REVIEW

How dangerous are mobile phones, transmission masts, and electricity pylons?

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Electrical power and mobile communications deliver enormous benefit to society, but there are concerns whether the electric and magnetic field (EMF) emissions associated with the delivery of this benefit are linked to cancer or other health hazards. This article reviews the strength of the available epidemiological and laboratory evidence and notes that this falls short of what is normally required to establish a causal link. However, because of scientific uncertainty a cautious approach is often advocated, but here, too, there may be a tendency to judge these risks more harshly than those in other areas with similar strength of evidence.

Although mobile phones, transmission masts, and electricity pylons are often linked together, they represent separate issues, especially the last, where the characteristics of the electric and magnetic fields (EMFs) associated with high voltage power lines are quite different from the radiofrequency (RF) emissions from mobile telephony systems. The issues differ also in that mobile phone handsets represent RF exposure which is voluntary (and to some extent controllable), whereas that from a mast, or base station, is involuntary and moreover perceived as delivering benefit to community members who may not necessarily be the same as those who bear the cost of proximity. In terms of absorbed RF energy, the delivery from a handset is typically around a thousand times more than that from a base station, but in terms of ''outrage factor'' the latter is more potent. The same considerations of cost and benefit apply to electricity pylons and again, the EMFs from pylons are similar in character to those associated with domestic appliances or wiring which are thus more under an individual's control. There are two concerns which are common to all three sources of non-ionising radiation: the possibility of a link to the incidence of certain forms of cancer and a perception by some individuals of an electromagnetic hypersensitivity or EHS.

EMFs are a form of non-ionising radiation and as such are not sufficiently energetic to cause the type of tissue damage caused by *x* rays, for example. Unlike exposure to chemicals, once exposure to EMF ceases so does the direct influence in tissue. Moreover, there is little evidence for a build up of influence of low exposures over time. For example, the occurrence of cataracts has been linked to RF overexposure but there is no evidence that cataracts would arise from long term exposure to moderate RF levels.[1]

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MOBILE PHONE HANDSETS

These battery-driven devices are designed to adjust their RF power transmission levels to those that are minimally required for acceptable communication with the base station. In normal use, these may only be a few percent of the maximum power output, which is typically 0.25 W. In listening mode the output power is minimal. In weak signal areas the output power will be close to the maximum. Inevitably, some of this transmitted power is absorbed by parts of the user's body, mainly the cheek and underlying structures. This absorption, or specific absorption rate (SAR) in Watts per kilogram, has been extensively studied in large-scale mathematical models and phantom and cadaver studies. Manufacturers perform SAR testing as part of compliance testing protocols using standardised phantoms.

The SAR is essentially a measure of the thermal effects of RF and can be used to estimate the amount of temperature elevation. International standards are designed to limit these temperature rises in tissue to less than 1℃. The possibility of localised hot spots has also been investigated. The maximum in situ gradients in temperature are limited by the diffusional and convectional properties of tissue, which give characteristic lengths of a few centimetres. The absorption also decays exponentially with distance below the skin surface. Typically SAR values in cortical tissue are substantially less than those in the skin. The temperature rises in skin itself (due to RF absorption) are well within natural diurnal variations and may be less than those due to the warmth of the handset itself due to the operation of electronic circuitry. It should also be pointed out that in order to conserve power the battery is pulsed and this pulsing gives rise to extremely low frequency (ELF) magnetic fields, which will be discussed below.

