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Review

Idiopathic Environmental Intolerance Attributed to Electromagnetic Fields (Formerly 'Electromagnetic Hypersensitivity'): An updated Systematic Review of Provocation Studies

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Idiopathic Environmental Intolerance attributed to electromagnetic fields (IEI-EMF; formerly 'electromagetic hypersensitivity') is a medically unexplained illness in which subjective symptoms are reported following exposure to electrical devices. In an earlier systematic review, we reported data from 31 blind provocation studies which had exposed IEI-EMF volunteers to active or sham electromagnetic fields and assessed whether volunteers could detect these fields or whether they reported worse symptoms when exposed to them. In this article, we report an update to that review. An extensive literature search identified 15 new experiments. Including studies reported in our earlier review, 46 blind or double-blind provocation studies in all, involving 1175 IEI-EMF volunteers, have tested whether exposure to electromagnetic fields is responsible for triggering symptoms in IEI-EMF. No robust evidence could be found to support this theory. However, the studies included in the review did support the role of the nocebo effect in triggering acute symptoms in IEI-EMF sufferers. Despite the conviction of IEI-EMF sufferers that their symptoms are triggered by exposure to electromagnetic fields, repeated experiments have been unable to replicate this phenomenon under controlled conditions. A narrow focus by clinicians or policy makers on bioelectromagnetic mechanisms is therefore, unlikely to help IEI-EMF patients in the long-term. Bioelectromagnetics, 2009.

Key words: environmental illness; electromagnetic fields; somatoform disorders; environmental exposure; cellular phone

INTRODUCTION

In recent years, many parts of the world have witnessed social and political controversies surrounding the introduction of new electrical technologies, particularly technologies which involve the transmission of digital radiofrequency fields. Despite the lack of any clear-cut evidence demonstrating that these technologies have adverse health effects and the lack of any generally accepted mechanism through which these effects could occur [Scientific Committee on Emerging and Newly Identified Health Risks, 2009], innumerable media stories about the potential effects of mobile phones, mobile phone base stations, wireless computer systems, digital baby monitors and the like, have left the public feeling uncertain and anxious. This anxiety has been further exacerbated by the precautionary advice given out by some governmental organisations concerning the appropriate use of these technologies [Barnett et al., 2008].

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Both media stories and the continuing provision of precautionary advice have been partially driven by the existence of people who claim to have detected a clear link between their own poor health and exposure to a specific electrical device [Burgess, 2004; Goldacre, 2007; Stewart, 2008]. Their condition, often described as either 'electromagnetic hypersensitivity' or 'electrosensitivity', manifests itself as the occurrence of subjective symptoms which the individual attributes to the presence of man-made electromagnetic fields. This condition can have major implications for a person's quality of life and is associated with decrements in general health status, increased levels of distress, increased levels of health service use, and impairments in occupational and social functioning [Roosli et al., 2004; Carlsson et al., 2005; Rubin et al., 2007]. The condition is also notable for its heterogeneity: no consistent pattern has been detected in the type of symptoms reported by sufferers [Hillert et al., 2002; Levallois et al., 2002; Roosli et al., 2004], the speed in which these symptoms develop following exposure [Roosli et al., 2004] or the types of electromagnetic exposure which apparently trigger the symptoms [Roosli et al., 2004]. Even the prevalence of the condition is heterogenous: while some areas such as California and Sweden have prevalence rates of 3.2% and 1.5%, respectively [Hillert et al., 2002; Levallois et al., 2002], over 10% of Germans attribute adverse health effects to mobile phone base stations [Blettner et al., 2009] while other countries, such as Iran, apparently have few, if any, sufferers [Mortazavi et al., 2007].

The aetiology of 'electromagnetic hypersensitivity' is controversial. While most patients and some scientists believe that the condition is caused by an as yet unrecognised 'bioelectromagnetic' mechanism, most mainstream medical bodies maintain that there is not sufficient evidence to support this theory and that the symptoms experienced by sufferers are unrelated to the presence of electromagnetic fields. Indeed, a working group of the World Health Organisation has recommended that the use of terms like 'electromagnetic hypersensitivity' should be discontinued in favour of the more aetiologically neutral phrase 'idiopathic environmental intolerance attributed to electromagnetic fields (IEI-EMF)' [Hillert et al., 2006]. Resolving this aetiological debate is an important task, not least because these two opposing theories have different implications in terms of identifying the most appropriate treatment [Rubin et al., 2006a].

