were different at different exposure periods. For example, some patients may only respond to EMF when in a reactive hypersensitive state (5,8); b) tissue resistance could influence the effect of the EMF. Zimmerman (24) reported that electrical resistance of skin decreased with increasing temperature and increased with progressive drying, as might be expected; c) injections of antigen neutralizing substances prior to test may have reduced the response to EMF. One patient with asthma was sensitive to high voltage power lines a well as low voltage house wiring. He experienced muscle spasms in head, neck, arms, and legs. This patient was also

sensitive to dust, weeds, dust mites, and some foods. He reacted in our tests to 2.5 and 60 Hz, and to 5 and 50 KHz with tightness in the chest. He then received an antigen shot to neutralize his hypersensitivity reactions. Five months later, he was unreactive to EMF; d) weather changes might affect the results, since we know that the weather can influence the propagation of EMF, as may alterations in the geomagnetic fields. Since humidity, pollution, temperature, etc. can affect resistance and total body load, weather should perhaps affect the results. Adverse weather (inversions, for example) may increase pollution load, while good weather lessens it. There is some evidence of resonance between geomagnetic fields and an applied ac magnetic field (25), which implies that the results may depend in part at least upon the strength and orientation of the geomagnetic field in the test area; and e) different wave forms might cause different responses. In these experiments, we used only square wave inputs to the coils. Consequently, we do not know whether other wave forms (sine, sawtooth, triangular, etc.) might induce different types or intensities of reactions.

Thus far, definitive information has not been sufficient to identify a plausible mechanism for EMF interactions with biological tissue. Interactions appear to take place at the cell surface, perhaps acting on receptor sites and altering ion and molecular transport across the membranes (25). Further work remains to be done in the field.

It is clear that EMF sensitivity is a real phenomenon in some environmentally sensitive patients, because some had consistent reactions while none of the controls did. THis study must be considered as only preliminary, but the evidence clearly points to sensitivity in some people.

In conclusion, it is evident that EMF testing is at a rudimentary stage; but clearly EMF sensitivity exists and can be elicited under environmentally controlled conditions. Further studies are needed to investigate the effects of EMF fields on human health.

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