Electromagnetic Hypersensitivity: A Systematic Review of Provocation Studies

G. James Rubin, PhD, Jayati Das Munshi, MBBS, and Simon Wessely, MD

Objectives: The objectives of this study were to assess whether people who report hypersensitivity to weak electromagnetic fields (EMFs) are better at detecting EMF under blind or double-blind conditions than nonhypersensitive individuals, and to test whether they respond to the presence of EMF with increased symptom reporting. **Methods:** An extensive systematic search was used to identify relevant blind or double-blind provocation studies. This involved searching numerous literature databases and conference proceedings, and examining the citations of reviews and included studies. The results of relevant studies were tabulated and metaanalyses were used to compare the proportions of "hypersensitive" and control participants able to discriminate active from sham EMF exposures. **Results:** Thirty-one experiments testing 725 "electromagnetically hypersensitive" participants were identified. Twenty-four of these found no evidence to support the existence of a biophysical hypersensitivity, whereas 7 reported some supporting evidence. For 2 of these 7, the same research groups subsequently tried and failed to replicate their findings. In 3 more, the positive results appear to be statistical artefacts. The final 2 studies gave mutually incompatible results. Our metaanalyses found no evidence of an improved ability to detect EMF in "hypersensitive" participants. **Conclusions:** The symptoms described by "electromagnetic hypersensitivity" sufferers can be severe and are sometimes disabling. However, it has proved difficult to show under blind conditions that exposure to EMF can trigger these symptoms. This suggests that "electromagnetic hypersensitivity" is unrelated to the presence of EMF, although more research into this phenomenon is required. **Key words:** electromagnetic hypersensitivity, provocation studies, systematic review.

EHS = electromagnetic hypersensitivity; **EMF** = electromagnetic field; **SMD** = standardized mean difference; **UMTS** = universal mobile telecommunications system (a "third-generation" mobile phone signal); **VDU** = visual display unit.

INTRODUCTION

"Electromagnetic hypersensitivity" (EHS) is a relatively new phenomenon in which sufferers report a range of symptoms that are apparently triggered by the presence of weak electromagnetic fields (EMFs) (1). These symptoms show no cohesive pattern (2,3) but are typified by nonspecific sensations such as sleep disturbance, headaches, fatigue, and subjective cognitive problems (2,3). In its more severe form, EHS can be disabling, preventing sufferers from pursuing normal work or social lives.

The electromagnetic triggers for the symptoms reported by EHS sufferers are diverse. Although a list of the more common would include visual display units (VDUs), mobile phones, mobile phone base stations, fluorescent lighting, overhead power lines, and household items such as televisions and microwave ovens (3), not all sufferers report being sensitive to all potential triggers and many report only 1 or 2 specific electrical items as being problematic. The EMFs emitted by these devices vary considerably and encompass frequencies in the radio, microwave, kilohertz, and extremely low-frequency ranges (3). In almost all cases, however, the intensity of the EMFs that seem to trigger EHS symptoms is far below that known to cause physiological changes in animal models (4,5).

The underlying causes of EHS are the subject of considerable debate. On the one hand, it has been proposed that biophysical factors may make a minority of people particularly sensitive to EMF, with mechanisms involving the release of histamine by mast cells (6) having been suggested. On the other hand, it has also been proposed that the condition may be more psychologic than physicochemical (7), with symptom amplification and classic conditioning being important. Clearly, the appropriate treatment and management of EHS will depend on which of these models is correct. The best way to determine this is to examine the results of blind and double-blind experimental provocation studies. These experiments typically expose volunteers with self-reported EHS to 2 conditions, an active condition in which weak EMFs are presented and an inactive condition in which they are not. Two outcomes can then be examined: the participant's ability to correctly discriminate active from inactive (their "electromagnetic sensibility") and the participant's tendency to experience more symptoms in the active condition (their "electromagnetic hypersensitivity") (8). Although electromagnetic sensibility may be a necessary precondition for EHS, it is certainly not sufficient as there is evidence that healthy individuals can display heightened sensibility without necessarily experiencing symptoms as a result (8).

Two previous reviews have looked at provocation studies for EHS in some detail. In 1997, a report for the European Commission (1) described the results of 13 such experiments and concluded that, although "'electromagnetic hypersensitive' people do react in these provocation studies, [. . .]these reactions have not been shown to be related to the fields." More recently, a systematic review considered the results of 8 experimental studies published in peer-reviewed journals before coming to a similar conclusion (9).

The systematic review reported here attempted to identify all blind or double-blind provocation studies for EHS that could help to answer the following questions: are people who are apparently hypersensitive to weak EMFs better at detecting these fields under blind or double-blind conditions than nonhypersensitive individuals, and do they respond to the presence of weak EMFs with increased symptom reporting?

METHODS

Search Strategy for the Identification of Studies

The following electronic databases were searched for potentially relevant studies: AMED, ASSIA, Cinahl, the Cochrane Collaboration Library, Em-

From the Mobile Phones Research Unit, Division of Psychological Medicine, Institute of Psychiatry and Guy's, King's and St. Thomas' School of Medicine, King's College London, UK.