One powerful technique for testing the role of electromagnetic fields in triggering IEI-EMF symptoms is the double-blind experimental provocation study, in which volunteers are exposed to active and sham electromagnetic fields under controlled conditions. In 2005, we reported a systematic review of all provocation studies for IEI-EMF published up to January 2004 [Rubin et al., 2005]. Of the 31 studies located, only 7 reported any significant effect of exposure on symptom severity. Of these, three had important shortcomings in their statistical methods, two could not be subsequently replicated by the same research teams and the final two produced contradictory results. Our conclusion was that 'we have therefore been unable to find any robust evidence to support the existence of (electromagnetic hypersensitivity) as a biologic entity.' In this article we report an update to that review. Our goals remained to test whether people who have IEI-EMF are better at detecting electromagnetic fields under blind conditions than people without IEI-EMF, and to test whether they respond to the presence of weak electromagnetic fields with increased symptom reporting.

METHODS

Search Strategy for the Identification of New Studies

We searched the following electronic databases for articles that included IEI-EMF-related keywords (e.g., 'electrosensitivity', 'environmental intolerance', 'electrosmog'): AMED, Embase, Medline, Psychinfo, Scopus, Web of Knowledge, the WHO EMF research database, the EMF-Portal database, WorldCatDissertations, and the Networked Digital Library of Theses and Dissertations. Four databases (AMED, Embase, Medline and Psychinfo) were also searched for articles which included combinations of stimulus and symptom keywords (e.g., 'mobile phone' and 'headache'). In addition, citation analyses were conducted for two review articles published on this topic in 2005 [Rubin et al., 2005; Seitz et al., 2005]; the journal Bioelectromagnetics was hand-searched and also conference proceedings from the Bioelectromagnetics Society; and the reference sections of the included articles were examined. All sources were checked for articles published between January 2004 and November 2008. Articles were initially screened by checking their titles and abstracts online. The full texts of any that appeared relevant were then obtained for a more detailed review.

Inclusion Criteria

The same inclusion criteria used in our original review were applied [Rubin et al., 2005]. In brief, studies were included only if they: tested a discrete sample of participants who reported experiencing subjective symptoms which they associated with common electrical devices; experimentally exposed those participants to at least two conditions involving different levels of electromagnetic fields; performed this exposure blind or double-blind; and either assessed levels of subjective symptoms following each exposure or assessed participants' abilities to discriminate between the experimental conditions. Studies that tested only 'healthy' participants who did not report IEI-EMF were excluded from the review.

Data Extraction

For each study we extracted data on the number of participants, type of exposures and results for any statistical tests, based on symptom severity or ability to discriminate between conditions. As IEI-EMF is defined solely in terms of an apparent relationship between subjective symptoms and electromagnetic fields, we did not extract data about any outcomes which were not directly related to self-reported symptoms or the ability to perceive electromagnetic fields. For example, we did not extract data concerning EEG measurements, blood chemistry results or objectively measured cognitive function.

Review Process

The initial search for articles was conducted by GJR. The application of the inclusion criteria and data extraction were conducted independently by GJR and RNH with any disparities resolved through discussion.

RESULTS

Search Results

In total, the searches retrieved 2093 citations. Of these, 77 articles appeared potentially relevant to the review and were examined in full. Sixteen articles detailing 17 experiments involving 487 IEI-EMF participants were included in the update. One of these, David et al. [2006], was a report about an experiment that was included in our previous review article [Reissenweber et al., 2000]. This new article was, nevertheless, included in the update because it described the results from a larger sample of IEI-EMF participants than had been previously reported. Taking this overlap into account and combining the update with our earlier review identified a total of 46 provocation studies for IEI-EMF that tested 1175 participants with the condition.