In view of the absorption of RF in the head, the major concern has been the possibility of brain tumours in general and acoustic neurinomas in particular. The International Agency for

Abbreviations: B-field, magnetic field; CI, confidence interval; E-field, electric field; EHS, electromagnetic hypersensitivity; EMF, electric and magnetic field; IARC, International Agency for Research into Cancer; ICNIRP, International Commission of Non-Ionising Radiation Protection; OR, odds ratios; RF, radiofrequency; SAR, specific absorption rate

Research into Cancer (IARC) sponsored Interphone study has involved studies in 13 countries (Australia, Canada, Denmark, Finland, France, Germany, Israel, Italy, Japan, New Zealand, Norway, Sweden, and the UK) and some of the results have now been published. The outcomes as at 1 November 2005 are presented in table 1. The target was to include (in toto) the following numbers of cases: 6000 glioma and menigioma, 1000 acoustic neurinoma, and 600 parotid gland cancers. The following percentages of these targets are reported in table 1: glioma 10%, meningioma 7.5%, and acoustic neurinoma 68%. In addition to this coordinated study, a number of independent studies have also been completed, and some of these are also summarised in table 1. Epidemiological studies involving RF exposures have recently been reviewed by the International Commission of Non-Ionising Radiation Protection (ICNIRP).[2]

A glance at table 1 will show that, in general, results are mixed, with glioma and meningioma risks being normal or less than normal in relation to phone use, but that acoustic neuroma shows a trend, in Swedish studies, to be elevated, especially in relation to ipsilateral exposure and to analog rather than digital phone exposure. Contrary to the Swedish (and pooled study) findings, the US study found greater numbers of acoustic neuroma on the contralateral side. It should also be noted that the chance of diagnosis of acoustic neuroma may be related to difficulties in hearing mobile phone calls and hence to the ipsilateral side.

There is no consistent evidence of increased tumour incidence or mortality in long term studies of experimental animals exposed for extended periods to RF emissions mimicking that from handsets. A major study carried out in Adelaide, Australia, which showed an approximate doubling of tumour incidence in a lymphoma-prone mouse strain[16] could not be replicated by a second group of researchers using similar protocols at the same location.[17]

In vitro studies, especially those directed at identifying genotoxic effects such as DNA strand breaks or cell micronuclei formation, have been more controversial, but a recent review[18] has noted that a number of experimental artefacts could account for some of the positive findings. Similarly, there has been a long standing controversy over whether blood-brain barrier permeability is affected by levels of RF associated with handset use. Some groups have found consistent evidence of alterations,[19] whereas other have not.[20–23]

With regard to non-cancer health concerns, numerous studies involving human volunteers have sought to identify changes in neuropsychological or neurophysiological performance during or following phone use. These have typically involved a double blind repeated measures design, in which individuals' responses to radiating and non-radiating phones have been compared. Some of these studies have been reviewed by Hamblin and Wood,[24] and a preponderance of reports of enhanced EEG power in the alpha band noted. However, as several groups have been unable to replicate their own initial findings of significant alterations, it would thus be unwise at this stage to come to firm conclusions. It should also be noted that the magnitude of changes reported are relatively small and are within normal physiological variation. Nevertheless, any changes in the ability of humans to make rational decisions or recall important information during or following a mobile phone call are important to fully identify and characterise.

Scientific studies in relation the effects of handset RF emissions on biological systems other than those mentioned have been extensively reviewed by several national and international agencies, including the Health Protection Agency of the UK (formerly NRPB).[25]

Several studies have identified an association between handset use and motor vehicle accidents. This is due to divided attention and is not in any way related to RF emissions. It appears, from several studies, that the association is still present where hands-free in-car kits are used, but a recent study[26] suggests that, with practice, young people are