Address correspondence and reprint requests to Gideon James Rubin, BSc, MSc, PhD, Mobile Phones Research Unit, New Medical School Building, Bessemer Road, London SE5 9PJ, UK. E-mail: g.rubin@iop.kcl.ac.uk

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base, Index to Theses, the Institute of Electrical and Electronics Engineers EMF research database, ISI Proceedings, ISI Web of Science, Medline, Psychinfo, and the World Health Organisation EMF research database. These were searched from inception to January 2004 for a wide range of MeSH or free-text key words relating to EHS, including, for example, "electrical sensitivity," "electromagnetic hypersensitivity," "electro-smog," "techno-stress," "screen dermatitis," and "environmental illness." The databases were also searched for papers using combinations of relevant stimulus MeSH or free-text key words (eg, "mobile phone," "computer," "power line") and hypersensitivity MeSH or free-text key words (eg, "allergy," "hypersensitivity," "intolerance").

In addition, the Bioelectromagnetics Society conference proceedings for 1996 to 2003 were handsearched, as were the documents available on the COST 281 web site. The reference sections of any pertinent studies and reviews were also examined for additional references.

Inclusion Criteria

Only blind or double-blind experimental provocation studies were eligible for inclusion in the review, with a provocation study defined as any experiment in which the participants were systematically exposed to higher EMFs in 1 experimental condition than in another. Because we were interested primarily in the effects of ambient EMF, studies in which an electrical current was directly applied to participants were excluded (e.g. 10).

Eligible studies were required to test a discrete sample of participants who reported symptoms associated with low-intensity manmade electromagnetic stimuli. This attribution had to have been explicitly made by either the participants themselves or the experimenters. So, for example, studies investigating symptomatic VDU users in which no attribution of the symptoms to the VDU had been explicitly made (e.g. 11) were excluded, as were studies in which participants reported symptoms that were suspected to be the result of visual or ergonomic features of the VDU. Studies that examined the putative effects of EMFs on healthy volunteers alone were also excluded.

Finally, only studies reporting data relating to certain outcomes were included in the review. In particular, we were only interested in experiments that examined outcomes that are central to the self-diagnosis of EHS, ie, subjective symptoms, physical signs such as observer-rated skin rash and subjective perception of whether EMF is present. Proxy measures of ill health such as blood tests or skin biopsies are less relevant to this process of self-diagnosis and are not covered in this article.

Data Extraction and Analysis

Details regarding the following aspects of each included study were extracted and tabulated: sample (n, details regarding any control sample), stimuli (type of provocation), design (number and length of provocations per participant), sensibility results (total number of provocations correctly identified as active or inactive by participants, number of participants classified as able to discriminate active from inactive), and hypersensitivity results (type of self-reported symptoms or other relevant health outcomes measured, significance level of any difference).

Metaanalyses were conducted to determine whether the proportion of EHS participants apparently able to discriminate active from inactive conditions was greater than the corresponding proportion of control participants.

Review Process

The literature searches, assessments of inclusion, and data extraction were conducted by Gideon James Rubin with uncertainties resolved through consultation with the 2 coauthors. Where uncertainty existed as to whether 2 papers reported data from the same experiment, clarification was sought from the authors of the original papers.

RESULTS

Search Results

In total, approximately 8600 titles or abstracts were examined from which 497 papers were selected as potentially relevant to the review and examined in full. Of these, 372 were excluded because they were review papers, editorials, duplicate publications, or did not include a sample of people whose symptoms were explicitly attributed to EMF. A further 83 did not describe provocation studies, and 13 reported unblinded provocations.

Details relating to 31 individual provocation experiments involving 725 EHS participants were included. Thirteen experiments (213 EHS participants) used VDU-related provocations as their active exposure condition, 7 (161 EHS participants) examined mobile phone-related provocations, 10 (315 EHS participants) examined other EMF provocations for participants with generalized EHS, and 1 (36 EHS participants) tested an apparently healthy group of volunteers categorized as electromagnetically hypersensitive based on a median split for the results of a single questionnaire item.

Visual Display Unit-Related Experiments

Details regarding the 13 VDU-related experiments are given in Table 1. Of these, 1 reported significantly worse symptoms in the active condition than in the sham condition for 1 of the 10 tests conducted (standardized mean difference [SMD] = 1.0, $p < .01$) (12), although the authors suggested that this result probably reflected a type 1 error caused by multiple significance tests. A second study found that more EHS participants reported a reduction in skin "tingling, prickling or itching" after 2 weeks of work with an activated electric-conductive filter fitted to their computer screen compared with 2 weeks of work with a deactivated "placebo" filter fitted (13). However, this effect was small (mean difference = 0.1 on a 10-point scale), no other symptoms were affected, and the authors were subsequently unable to replicate this finding in a larger study with a longer exposure period (14). Of the remaining 10 studies, none found any evidence that EHS participants had greater sensibility than healthy controls or experienced more symptoms in active compared with inactive conditions (7,15–22).