Of the 16 experiments included in the update, seven involved exposure to a signal designed to emulate a mobile phone handset [Wilen et al., 2006; Rubin et al., 2006b; Oftedal et al., 2007; Bamiou et al., 2008; Hillert et al., 2008; Kim et al., 2008; Kwon et al., 2008], four tested the effects of exposure to mobile phone base station-type signals [Regel et al., 2006; Eltiti et al., 2007; Augner et al., 2009; Furubayashi et al., 2009], four involved exposure to magnetic fields generated using transcranial magnetic stimuli or other magnetic coils [Frick et al., 2005; Wenzel et al., 2005; David et al., 2006; Landgrebe et al., 2008b] and one assessed the effects of installing a protective Faraday cage over the beds of IEI-EMF sufferers [Leitgeb et al., 2008].

Mobile Phone Handset Experiments

Table 1 shows the results for the mobile phone handset-related experiments. No significant effect of exposure was reported in five of these studies [Wilen et al., 2006; Rubin et al., 2006b; Oftedal et al., 2007; Bamiou et al., 2008; Kwon et al., 2008]. In one study, a significant increase in headache severity was detected after $2\frac{3}{4}$ h exposure [Hillert et al., 2008], however this effect was attributable to an increase in the healthy control group rather than the IEI-EMF group [Hillert et al., 2008]. This same study also reported a significant increase in heat sensations at the ear in both groups following exposure. However, this effect was observed only in one of the three techniques used for scoring heat sensations and the authors reported that the result may, therefore, have been a chance finding [Hillert et al., 2008]. In another study, significant differences between the IEI-EMF and control groups in the ability of participants to differentiate between conditions, was noted [Kim et al., 2008]. However, this effect mainly reflected the greater tendency of IEI-EMF participants to reply 'yes' when asked the prompt question 'do you feel EMF?' Despite this, the accuracy of IEI-EMF participants in detecting the genuine EMF exposure in this study was only 42.2%, less than the 50% rate that would be expected by chance alone.

Mobile Phone Base Station Experiments

The results for the mobile phone base station experiments are shown in Table 2. In one study, participants randomised to receive higher levels of exposure reported significantly higher levels of 'calmness' than those who received lower levels of exposure [Augner et al., 2009]. However, this effect was identified only when both the control and IEI-EMF groups were combined together and was no longer observed once the authors corrected for the number of endpoints tested [Augner et al., 2009]. In another study, exposure to UMTS (3G) signals was found to be significantly associated with higher levels of agitation

TABLE 1. Provocation Studies Using Mobile Phone Handset-Related Exposures

Refs	Sample	Active stimulus	Number of exposures	Total number of correct discriminations between active and sham (number of participants successfully discriminating)	Type of self-report symptoms measured and comparison between active and inactive conditions (results all $P > 0.05$ unless indicated)
Bamiou et al. [2008]	9 IEI-EMF, 21 controls	GSM handset exposure (882 MHz), and a carrier wave (CW) signal	Six 30 min exposures: two GSM, two CW, and two sham	For both groups combined: 77/180 (43%). There was no significant difference in mean number of correct guesses between IEI-EMF and controls (IEI-EMF: 0/9. Control: 0/21)	None
Hillert et al. [2008]	38 IEI-EMF, 33 controls	GSM handset exposure (884 MHz)	Two exposures: one GSM, one sham	IEI-EMF: 26/75 (35%) (2/37), control: 21/62 (34%) (5/31)	Headache (control group: more headache in the active condition, $P < 0.05$), fatigue, nausea, vertigo, difficulty concentrating, feeling low-spirited, vision problems, dermal complaints, stress, ear heat (higher scores for both groups in active condition ($P < 0.05$)), ear pain, other
Kim et al. [2008]	18 IEI-EMF, 19 controls	CDMA handset (835 MHz)	Two 30 min exposures: one CDMA and one sham	IEI-EMF: accuracy for exposure = 42%, accuracy for non-exposure = 74%. Control: accuracy for exposure = 3%, accuracy for non-exposure = 95%. Significant differences ($P < 0.01$) between groups for both exposure types	Redness, itching, throbbing, burning, fatigue, headache, dizziness, nausea, palpitation, indigestion
Kwon et al. [2008]	6 IEI-EMF, 78 controls	GSM handset exposure (902 MHz)	Minimum of 600 trials per participant of active or sham stimulus. Each condition lasted for 5 s	Mean correct response rate for IEI-EMF ($n = 6$, 100 'on/off' trials) = 47% and for most controls ($n = 76$, 100 'on/off' trials) = 51% (After retesting three participants: IEI-EMF 0/6, control 0/78)	None
Oftedal et al. [2007]	17 IEI-EMF	GSM handset exposure (902.4 MHz)	Up to eight 30 min trials per participant (four active and four sham for most participants)	IEI-EMF: 52/129 (40%)	Headache, 'any other symptoms' affecting the head
Rubin et al. [2006b]	69 IEI-EMF, 60 controls	GSM handset exposure (900 MHz) and a CW signal	Three 50 min exposures per participant: one GSM, one CW and one sham	IEI-EMF: 110/192 (57%), controls: 96/180 (53%)	Headaches; nausea; fatigue; dizziness; skin itching, tingling or stinging; warmth or burning on skin; eye pain or dryness; 'severe reaction'
Wilen et al. [2006]	20 IEI-EMF, 20 controls	GSM handset exposure (900 MHz)	Two 30 min exposures; one GSM and one sham	Not reported	Whether the participant reported any symptoms during or after the experiment