Table 1 Summary of epidemiological studies relating to mobile phone handset use

Country	Year	Phone*	No. cases	OR (95% CI)	Notes
Glioma					
Denmark†[3]	2005	G	171	0.58 (0.37 to 0.9)‡	High grade
			81	1.1 (0.58 to 2)	Low grade
Sweden†[4]	2005	G	371	0.8 (0.6 to 1)	
Finland[5]	2002	G+A	198	1.5 (1.0 to 2.4)	2.1 (1.3 to 3.4)§ **
Menigioma					
Denmark†[3]	2005	G	175	1.0 (0.54 to 1.3)	
Sweden†[4]	2005	G	273	0.7 (0.5 to 0.9)‡	
Sweden[6]	2005	A	35	1.7 (1.0 to 3.0)	G and C: NS
Acoustic neuroma					
Denmark†[7]	2004	G	106	0.9 (0.51 to 1.6)	
Sweden†[8]	2004	G	148	1.0 (0.6 to 1.5)	3.9 (1.6 to 10)§ ††
Sweden[6]	2005	A	20	4.2 (1.8 to 10)§	G and C: NS§
USA[9]	2002	G	90	0.9 (0.4 to 1.3)	Higher OR on contralateral side
Pooled UK+Nordic†[10]¶	2005	A+G	678	0.9 (0.7 to 1.2)	1.8 (1.1 to 3.1)†† and >10 years use§
Uveal melanoma					
Germany[11]	2001	U	118	4.2 (1.2 to 15)§	Based on ~6 cases reporting phone use
Salivary gland cancer					
Finland[5]	2002	G+A	34	1.3 (0.4 to 4.7)	
Brain tumour (all)					
Finland[5]	2002	G+A	398	1.3 (0.9 to 1.8)	Inc. glioma data
Sweden[12]	2002	U	1429	1.3 (1 to 1.6)	0.9 (0.8 to 1.2)‡‡
Sweden[13]	2001	U	233	2.4 (1.0 to 6)	Ipsilateral exposure
USA[14]	2000	U	469	0.85 (0.6 to 1.2)	
USA[15]	2001	U	782	1.0 (0.6 to 1.5)	

*Phone type indicated thus: A: analog; C: cordless; G: GSM (digital); U: unspecified or pooled; †indicates data forming part of the Interphone project; ‡odds ratios (OR) significantly low; §OR significantly high; ¶includes data from the Danish and Swedish studies[7 8]; **OR (95% CI) for a subset of data for analog (A) phones; ††OR (95% CI) for a subset of data with tumour ipsilateral to normal side of phone use; ‡‡OR (95% CI) for a subset of data for subjects in urban areas: for rural area OR higher.
In several of these studies multiple sub-analyses on particular conditions of exposure have also been reported. The number of cases in each study often does not relate to the OR estimate quoted, since the definition of a frequent user varies between studies. CI, confidence interval.

better able to adapt to competing (phone call and driving) attentional demands than older people. This does not entirely eliminate the added risk, however.

One of the recommendations of the 2000 Stewart report[27] was that the use of mobile phones by children should be minimised. However, there is little scientific justification for this on the grounds of enhanced absorption patterns in infant brains[28 29] and increased susceptibility of brain tissue during development to unspecified RF effects is largely conjectural. The possible harm has to be weighed against the positive and quantifiable benefits of mobile telephony in emergency situations.[30] The current advice issued by WHO is discussed in the section Precautionary policies below. Furthermore, future research policies in relation to risk to children were discussed at a recent WHO workshop, whose proceedings have recently been published.[31]

MOBILE PHONE TRANSMISSION MASTS (BASE STATIONS)

The greater concern among the public over proximity of masts rather than the use of handsets, even by children, is understandable. The apparent unrestrained proliferation of masts and antennas, in some cases with minimal public consultation, has led to suspicion and organised protest, particularly where these facilities have been sited, or have been planned to be sited, near schools, childcare centres, and the like. Masts often represent a visual obtrusion, and the sheer number of antennas on a mast shared by several carriers encourages the casual observer to assume that the EMFs can be focussed or at least enhanced in particular locations. Although the levels, when measured, are indeed very low (up to a few thousandths of the permitted levels), the continuous and whole-body nature of the exposure gives the concern some justification (fig 1). However, it must be remembered that mobile phone transmissions are only part of the spectrum of EMF transmissions, along with radio, TV, and other communications networks. Radio transmitting towers have been operating for almost a century and in some cases at much higher levels of public exposure. In response to public concerns, several national radiation laboratories carry out surveys of EMF levels, including the Health Protection Agency in the UK (http://www.nrpb.org/hpa/radio_surveys/) and the corresponding Australian agency (http://www.arpansa.gov.au/issues.htm).