Two of the 99 EHS participants (2.0%) for whom information was available in these studies appeared to be reliably able to discriminate EMF from sham conditions, compared with 1 of 32 healthy controls (3.1%). This difference was not statistically significant (chi-square = 0.13, $df = 1$, $p = .72$).

Mobile Phone-Related Experiments

Details of the 7 studies relating to mobile phone hypersensitivity are given in Table 2. One of these reported that a single participant of the 7 tested could detect whether a mobile phone hidden inside a bag was "on" or "off" 9 times out of 9 (23). Unfortunately, this study did not include a nonsensitive control group. Moreover, in an as-yet unpublished study, the same group previously used similar methods to test "about 70" EHS participants 3 to 12 times each without finding any who could reliably make this discrimination (Johansson, personal communication), suggesting that the significant finding may be a statistical artefact caused by repeated testing.

In another study, Zwamborn et al. (24) reported that exposure to a universal mobile telecommunications system

TABLE 1. Provocation Studies for Visual Display Unit-Related Sensitivities

Reference	Sample	Active Stimulus	Number and Length of Exposures	Results (all $p > .05$ unless otherwise indicated): Total Number of Correct Discriminations Between Active and Sham (number of participants apparently demonstrating electromagnetic sensibility)	Results: Comparison Between Electromagnetic Field Conditions for Self-Reported Symptoms	Results: Comparison Between Electromagnetic Field Conditions for Other Health Outcomes
Nilsen, 1982 (17)	5 EHS	Exposure to a VDU	Two 6-hr provocations, 1 active and 1 inactive	Not measured	None	Observer-rated skin rash
Swanbeck, 1989 (18)	30 EHS	Exposure to moderate EMF VDU and low EMF VDU	One 3-hr provocation to each VDU	Not measured	Heat or reddening, itching, stinging, oedema, "others"	None
Hamnerius, 1993 (19)	30 EHS	Exposure to VDU-like magnetic fields	Up to 8 1-hr provocations, in pairs of active and inactive	EHS: 38/80 (0/30)	Unspecified symptoms	Erythema, observer-rated skin redness
Hellbom, 1993 (22)	6 EHS	Exposure to a VDU	Four 30-min provocations; 2 active, 2 inactive	EHS: 8/24 (0/6)	Symptoms—unspecified in translation	None
Sandstom, 1993 (20)	22 EHS	Various VDU provocations	Varying durations of exposure	Not measured	Skin tightness, heat, itching, pricking, aching, other	None
Oftedal, 1995 (13)	19 EHS	Normal office work with an active or inactive VDU filter	Participants worked for 2 weeks with each filter	Not measured	Heat, itching ($p = .03$), skin tightness, tenderness, redness, blisters/acne, desquamation	Observer-rated dermatologic status
Sjoberg, 1995 (12)	7 EHS, 5 healthy controls for a subset of provocations	Exposure to 3 different VDU strengths	Four active and 4 inactive 1-hr provocations for each exposure	EHS: 99/176 (0/7); control: not reported (0/5)	"Comparison with symptoms from (liquid crystal display) work" ($p < .01$); 9 other unspecified symptoms	None
Andersson, 1996 (21)	16 EHS	Exposure to a computer and VDU	At least 2 pairs of 30-min provocations (1 active and 1 inactive) before and after a period of cognitive behavioral therapy	EHS: 41/80 (1/16)	Unspecified symptoms previously reported by the participants as elicited by EMF	None
Keisu, 1996 (15)	1 EHS, 1 healthy control	Exposure to a personal computer	Ten provocations, each randomized to active or inactive	EHS: 6/10 (0/1); control: 5/10 (0/1)	Not measured	None
Oftedal, 1999 (14)	38 EHS	Normal office work with an active or inactive VDU filter	Participants worked for 3 months with each filter	Not measured	Heat, itching, skin tightness, skin redness, eye stinging, eye pain, eye redness, eye tiredness, sensitivity to light, headaches, dizziness, tingling, fatigue	None
Flodin, 2000 (16)	15 EHS, 26 healthy controls	Different provocations, most using a VDU	Two active and 2 sham exposures of up to 1 hr each	EHS: 29/60 (1/15); control: 30/60 (1/26)	Ten unspecified symptoms relating to skin, mouth, airways, abdominal sensations, mental sensations	None
Lonne-Rahm, 2000a (7)	12 EHS, 12 healthy controls	Exposure to a computer and VDU, with or without the presence of a stressor	One 30-min provocation to each of 4 conditions (VDU on or off, stressors present or absent)	EHS: 22/48 (0/12); control: not reported	Facial skin sensations, stress level, tiredness; no interactions were found between stressor and EMF condition	None
Lonne-Rahm, 2000b (7)	12 EHS, 12 healthy controls	Exposure to a computer and VDU, with or without the presence of a stressor	One 30-min provocation to each of 4 conditions (VDU on or off, stressors present or absent)	EHS: 29/52 (0/12); control: not reported	Facial skin sensations, stress level, tiredness; no interactions were found between stressor and EMF condition	None

EHS = electromagnetic hypersensitivity; EMF = electromagnetic field; VDU = visual display unit.