GSM, General System for Mobile Communication; IEI-EMF, Idiopathic Environmental Intolerance with attribution to Electromagnetic Fields.

TABLE 2. Provocation Studies Using Mobile Phone Base Station-Related Exposures

Refs	Sample	Active stimulus	Number of exposures	Total number of correct discriminations between active and sham (number of participants successfully discriminating)	Type of self-report symptoms measured and comparison between active and inactive conditions (results all $P > 0.05$ unless indicated)
Augner et al. [2009]	8 IEI-EMF, 49 controls	Predominantly GSM base station exposure (900 MHz), with three intensities: 'low', 'medium' or 'high'	Five 50 min exposures, separated by 5 min breaks	Not reported	Good mood, alertness and calmness. 'No exposure/hypersensitivity-interaction was detected'. With IEI-EMF and control participants combined, participants randomised into groups which received one 'high' and one 'medium' exposure (in different orders, $n = 22$ and 26) had significantly higher calmness than participants who received low levels of exposure ($n = 9$, $P = 0.04$, and $P = 0.03$)
Eltiti et al. [2007]	44 IEI-EMF, 114 controls	GSM (combined 900 and 1800) and UMTS base station exposure	Three 50 min exposures: one to GSM, one to UMTS and one to sham. Plus three 5 min exposures, one to each condition	IEI-EMF: 73/132 (55.2%, 5 min exposures) and 79/132 (59.8%, 50 min exposures). Controls: 176/342 (51.4%, 5 min exposures) and 171/342 (50.1%, 50 min exposures) (IEI-EMF: 2/44. Control 5/114)	Anxiety, tension, agitation (IEI-EMF: UMTS vs. sham $P < 0.0025$), relaxation, discomfort, tiredness, plus overall symptom severity and occurrence for a list of 57 symptoms
Furubayashi et al. [2009]	11 IEI-EMF, 43 controls	Continuous exposure to W-CDMA base station exposure (2.14 GHz), and intermittent exposure with EMF randomly turned on and off every 5 min	Four 30 min sessions, consisting of the two active exposures, a sham exposure, and a sham exposure with noise as a stressor	During the intermittent exposure condition: IEI-EMF: 34/66 (52%). Controls: 126/258 (49%)	Tension, depression, anger, vigour, fatigue, confusion, discomfort
Regel et al. [2006]	33 IEI-EMF, 84 controls	UMTS base station exposure of 10 V/m or 1 V/m	Three 45 min exposures, one each to strong, weak or sham exposure	Mean perceived field strength, rated on a 0–100 scale, showed no significant association with actual field strength. IEI-EMF: 17/31 (55%), controls 22/57 (47%)	Tenseness, apprehension, worry, anxiety, being skeptical, unease, anxiety, somatic symptoms, inadequacy, depression, hostility