With regard to the question of identifying any cancer risks from proximity to transmitting masts (as opposed to RF EMF exposure in general), studies carried out in the USA, UK, Australia, and the Vatican City have been reviewed,[2 32 33] but the inconsistency between and within studies and the lack of correlation with RF levels have rendered these studies inconclusive. It should be pointed out that these studies have been on RF transmitters other than mobile phone base stations. There are considerable technological difficulties in estimating phone base station "dose" to an individual, even among non-users of handsets, and for this reason no epidemiological studies in relation to mast exposure have been completed. The reviews just referred to also discuss, in passing, non-cancer outcomes, such as sleep disturbances and fatigue, in relation to (non-phone) RF transmitters. These data also fall far short of what is required to establish cause and effect. However, a major laboratory study carried out in the Netherlands to examine the effects of three types of *simulated* mobile phone base station transmissions (rather than handset transmissions) concluded that one of the signals (UMTS-like) had a negative influence on wellbeing, as measured by responses to a questionnaire. The findings of this study and the response of the Netherlands Health Council can be accessed at http://www.healthcouncil.nl/referentie.php?ID = 1042. The chief recommendation of this body was that the study should be repeated, perhaps with an improved wellbeing questionnaire. The UMTS (or Universal Mobile Telephony System) mode of transmission is part of the incoming 3G (third generation) system and is certainly deserving of further study.

The introduction of new communications technologies has been accompanied by the installation of subsidiary low-power transmission antennas, typically on the walls of buildings or on ceilings of rooms. These are less obtrusive,

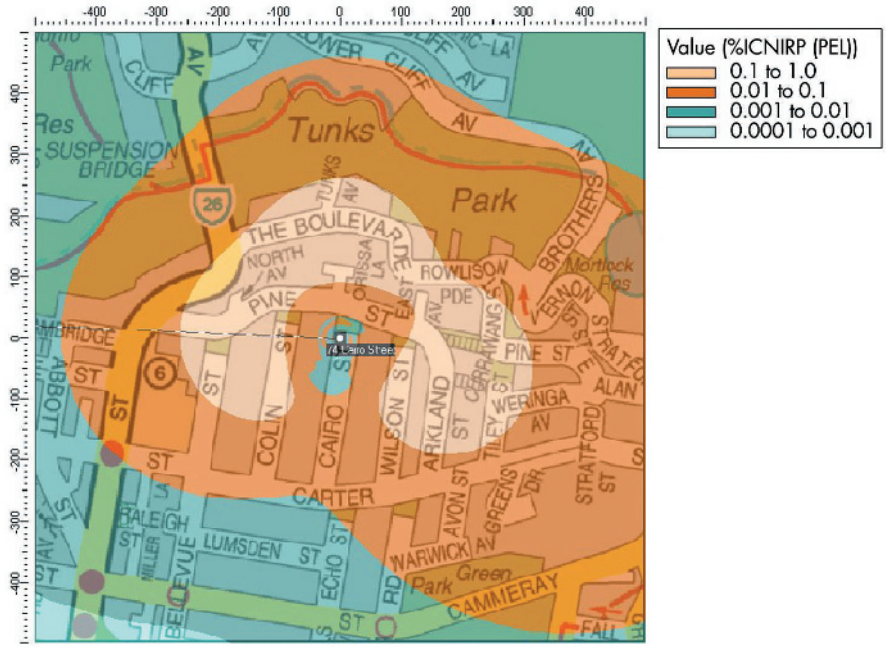

Figure 1 RF exposure levels (as a % of the ICNIRP permitted levels for general public exposure) at ground level as a function of horizontal distance from a mobile phone mast (base station). Scale is in m. Note that maximum values are obtained between 100 and 200 m from the mast. PEL, permitted exposure level. (Acknowledgement: MP Wood, Telstra Corporation, Melbourne, for the provision of this figure)

but because of the possibility of closer approach, the exposure levels to individuals may be a little higher than from the more familiar masts. Within the home, the use of wireless local area networks (wireless LANs) and cordless phones also represents sources of low-level RF exposure. It should be emphasised that all communications devices are required to comply with international RF exposure safety standards.