TABLE 2. Provocation Studies for Mobile Phone-Related Sensitivities

Reference	Sample	Active Stimulus	Number and Length of Exposures	Results (all $p > .05$ unless otherwise indicated)		
				Total Number of Correct Discriminations Between Active and Sham (number of participants apparently demonstrating electromagnetic sensibility)	Type of Self-Reported Symptoms Measured and Comparison Between Active and Inactive Conditions	Other Health Outcomes Measured and Comparison Between Active and Inactive Conditions
Johansson, 1995 (23)	7 EHS	Mobile phone hidden inside a bag	Participants exposed up to 9 times each; each exposure randomized as active or inactive; exposures lasted for twice the time necessary to provoke symptoms during a nonblind provocation	EHS: 25/37 (1/7 [$p = .002$])	None	None
Radon, 1998 (25)	11 EHS	GSM 900 signal	A series of 12 trials, each consisting of 3 2-min exposures, 1 active and 2 inactive	EHS: 54/132 (0/11)	None	None
Raczek, 2000 (27)	16 EHS	GSM 900 signal	A series of 21 trials, each consisting of 3 3-min exposures, 1 active and 2 inactive	EHS: 94/336 (0/16)	None	None
Barth, 2000 (26)	1 EHS	Mobile phone	Patient exposed to 15 active provocations and 16 inactive provocations	EHS: 13/31 (0/1)	None	None
Hietanen, 2002 (28)	20 EHS	Analog, GSM 900 and GSM 1800 signals	One 30-min exposure to each condition	EHS: not reported (0/20)	Number of symptoms reported by participants during experiment was greater in inactive condition (no statistical analysis)	None
Johansson, 2003 (unpublished data)	70 EHS	Mobile phones	Between 3 and 12 provocations per participant; exposures lasted for twice the time necessary to provoke symptoms during a nonblind provocation	EHS: not reported (0/70)	Unspecified symptoms	None
Zwamborn, 2003 (24)	36 EHS, 36 healthy controls	GSM 900, GSM 1800, and UMTS mobile phone base station signals	Each volunteer exposed to 3 45-min provocations, 1 inactive and 2 active	Not measured	Anxiety ($p < .05$) [B], somatic symptoms ($p < .05$) [B], inadequacy ($p < .05$) [B, E], depression, hostility ($p < .05$) [B, C]	Reaction time ($p < .05$) [A, E], memory comparison ($p < .05$) [D,E], selective attention ($p < .05$) [B, E], dual-tasking reaction time ($p < .05$) [D], filtering irrelevant information ($p < .05$) [A]

A, Comparison of inactive and 900 MHz for EHS group; B, comparison of inactive and 2100 MHz for EHS group; C, comparison of inactive and 900 MHz for control group; D, comparison of inactive and 1800 MHz for control group; E, comparison of inactive and 2100 MHz for control group.
EHS = electromagnetic hypersensitivity; UMTS = universal mobile telecommunications system.

(UMTS) mobile phone base station signal resulted in greater levels of anxiety, somatic symptoms, inadequacy, and hostility for EHS participants than exposure to a sham signal ($p < .05$). A healthy control group was also significantly more affected by the UMTS signal than the sham signal, experiencing an increase in inadequacy only ($p < .05$). These effects were smaller in the control group (overall SMD for well-being = 0.22) than in the EHS group (SMD = 0.36), although the authors of the study caution against direct comparison between the groups because of the demographic differences observed between them. Some changes in objective cognitive measures were also apparent for both samples as a result of exposure to UMTS, 900-MHz and 1800-MHz signals, although no consistent pattern was found in terms of which cognitive variables were affected by which type of signal (see Table 2). Furthermore, although some cognitive parameters (ability to filter information, reaction time) showed significant decrements as a result of exposure, others (memory, visual attention, dual-tasking reaction time) showed significant improvements.

Of the 4 remaining blind or double-blind mobile phone-related studies (25–28), none found any effect indicative of biophysical hypersensitivity.

Only 1 EHS participant (0.8%) of the 125 for whom information was available in these studies was consistently able to discriminate active from inactive exposures. No comparable data were available for any control participants. Nevertheless, the probability of 1 or more of 125 participants identifying "on" from "off" 9 times out of 9, as this participant did, but purely by chance, is $p = .22$.

General Electromagnetic Hypersensitivity-Related Studies

Ten studies tested individuals reporting EHS using provocations with other sources of weak EMF (Table 3). One of the earliest, by Rea et al. (29), tested 100 patients with EHS and comorbid "biological inhalant, food and chemical sensitivities." Of these, 16 individuals were identified who repeatedly responded to certain EMF frequencies with symptoms but who did not respond to inactive challenges. A control group of healthy volunteers showed no response to either type of challenge. Although the substantive parts of this study were described as double-blind, the authors reported that the exposure equipment and its operator were present in the testing room during the experiment. A subsequent attempt by this group to replicate their findings, but this time using a screen to prevent participants from seeing the manipulation of the exposure equipment, did not find any evidence of biophysical hypersensitivity (30).