GSM, General System for Mobile Communication; IEI-EMF, Idiopathic Environmental Intolerance with attribution to Electromagnetic Fields; UMTS, Universal Mobile Telecommunications System.

in the IEI-EMF group [Eltiti et al., 2007]. However, further analyses controlling for the order in which the active and sham exposures were presented suggested that this effect was an artefact 'most likely due to a higher proportion of sensitive individuals receiving the UMTS signal first' [Eltiti et al., 2007], although this interpretation has been the subject of some debate [Eltiti et al., 2008; Roosli and Huss, 2008]. The other two studies in this category reported no significant effect of exposure [Regel et al., 2006; Furubayashi et al., 2009].

Magnetic Field Experiments

Of the four studies using magnetic field exposures (Table 3) [Frick et al., 2005; Wenzel et al., 2005; David et al., 2006; Landgrebe et al., 2008b], two reported significant differences between IEI-EMF participants and control participants [Frick et al., 2005; Landgrebe et al., 2008b]. In both cases, however, these differences reflected a reduced ability of IEI-EMF participants to discriminate between genuine and sham stimulation, resulting from an increased tendency of IEI-EMF participants to report physical sensations during the sham exposures.

Other Experiments

In one final study (Table 4), 43 IEI-EMF participants spent three nights at home sleeping under protective netting designed to shield them from electromagnetic fields, three nights under sham netting and three nights under no netting [Leitgeb et al., 2008]. Three participants experienced significant benefits in terms of subjective sleep quality from the genuine netting, in comparison to the other two conditions. However, subsequent checks of monitoring equipment installed inside the netting revealed 'suspicious' changes in electromagnetic field levels during the evenings for each of these volunteers. The authors concluded that the participants may have been checking whether the netting was genuine or sham and advised that 'these faking volunteers could not be considered as evidence for anything, in particular not for causal effects of (radiofrequency field) immissions (sic) on sleep' [Leitgeb et al., 2008].

TABLE 3. Provocation Studies Using Magnetic Field Exposures

Ref	Sample	Active stimulus	Number of exposures	Total number of correct discriminations between active and sham (number of participants successfully discriminating)	Type of self-report symptoms measured and comparison between active and inactive conditions (results all $P > 0.05$ unless indicated)
Frick et al. [2005]	30 IEI-EMF, 27 controls: high symptoms, 28 controls: low symptoms	Transcranial magnetic pulses to the dorsolateral prefrontal cortex of increasing magnitude	Four series of 19 tests per participant. Two series involved increasing output capacity of the magnetic coil, with 3% increments, rising from 0% to 57% of 1.8 T. A sham coil with no output was applied for the other two series	No significant differences between the groups in detection thresholds for the genuine magnetic coil. IEI-EMF participants had 'significantly' worse ability to discriminate magnetic from sham coils compared to the high symptom load control group	None
Landgrebe et al. [2008b]	88 IEI-EMF, 107 controls	Transcranial magnetic pulses to the dorsolateral prefrontal cortex of increasing magnitude	Four series of 19 tests per participant. Two series with increasing magnetic coil output, with 3% increments, from 0% to 57% of 1.8 T. A sham coil with no output was applied for the other two series	No significant differences between the groups in detection thresholds for the genuine magnetic coil. IEI-EMF participants had worse ability to discriminate magnetic from sham coils compared to the control group ($P = 0.01$)	None
David et al. [2006]	'More than' 50 IEI-EMF, similar number of controls	50 Hz magnetic flux densities of 10 μT	Twenty 2 min exposures per participant: 10 of the active condition, 10 of a sham condition	'The rating of field situation by (IEI-EMF) during exposure in weak fields did not differ from healthy controls'	None
Wenzel et al. [2005]	3 IEI-EMF, 7 controls	Total body exposure to 50 Hz magnetic flux of 96 mT	Ten 5 min exposures, five of the active condition and five of a sham condition	Not reported	Any sensations experienced during the experiment

IEI-EMF, Idiopathic Environmental Intolerance with attribution to Electromagnetic Fields.