ELECTRICITY PYLONS

The epidemiological study carried out in Denver, Colorado, in the late 1970s[34] first raised a concern of a link between living close to electrical power transmission and distribution cabling and childhood cancer. In the intervening period over 100 epidemiological studies have been carried out in relation to EMF exposures either in the home or in the workplace and specific cancer outcomes, the most recent being a study of 9700 cases of leukaemia among children in the UK.[35] Before discussing the outcome of these studies, some brief clarifications regarding the nature of the exposure are in order.

There are two types of field associated with electrical power systems, including high voltage power lines, underground or overground distribution systems, and wiring within domestic and commercial premises. The electric field (often referred to as the E-field) varies with the voltage between conductors and the magnetic field (the B-field) varies with the current flowing in the cables. E-fields are often quite small because of the shielding effect of trees, buildings, and the ground, but B-fields are unaffected by these factors. For example, the undergrounding of high voltage cables will effectively remove the E-field, but the B-field will remain. The Denver study showed a specific association with current and not with voltage and thus B-field exposures have been the continuing concern. This study was also not specifically of high voltage transmission pylons as many of the high current configurations were of street distribution systems. The fields from a typical 400 kV transmission power line are shown in fig 2. At 50 m from the centre line of the structure the B-field values due to the line are essentially similar to those found in homes far away from a line.

Taken individually, some, but by no means all of the studies show evidence of raised cancer risk and B-field exposure. The most consistent studies are in relation to childhood leukaemia and most report an approximate doubling of risk for exposed individuals. The definition of an exposed individual is somewhat arbitrary – the entire population is exposed to power-frequency EMF to a greater or lesser extent. Many studies have used a value of 0.4 μT (which is approximately the value 50 m from the centre line shown in fig 2) as the threshold for the exposed category. Some pooling of individual studies is possible, to give the evidence greater statistical power. Recent analyses of this type[36 37] show a narrowing of the 95% confidence interval but with the risk remaining at around twofold, and thus fairly weak (table 2). The IARC in taking note of these data have assigned power frequency magnetic fields to category 2B – ''possibly carcinogenic''.

There is a possibility of this association being spurious because of methodological limitations such as selection bias, misclassification, or other factors which confound the association[38]; it is unlikely, due to the relatively large numbers in the pooled studies, that this association is due to random error. The more important question is whether the causative agent is the magnetic fields themselves, or something with which these fields are naturally associated. The lack of consistent evidence from long term animal experiments and of a credible mechanism of interaction between μT-level B-fields and cellular regulatory processes are two strong lines of evidence against causation. It is noted that there are a number of candidate interaction mechanisms for low levels of exposure, some with careful analysis of physical theory (see Brocklehurst,[39] for example), but at present, none of these reaches a level of plausibility required to gain general acceptance. Some of these candidate mechanisms involve the influence of power line fields on other agents which could in turn be leukaemogenic.[40] Apart from the question of causation is that of whether reduction of B-fields would also tend to mitigate the true causative agent. To set these issues in context, based on attributable fraction estimates, the number of extra leukaemia cases in the UK due to proximity to power lines has been put at five per year[35] (1% of cases). It is difficult, because of differing wiring conventions, to predict increases in incidence in other countries based on these data. The level of B-field exposure in the home is only partially dependent on external sources. Many internal sources such as appliances and internal wiring are important factors in determining exposure of an individual. For example, the B-field in the head due to the pulsed battery current in digital mobile phones expressed as a percentage of the ICNIRP limit can be higher than the comparable figure below a major electricity transmission line.[41]