Aside from this study, only 1 other in this category found any significant effect of EMF (31). This crossover experiment exposed EHS participants to 4 hours of nighttime EMF or an inactive sham condition over the course of 4 weeks. Measurements of mood during the morning revealed significantly higher levels of pleasure ($p = .01$) and arousal ($p = .05$) during the EMF condition, a finding that runs contrary to the self-reports of EHS sufferers. The explanation for these findings is still unclear, but given their unexpected direction, they do not seem to support the hypothesis that EHS sufferers are adversely affected by EMF. Of the remaining 7 studies, none identified any significant effect of EMF on EHS sufferers (32–38).

Six of 95 EHS participants (6.3%) and 1 of 47 control participants (2.1%) were reliably able to discriminate active from inactive conditions in these experiments, a nonsignificant difference in proportions (chi-square = 1.18, $df = 1$, $p = .28$).

Other Studies

One other study (39) was identified. This used a between-participants design to test a group of 66 volunteers drawn from student and military populations. Two of the 3 provocations used are particularly relevant here: exposure to EMF and noise, and exposure to noise only. Adjusting for performance in a third condition in which noise and EMF were not present, participants classified as hypersensitive were significantly more affected by the presence of EMF than control participants in terms of their performance on visual processing and visual attention tasks ($p < .05$). No such effects were seen for 3 other cognitive variables or for subjective discomfort (see Table 4). However, interpretation of these results is complicated by several methodologic factors, including the categorization of participants into sensitive or control groups on the basis of responses given after testing had been completed and the inappropriate use of 1-tailed significance tests.

DISCUSSION

Current Evidence

To date, 7 blind or double-blind provocation studies have found some effect of EMF provocation on people who report EHS (12,13,23,24,29,31,39). However, even the original authors have been unable to replicate the results of 2 of these (14,30), the results of 3 more seem to be statistical artefacts reflecting the large number of significance tests conducted (12), the large number of participants tested (23); unpublished Johansson study), or the inappropriate use of 1-tailed significance tests (39), and the results of the remaining 2 are mutually inconsistent, with one showing improved mood as a result of provocation (31), while the other shows worse mood (24). Meanwhile the cognitive effects of this last study were apparent in both the control group and the hypersensitive group and appeared to reflect both improvements and impairments in cognition (24). Twenty-four other blind or double-blind provocation studies have found no evidence that people with apparent EHS are especially sensible or hypersensitive to EMF. Our metaanalyses also confirmed these findings. In summary, we have therefore been unable to find any robust evidence to support the existence of EHS as a biologic entity.

On the other hand, several of the experiments reviewed also examined the effects of a nonblind exposure to the relevant stimulus (7,22,23). All found that when the participants were aware that the EMF source was switched on, they

TABLE 3. Provocation Studies for Generalized Electromagnetic Hypersensitivity.

Reference	Sample	Active Stimulus	Number and Length of Exposures	Results (all $p > .05$ unless otherwise indicated): Total Number of Correct Discriminations Between Active and Sham (number of participants apparently demonstrating electromagnetic sensibility)	Type of Self-Reported Symptoms Measured and Comparison Between Active and Inactive Conditions	Other Health Outcomes Measured and Comparison Between Active and Inactive Conditions
Rea, 1991 (29)	100 EHS, 25 healthy controls	Exposure to EMFs of varying frequencies	Three testing phases involving repeated testing with 3-min exposures to different frequency EMFs and inactive challenges	EHS: not measured; control: not measured	Patients asked to describe any symptoms; 16/100 EHS participants consistently reported symptoms in active, but not inactive conditions, compared with 0/25 control participants	None
Wennberg, 1994 (32)	25 EHS, 13 healthy controls	ELF/VLF fields	Multiple exposures of less than 10 min	EHS: unreported (0/25); control: unreported (0/13)	Patient asked to report onset of any symptoms	None
Johansson, 1995 (33)	7 EHS	"Electric and/or magnetic fields"	Unknown number of 60-min provocations	Study abandoned; authors reported that "several milieu factors" may have interfered with the study	Not reported	Not reported
Wang, 1995 (30)	19 EHS, 34 healthy controls	Exposure to EMFs of varying frequencies	Nine 3-min provocations; 6 active, 3 inactive	Not measured	Unspecified symptoms	None
Bertoft, 1996 (34)	4 EHS	Exposure to EMFs generated by a dental chair and unit	Two 1-hr provocations; 1 active and 1 inactive	Not measured	Neurologic, musculoskeletal, cardiovascular, oral/respiratory, gastrointestinal, ocular, and dermal symptoms	None
Toomingas, 1996 (35)	1 EHS	Whole-body Helmholtz coil with 2 field intensities	Twenty-four 1 or 10-s provocations to inactive or active conditions	EHS: unreported (0/1)	Patient asked to describe any symptoms	None
Mueller, 2000 (31)	53 EHS	Exposure to intermittent or constant EMF	Exposure to active or inactive provocations (1 4-hr period per night for 25 nights) conducted while participant was sleeping	Not measured	Sleep quality, pleasure (p = .01), arousal (p = .05)	None
Reiβenweber, 2000 (36)	37 EHS, 37 healthy controls	50-Hz sinusoidal field	Twenty 2-min exposures, half active, half inactive	EHS: unreported (unreported); control: unreported (unreported); authors report "no significant differences in guess probabilities of groups"	Patients asked to describe any symptoms, but no analyses reported	None
Lyskov, 2001 (37)	20 EHS, 20 healthy controls	Weak magnetic fields, with or without concurrent mathematical task	Two testing days: day 1 entirely inactive, day 2 had 4 10-min exposures to active and inactive fields, with or without maths task	EHS: unreported (0/20); control: unreported (0/20)	Tactile feelings and general fatigue more prevalent in inactive condition (no statistical analysis)	None.
Mueller, 2003 (38)	49 EHS, 14 healthy controls	Low-intensity EMF	Twenty 2-min provocations: 10 active and 10 inactive	EHS: unreported (6/49); control: unreported (1/14)	None	None