TABLE 4. Other Provocation Studies

Refs	Sample	Active stimulus	Number of exposures	Total number of correct discriminations between active and sham (number of participants successfully discriminating)	Type of self-report symptoms measured and comparison between active and inactive conditions (results all $P > 0.05$ unless indicated)
Leitgeb et al. [2008]	43 IEI-EMF	A Faraday cage of electric conductive material mounted around the participant's own bed at home	Nine nights of sleep: three were under the genuine protective material, three under sham material, and three under no material	Not assessed	Sleep quality, awakening quality, sleep efficiency, overall sleep score. Three participants showed results indicating significant ($P < 0.05$) improvements in total sleep score in the genuine protective condition compared to the other two conditions, as well as significant improvements in sleep quality ($n = 1$), awakening quality ($n = 1$) or sleep efficiency ($n = 1$). However, subsequent checks revealed that all three participants appeared to have unblinded the study

IEI-EMF, Idiopathic Environmental Intolerance with attribution to Electromagnetic Fields.

DISCUSSION

Current Evidence

In our original review of 31 provocation studies for IEI-EMF, we reported being 'unable to find any robust evidence to support the existence of (electromagnetic hypersensitivity) as a biologic entity' [Rubin et al., 2005]. Five years and 15 experiments later, this update has failed to uncover any evidence which challenges that conclusion. While seven studies did report some effects of exposure on IEI-EMF participants, without exception these effects had either methodological explanations, be it a type 1 error due to multiple testing [Hillert et al., 2008; Augner et al., 2009], an effect caused by the order of exposure [Eltiti et al., 2007] an unblinding of the study by the participants [Leitgeb et al., 2008], or they reflected an increased tendency of IEI-EMF participants to claim to have detected the presence of EMF, regardless of the accuracy of these claims [Frick et al., 2005; Kim et al., 2008; Landgrebe et al., 2008b]. At the same time, several studies included in this update contradicted two of the 'positive' studies identified in our original review [Mueller et al., 2000; Zwamborn et al., 2003]. In one of these, the original study reported a significant effect of mobile phone base station exposure on self-reported symptoms in IEI-EMF participants and in healthy control participants [Zwamborn et al., 2003]. Two studies included in this update consisted of explicit attempts to replicate these findings; neither was able to do so [Regel et al., 2006; Eltiti et al., 2007], although questions have been raised about the adequacy of the statistical analysis in one of these replication attempts [Roosli and Huss 2008; Eltiti et al., 2008]. In the other study, our original review showed that night-time exposure to higher levels of electromagnetic fields resulted in significantly higher levels of pleasure and arousal upon awakening [Mueller et al., 2000]. However, a subsequent study failed to identify any effect of altering field levels on subjective sleep parameters [Leitgeb et al., 2008]. The evidence that IEI-EMF symptoms are related to exposure to electromagnetic fields is, therefore, now weaker than it was at the time of our original review.

This conclusion is in agreement with most other reviews of this area [Seitz et al., 2005; Hillert et al., 2006; Roosli, 2008; SCENIHR, 2009], with one notable exception: the 'Bioinitiative Report' [Carpenter and Sage, 2007]. Subsection seven of section nine in this report dealt with 'human subjective effects' of exposure to mobile phone signals and stated that 'none of these effects has been studied under controlled laboratory conditions. Thus, whether they are causally related to (mobile phone) exposure is unknown'. Given that seven relevant studies were reported in our original review [Rubin et al., 2005], 12 further studies were identified in this update (Tables 1,2 and 4) and at least six additional provocation studies involving only healthy volunteers have also been reported [Roosli, 2008], we are unable to explain how this conclusion was reached.