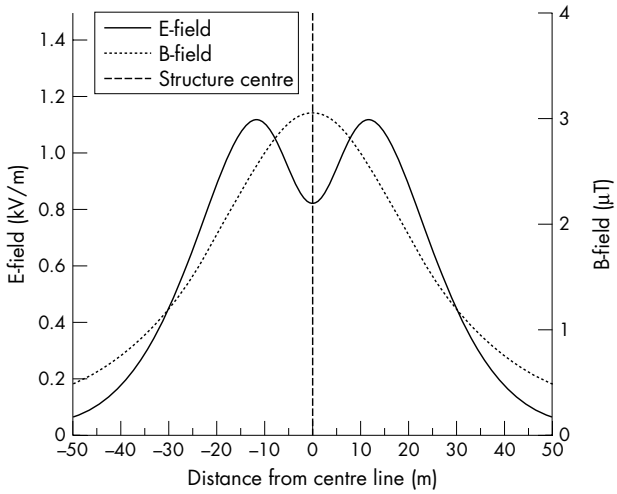

Figure 2 Electric fields (E-field; solid line, in kV/m) and magnetic fields (B-field; dotted line, in μT) at a height of 1 m as a function of horizontal distance from the centre line of a two circuit 400 kV transmission line, at lowest point of line sag.

Table 2 Combined analysis of epidemiological studies of childhood leukaemia in relation to 50/60 Hz (pylon-type) magnetic fields

Lead author	No. of studies	No. exposed cases	Cutpoint*	OR (95% CI)
Main analysis				
Greenland	12	98	0.3 μT	1.7 (1.2 to 2.3)
Ahlbom	9	44	0.4 μT	2.0 (1.3 to 3.1)
Measured fields				
Ahlbom	5	36	0.4 μT	1.9 (1.1 to 3.2)
Calculated fields				
Ahlbom	4	8	0.4 μT	2.1 (0.9 to 4.9)
Field surrogate				
Greenland	6	199	VHCC	1.5 (1.2 to 1.9)

Data are from two combined analyses carried out in the year 2000.[34 35]
*Cut point: participants are considered to be exposed and unexposed, respectively, above and below this measure. Several cut points are considered. Explanation of cutpoint measures: μT, microTesla (the time-weighted average (TWA) measured or calculated 50/60 Hz magnetic field within the home); VHCC, very high current configuration (an estimate of TWA magnetic field based on the number, distance, and thickness of nearby electrical transmission and distribution wires).

THE PRECAUTIONARY PRINCIPLE AND CAUTIONARY POLICIES

In the event of scientific uncertainty as to either the nature or origin of a risk to human health, responsible agencies may wish (in the words of the European Court of Justice's BSE judgement) ''to take protective measures without having to wait until the reality or seriousness of those risks becomes apparent''. There is on-going debate on whether any of the three sources of EMF exposure have sufficiently consistent scientific evidence of harm to actually trigger this ''precautionary principle''.[42] Nevertheless, in Australia and New Zealand, for example, safety standards have a mandatory requirement of ''…minimizing, as appropriate, RF exposure which is unnecessary or incidental to achievement of service objectives or process requirements, provided that this can be readily achieved at modest expense''.

Strictly, application of the precautionary principle as defined by the European Union involves a preliminary analysis of whether such policies are appropriately tailored to the estimated nature and magnitude of the risk, can be consistently applied, and are consistent with what is done for other risks of similar magnitude. Policies are also to follow from a cost-benefit analysis, be provisional on additional information becoming available, and should assign responsibility for how this additional information should be acquired. These elements do not appear to have been evaluated in relation to the putative risks under discussion. Current advice on mobile phone handset use by WHO for example is that ''present scientific information does not indicate the need for any special precautions for use of mobile phones. If individuals are concerned, they might choose to limit their own or their children's RF exposure by limiting the length of calls, or using ''hands-free'' devices to keep mobile phones away from the head and body'' (http://www.who.int/mediacentre/factsheets/fs193/en/). The onus is thus placed on the individual rather than on statutory authorities to take what cautionary approaches are deemed necessary. Nevertheless, phone manufacturers have responded to community concerns by making SAR values associated with handsets available, to allow this to be a factor in consumer choice.