EHS = electromagnetic hypersensitivity; EMF = electromagnetic field.

TABLE 4. Other Provocation Studies

Reference	Sample	Active Stimulus	Number and Length of Exposures	Results (all $p > .05$ unless otherwise indicated)		
				Total Number of Correct Discriminations Between Active and Sham (number of participants apparently demonstrating electromagnetic sensibility)	Type of Self-Reported Symptoms Measured and Comparison Between Active and Inactive Conditions	Other Health Outcomes Measured and Comparison Between Active and Inactive Conditions
Trimmel, 1998 (39)	36 EHS, 30 healthy controls	EMFs generated by a transformer coil	Exposure to either 1 hr of EMF + noise or to 1 hr of just noise	Not measured	Discomfort	Unsuccessful visual processing, precise visual processing ($p < .05$), visual attention ($p < .05$), visual perception, verbal memory

EMF = electromagnetic field.

reported being able to detect the EMF or experienced more symptoms. Another study found that participants' beliefs about the status of a double-blind exposure significantly predicted symptom reporting regardless of whether these beliefs were correct (21). Given that the actual presence of EMF did not correlate with increased symptom severity in these studies, these findings suggest that psychologic mechanisms may play at least some role in causing or exacerbating EHS symptoms.

Review Methodology

Our results illustrate the need to conduct reviews systematically and without heed to the publication status, language, or conclusions of the primary research. By doing this, we have been able to identify a large number of studies that have gone unreported in previous reviews. It is always possible, however, that additional provocation studies exist that we were not able to find. Yet, given that publication bias makes studies with significant results easier to locate, it is very unlikely that any missing studies would alter our conclusions.

A subtler problem for this review concerns the homogeneity of the participants included in the original research. Although some studies focused on participants with a single complaint such as skin rashes caused by VDUs (17) or symptoms caused by mobile phones (28), others tested volunteers with more generalized and typically more severe sensitivities under the assumption that this would make any effect easier to detect (16). In this review, we have made no distinction between these categories. Given that there is no a priori reason to assume that any biophysical mechanisms governing the adverse effects of EMF will differ between these groups, we believe we are justified in doing this. Nevertheless, arguments might be made for assessing these groups independently. Although poor reporting by the original studies makes subdivision into these categories difficult (1), we do not believe that doing this would alter our conclusions; the studies reviewed provide no robust evidence for the existence of generalized EHS, and there is currently no good evidence for the existence of more specific sensitivities to mobile phone signals or VDU emissions. However, as new technologies with different EMF characteristics are developed, it is likely that new sensitivities to them will be reported. As such, there will always be room to argue that the latest form of EHS has yet to be fully investigated.

Research Methodology

Why have so many provocation studies failed to produce significant findings? A number of suggestions have been put forward. For example, it has been suggested (24,29) that only studies conducted in specially designed chambers, which shield against all extraneous background EMF, would be able to produce a significant result. However, although this would presumably reduce any "noise" in symptom reporting and make increased symptoms easier to identify, people with EHS do usually report being able to detect the presence of electromagnetic triggers in everyday life. It should therefore also be possible for scientists to detect this sensitivity against the backdrop of normal EMF levels. Moreover, many of the studies reviewed did use techniques to reduce or control for background EMF but were still unable to identify an effect (7,12,16,19,21,28,30,36,38).

Other arguments sometimes heard are that the participants in an experiment were not sensitive enough, that the wrong symptoms were measured, that the exposure used was the wrong kind, or that the follow up was too short. Again, none of these seem very plausible as an explanation for all the negative results. In particular, we note that when provocation studies have included nonblind arms or training sessions, then it usually has been possible to measure an increase in symptoms (7,22,23). Other studies have found participants to be confident in their assertions that a particular session was active or inactive (15,21) or have identified increases in symptoms that are similar to those found after exposure to real-life triggers (18,34,37). The conclusions of the 1997 European Commission report thus still seem to be valid: participants do experience "realistic" symptoms in these experiments, but this is apparently not associated with the presence of EMF (1).