While this update has provided no support for the theory that bioelectromagnetic mechanisms are responsible for IEI-EMF, additional support was found for the theory that psychological factors have an important role in triggering, maintaining or exacerbating IEI-EMF symptoms [Rubin et al., 2007]. In particular, although no specific effects of active exposure were found in the studies that we identified, many studies noted that both active and sham conditions were equally effective in triggering symptoms [Wenzel et al., 2005;

Wilen et al., 2006; Rubin et al., 2006b; Eltiti et al., 2007; Oftedal et al., 2007; Hillert et al., 2008; Leitgeb et al., 2008; Furubayashi et al., 2009]. Given that sham exposures appear sufficient to trigger the symptoms reported by IEI-EMF participants in the laboratory, it seems likely that similar 'nocebo' effects may also account for many of the acute symptoms that they experience in everyday life. This mechanism would predict that conscious expectation of symptoms following perceived exposure to electrical devices results in the formation or detection of symptoms, while heightened vigilance for possible indicators of exposure leads to a higher frequency of such effects occurring [Frick et al., 2005; Landgrebe et al., 2008b]. In support of this, one study not included in this review has demonstrated that triggering symptom expectations by deceiving IEI-EMF participants into thinking that they are being exposed to a mobile phone signal does indeed result in symptom formation, accompanied by activation of brain regions previously shown to be involved in pain perception [Landgrebe et al., 2008a].

Quality of the Current Evidence

Provocation studies for any variant of IEI can be difficult to conduct [Das Munshi et al., 2007]. From a pragmatic point of view, recruiting sufficient numbers of participants is often the hardest challenge, explaining why many of the studies we reviewed have been relatively small (median number of IEI-EMF participants = 19). However, while it is possible that reduced statistical power resulting from low sample sizes may have restricted the ability of individual studies to identify a genuine effect of exposure, the consistency in which this finding has been reported throughout the literature suggests that this is not the reason for the overall failure of provocation studies to support the bioelectromagnetic theory of IEI-EMF. This conclusion is also supported by results of a recent meta-analysis which pooled together outcomes from five mobile phone-related studies (combined $n = 180$), and still failed to identify any significant effect of exposure [Roosli, 2008]. Nonetheless, we would recommend that researchers, and their funding bodies, ensure that future studies are allowed sufficient time and money to recruit enough participants to meet the study objectives: additional small-scale or pilot studies are unlikely to substantially advance this literature.

As well as allowing more time for recruitment, two other ways to increase sample sizes are to advertise widely for participants (e.g., through newspaper articles, approaches to support groups or via referrals from clinicians) and to adopt broader inclusion criteria allowing sufferers with differing subjective experiences or levels of impairment to take part. Both of these approaches have been used in several of the studies included in this review [Rubin et al., 2006b] and both have been criticised for increasing the heterogeneity of a study's sample [Schrottner et al., 2007; Hillert et al., 2008]. Is it helpful, for example to include participants who describe numerous symptoms associated with multiple electrical and chemical stimuli along with participants whose sole concern is that they experience headaches when using their mobile phone? In practice, however, several recent studies have deliberately used homogenous samples of participants who reported sensitivity to mobile phones alone: these too have failed to identify any robust effect of exposure [e.g. Wilen et al., 2006; Oftedal et al., 2007; Hillert et al., 2008].

A slightly more complex homogeneity issue concerns whether only a small subset of those who report IEI-EMF, regardless of its severity, are actually sensitive to electromagnetic fields while the majority suffer from unrelated conditions and/or nocebo reactions. If true, this would adversely affect the ability of studies which rely on group means or overall response frequencies to test the bioelectromagnetic theory of IEI-EMF. It should be noted, however, that 21 studies used designs in which individual participants were repeatedly exposed to sham or active stimuli and reported data enabling the identification of individuals who were reliably able to discriminate one form of exposure from the other. These include three studies reported in this update that involved 6–600 exposures per participant [Eltiti et al., 2007; Bamiou et al., 2008; Kwon et al., 2008] and 18 studies reported in our original review [Rubin et al., 2005]. Of the 378 participants tested in this way, only 11 (2.9%) appeared able to make this distinction, with a similar proportion of healthy control participants also falling into this category (7 out of 292 (2.4%)). While differences between the studies in terms of the number of tests used and the statistical criteria employed for identifying someone as 'reliably able to discriminate' make it difficult to perform any meta-analysis, it seems likely that these figures are no higher than might be expected by chance. Of particular interest is one study in which participants were exposed to EMF or sham conditions up to several hundred times each [Kwon et al., 2008]. Although this study did identify two healthy control participants who achieved remarkable success in one round of 100 exposures, identifying over 90% of them correctly, neither participant was subsequently able to replicate their performance.