Similarly, policies of co-locating antennas owned by several operators on a single mast and where possible, locating these masts away from schools, represents a prudent approach that the industry can and mainly does take in response to public concern. However, the emphasis in the UK at least, is to make available to the public detailed data on the type and location of masts (see http://www.sitefinder.radio.gov.uk) in order to promote effective dialog between planners, operators, and the community in decisions on where masts should be located. Although some countries have adopted precautionary limits in relation to exposure from masts, WHO cautions against the ''undermin(ing) of the science base … by incorporating arbitrary additional safety factors into the exposure limits''. Of the three forms of EMF exposure discussed here, the scientific evidence of actual harm from phone masts is perhaps the least persuasive. However, there is clearly a need for more publicly accessible information on base station characteristics and exposures. Wiedemann and Schutz[43] have recently argued that precautionary measures may, per se, ''amplify EMF related risk perceptions and trigger concerns''. Thus any cost-benefit analysis of introducing precautionary measures should also take this into account.

On the other hand, the classification of pylon magnetic fields as a category 2B carcinogen is an indication of somewhat more persuasive, but still not conclusive, evidence. Electrical utilities have, for over 15 years, factored modest additional costs into new transmission projects for field mitigation measures. A number of modifications to transmission line design can specifically reduce magnetic field exposure. In some cases, transmission systems have been routed via underground cable, although this adds considerably to project cost. There are a number of measures a concerned individual can take to reduce domestic exposures, some such as moving a bed away from localised high fields (next to a meter box, for example) involving minimal cost. It is unclear whether substantially altering wiring within homes or in offices will lead to reduced risk and indeed this type of measure could be dangerous if carried out by unqualified personnel. On the other hand, situations where relatively high magnetic field levels have resulted in TV tube-based computer screen shimmer have benefited from such mitigation measures.

PERCEIVED ELECTROMAGNETIC HYPERSENSITIVITY

There are many anecdotal reports of headaches and other less specific sensations associated with prolonged mobile phone use. Whilst it is difficult to disentangle the mechanical influences of holding a handset to the ear, many claim not to have similar symptoms from landline handsets. Most are not unduly concerned by the symptoms they claim. However, a small number of individuals report quite debilitating symptoms associated with the use of mobile phone handsets, or indeed with proximity to electrical installations or appliances in general. Despite several well-conducted, independent, provocation studies, in which sufferers have been subjected to energised and un-energised sources in random order, no association between exposure status and occurrence of symptoms has been established.[44] The Dutch study of psychological sequelae of mobile phone base station exposure (already referred to) reported that the overall baseline responses (to tests) in a group of electro-sensitive individual differed from a similarly sized group of normal subjects, but that the changes associated with mobile phone use were similar in both groups.

SUMMARY

Of these sources of EMF, the association between elevated power-frequency magnetic fields and childhood leukaemia is the only identified hazard. Causality has not been established, but if it were, estimates put the percentage of childhood leukaemia cases attributable to this factor at around 1%. Some precautions with respect to the forms of EMF emissions covered in this review are warranted, but given the enormous societal benefits of electric power and efficient communication, any such precautionary measures should take these benefits into account and also be commensurate with informed estimates of the magnitude of putative risk.

ELECTRONIC-DATABASE INFORMATION

The ''Radio Wave Surveys'' website of the UK Health Protection Agency is at http://www.nrpb.org/hpa/radio_surveys/; the ''Topical Radiation Issues'' website of the Australian Radiation Protection and Nuclear Safety Agency is at http://www.arpansa.gov.au/issues.htm; the ''TNO study on the effects of GSM and UMTS signals on well-being and cognition'' website of the Health Council of the Netherlands is at http://www.healthcouncil.nl/referentie.php?ID=1042; the ''Electromagnetic fields and public health: mobile telephones and their base stations'' website of the World Health Organization is at http://www.who.int/mediacentre/factsheets/fs193/en/; and the ''sitefinder Mobile Phone Base Station database'' website of the UK Office of Communications is at http://www.sitefinder.radio.gov.uk.

Competing interests: none declared

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