More of an issue are "hangover effects." EHS sufferers sometimes report symptoms that can last for several days (3). It is therefore important that studies use an appropriate interval between provocations to prevent symptoms experienced in one from masking any effects of the next. It is difficult to know how many studies were affected by this, but at least 2 reported that hangover effects did seem to have an impact on their results (18,29).

Low statistical power might also explain some of the negative findings. This is not simply an issue of sample size; testing a single participant numerous times can be a powerful design, although it does reduce the generalizability of any negative findings. Nevertheless, the majority of studies included relatively small sample sizes and failed to justify this by providing a power calculation. Such a calculation could be based on participant reports of usual symptom severity after real-life exposure to the stimulus and should now be given in any future research.

Implications for Researchers and Clinicians

We are aware of at least 6 more double-blind provocation studies into EHS that are currently ongoing, each of which is examining hypersensitivity symptoms associated with mobile phone-type signals. The results of these studies will determine whether any more research in this area is needed. If further studies are necessary, the following guidelines should be considered: 1) Studies should include a healthy control group. This will not only provide a standard against which to judge heightened sensibility (38), but it will also provide a useful indication of the adequacy of the blinding (16). 2) The nature and severity of participants' self-reported sensitivities should be assessed and reported. This might then be used to produce a power calculation, which should also be reported. 3) The inclusion of open-blind provocation sessions should be considered as a useful way of ensuring the face validity of the experiment. 4) Hangover effects should be controlled by the use of lengthy intervals between exposures or else checked for by the use of preexposure measures of symptom severity.

Our review suggests that treatment for EHS should not simply focus on reducing EMF exposure because this is unlikely to address the root causes of the problem (14). Identifying what these causes are may require careful investigation. For some, complaints of EHS may mask organic or psychiatric pathology, whereas others may benefit from a course of cognitive behavioral therapy (21).

CONCLUSIONS

This systematic review could find no robust evidence to support the existence of a biophysical hypersensitivity to EMF.

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REFERENCES

1. Bergqvist U, Vogel E, Aringer L, Cunningham J, Gobba F, Leitgeb N, Miro L, Neubauer G, Ruppe I, Vecchia P, Wadman C. Possible health implications of subjective symptoms and electromagnetic fields; a report prepared by a European group of experts for the European Commission, DG V. Solna: Arbete och Halsa; 1997.
2. Hillert L, Berglind N, Arnetz BB, Bellander T. Prevalence of self-reported hypersensitivity to electric or magnetic fields in a population-based questionnaire survey. Scand J Work Environ Health 2002;28: 33–41.
3. Röösli M, Moser M, Baldinini Y, Meier M, Braun-Fahrländer C. Symptoms of ill health ascribed to electromagnetic field exposure—a questionnaire survey. Int J Hyg Environ Health 2004;207:141–50.
4. Independent Expert Group on Mobile Phones. Mobile phone and health. Report of an independent expert group on mobile phones. Chilton: National Radiological Protection Board; 2000.
5. Ziskin MC. Electromagnetic hypersensitivity: a COMAR technical information statement. IEEE Eng Med Biol 2002;21:173–5.
6. Gangi S, Johansson O. A theoretical model based upon mast cells and histamine to explain the recently proclaimed sensitivity to electric and/or magnetic fields in humans. Med Hypotheses 2000;54:663–71.
7. Lonne-Rahm S, Andersson B, Melin L, Schultzberg M, Arnetz B, Berg M. Provocation with stress and electricity of patients with 'sensitivity to electricity.' J Occup Environ Med 2000;42:512–6.
8. Leitgeb N, Schröttner J. Electrosensibility and electromagnetic hypersensitivity. Bioelectromagnetics 2003;24:387–94.
9. Levallois P. Hypersensitivity of human subjects to environmental electric and magnetic field exposure: a review of the literature. Environ Health Perspect 2002;110(suppl 4):613–8.
10. Leitgeb N, Fluhr H. Einflussfaktoren der Elektrosensibilitat. VEO J 1998;6:44–50.
11. Skyberg K, Skulberg K, Eduard W, Vistnes AI, Levy F, Djupesland P. Electric fields, dust and health problems among VDU-users in an office environment. An intervention program. Advances Occup Ergonomics Safety 1998;2:81–3.
12. Sjöberg P, Hamnerius Y. Study of provoked hypersensitivity reactions from a VDU. In: Katjalainen, Knave B, eds. Electromagnetic Hypersensitivity. 2nd Copenhagen Conference; 1995.
13. Oftedal G, Vistnes AI, Rygge K. Skin symptoms after the reduction of electric fields from visual display units. Scand J Work Environ Health 1995;21:335–44.
14. Oftedal G, Nyvang A, Moen BE. Long-term effects on symptoms by reducing electric fields from visual display units. Scand J Work Environ Health 1999;25:415–21.