Aside from issues surrounding the recruitment of participants, a second set of concerns relates to the ecological validity of provocation studies. This issue encompasses uncertainty as to whether carefully constructed chambers which screen out extraneous electromagnetic fields increase the chances of detecting an effect of exposure or removes important (if unknown) synergistic elements present in the environment; that attendance at a laboratory may cause anxiety for participants which may affect their results [Eltiti et al., 2007; Augner et al., 2009]; that exposure produced using specially designed equipment as opposed to, say, a genuine mobile phone, may miss some important element of exposure that is essential for triggering symptoms [Oftedal et al., 2007]; that low-level leakage from the equipment during sham exposures may invalidate any comparison [Rubin et al., 2006b]; that other environmental stimuli encountered in the laboratory or on a participant's journey to the laboratory may themselves trigger symptoms; and criticism that follow-up times in laboratory experiments are insufficiently long to capture a participant's response. Although none of these issues is entirely without foundation, the importance of them can be overstated. In particular, the use by several studies of non-blind 'practice' sessions involving the active exposure condition have explicitly demonstrated that the artificiality of a laboratory setting does not prevent participants from experiencing their usual IEI symptoms [Rubin et al., 2005; Eltiti et al., 2007; Oftedal et al., 2007]. At the same time, the high level of confidence reported by participants in their ability to detect which condition is which, in many of these studies, also suggests that the participants themselves believe these experiments to be a fair test of their sensitivities [Rubin et al., 2005, 2006b]. Meanwhile, several studies have deliberately used a more naturalistic setting without noting any robust effect of exposure [Rubin et al., 2005].

While the majority of people with IEI-EMF report that their symptoms usually occur within minutes to hours after exposure, a minority of sufferers report a lengthier onset, with an accumulation of exposure over days or weeks seen as causing increased symptom severity [Roosli et al., 2004]. While most provocation studies have used short-term exposures to test the former type of IEI-EMF, the more chronic form of the condition remains underinvestigated. To date, three double-blind experiments have used real or sham shielding material to test whether reducing electromagnetic fields in a participant's workplace or home for periods between 3 days and 3 months is effective in reducing symptoms: these studies have not produced any convincing evidence for such an effect [Oftedal et al., 1995, 1999; Leitgeb et al., 2008]. Although care must be taken to ensure that the double-blinding of such studies is not compromised by the understandable inquisitiveness of some participants [Leitgeb et al., 2008], additional research using this paradigm would be of interest.

CONCLUSIONS

To date, 46 studies involving 1175 volunteers with IEI-EMF have tested whether exposure to electromagnetic fields can trigger the symptoms reported by this group. These studies have produced little evidence to suggest that this is the case or that individuals with IEI-EMF are particularly adept at detecting the presence of electromagnetic fields. On the other hand, many of these studies have found evidence that the nocebo effect is a sufficient explanation for the acute symptoms reported in IEI-EMF. Thus while continued experimental research in this area will be required to clarify the role of chronic exposures and to test the effects of new varieties of electromagnetic emissions, the best evidence currently available suggests that IEI-EMF should not be viewed as a bioelectromagnetic phenomenon. Despite this, some commentators continue to discuss the condition without sufficient reference to this literature [Carpenter and Sage, 2007; Goldacre, 2007]. This is regrettable and suggests that the scientific community should do more to communicate the current state of the art in this area.

In the meantime, when faced with someone who describes subjective symptoms that are apparently associated with exposure to an electrical device, it would be wise for clinicians and policy makers to begin with the assumption that an alternative explanation for these symptoms may be present, either in the form of a conventional organic or psychiatric disorder, or in terms of the more subtle psychological processes associated with the nocebo response. In the latter case, treatment based on cognitive behaviour therapy may be helpful for some patients [Rubin et al., 2006a].

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