15. Keisu L. Successful treatment of 'electricity hypersensitivity.' The patient was assisted in curing himself. [Swedish] Lakartidningen 1996;93: 1753–5.
16. Flodin U, Seneby A, Tegenfeldt C. Provocation of electric hypersensitivity under everyday conditions. Scand J Work Environ Health 2000; 26:93–8.
17. Nilsen A. Facial rash in visual display unit operators. Contact Dermatitis 1982;8:25–8.
18. Swanbeck G, Bleeker T. Skin problems from visual display units. provocation of skin symptoms under experimental conditions. Acta Derm Venereol 1989;69:46–51.
19. Hamnerius Y, Agrup G, Galt S, Nilsson R, Sandblom J, Lindgren R. Double-blind provocation study of hypersensitivity reactions associated with exposure from VDUs. Preliminary short version. R Swed Acad Sci Rep 1993;2:67–72.
20. Sandström M, Stenberg B, Hansson-Mild K. Experiences of provocations with electric and magnetic fields. R Swed Acad Sci Rep 1993;2:62–6.
21. Andersson B, Berg M, Arnetz BB, Melin L, Langlet I, Lidén S. A cognitive-behavioral treatment of patients suffering from 'electric hypersensitivity': subjective effects and reactions in a double-blind provocation study. J Occup Envion Med 1996;38:752–8.
22. Hellbom M. Provocation attempt with individuals hypersensitive to electricity. Effects of information about the presence of electric and magnetic fields. [Swedish Dissertation] Uppsala: Department of Applied Psychology, University of Uppsala; 1993.
23. Johansson O. Hypersensitivity to electricity and sensitivity to mobile phones. Results from a double-blind provocation study of methodological character [Swedish Report]. Stockholm: Department of Experimental Dermatology, Karolinska Institute; 1995.
24. Zwamborn APM, Vossen SHJA, van Leersum BJAM, Ouwens MA, Makel WN. Effects of global communication system radio-frequency fields of well being and cognitive functions of human subjects with and without subjective symptoms [Report]. The Hague: Netherlands Organisation for Applied Scientific Research (TNO); 2003.
25. Radon K, Maschke C. Hypersensitivity to electricity. [German] Umweltmedizin in Forschung und Praxis 1998;3:125–9.
26. Barth A, Maritczak L, Valic E, Konnaris C, Wolf C. Pseudoangina caused by exposure to electromagnetic fields ('electrosmog'). [German] Dtsch Med Wschr 2000;125:830–2.
27. Raczek J, Runow K, Oetzel H, Gailus T, Herget I. Investigations of electrosensitivity to a GSM signal at 900MHz for a self-reported electrosensitive target group. The Bioelectromagnetics Society 22nd Annual Meeting; 2000:269–70.
28. Hietanen M, Hämäläinen AM, Husman T. Hypersensitivity symptoms associated with exposure to cellular telephones: no causal link. Bioelectromagnetics 2002;23:264–70.
29. Rea WJ, Pan Y, Fenyves EJ, Sujisawa I, Samadi N, Ross GH. Electromagnetic field sensitivity. J Bioelectricity 1991;10:241–56.
30. Wang T. Sick building syndrome: a study of some contributing factors [Dissertation]. University of Surrey; 1995.
31. Mueller Ch H, Krueger H, Schierz Ch. Project NEMESIS: double-blind study on effects of 50Hz EMF on sleep quality and physiological parameters in people suffering from electrical hypersensitivity. The Bioelectromagnetics Society 22nd Annual Meeting; 2000:89–90.
32. Wennberg A, Franzén O, Paulsson L-E. Electromagnetic field provocations of subjects with 'electric hypersensitivity.' In: Simunic D, ed. COST 244 meeting on Electromagnetic Hypersensitivity. Graz: COST 244; 1994:133–9.
33. Johansson O, Liu P-Y. 'Electrosensitivity,' 'electrosupersensitivity' and 'screen dermatitis': preliminary observations from on-going studies in the human skin. In: Simunic D, ed. Proceedings of Cost 244: Biochemical effects of electromagnetic fields—workshop on electromagnetic hypersensitivity. Graz: EU (DG XIII); 1995:52–7.
34. Bertoft G. Patient reactions to some electromagnetic fields from dental chair and unit: a pilot study. Swed Dent J 1996;20:107–12.
35. Toomingas A. Provocation of the electromagnetic distress syndrome. Scand J Work Environ Health 1997;22:457–8.
36. Reiβenweber J, David E, Kentner S. Different aspects of electromagnetic hypersensitivity. The Bioelectromagnetics Society 22nd Annual Meeting; 2000:270–1.
37. Lyskov E, Sandstrom M, Hansson Mild K. Provocation study of persons with perceived electrical hypersensitivity and controls using magnetic field exposure and recording of electrophysiological characteristics. Bioelectromagnetics 2001;22:457–62.
38. Mueller CH, Krueger H, Schierz C. Project NEMESIS: perception of a 50 Hz electric and magnetic field at low intensities (laboratory experiment). Bioelectromagnetics 2002;23:26–36.
39. Trimmel M, Schweiger E. Effects of an ELF (50 Hz, 1 mT) electromagnetic field (EMF) on concentration in visual attention, perception and memory including effects of EMF sensitivity. Toxicol Lett 1998;96–97: 377–82.