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Literature Review

Children's Sensitivity to Environmental Electromagnetic Fields

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Abstract
This review concerns children's health in relation to their typical environmental exposure at home and school to electromagnetic fields (EMFs), including radiofrequency from Wi-Fi, mobile phones and masts. It examines the extent to which children, here defined as including adolescents up to adulthood, are physiologically more sensitive to EMFs than adults, especially in the early years and while the brain is still developing myelin. It is challenging for parents, teachers and clinicians to identify the level of sensitivity to EMFs in a particular child and whether that child suffers electromagnetic hypersensitivity (EHS). There are well established short-term and long-term health hazards associated with EMF exposure. In addition, the psychological and social harms from digital addiction are becoming better recognised. Finally, children's rights and the appropriate protection of children from EMF exposure are considered. This includes the problems of the ICNIRP's thermal guidelines which are unprotective of sensitive groups like children, and the World Health Organization's arbitrary denial of physiological sensitivity to EMFs. With accurate information and appropriate long-term guidelines, parents, teachers and general practitioners can help ensure that children's EMF environments are safe and healthy.

Key words: Sensitivity; hypersensitivity; electromagnetic fields; radiofrequency; home; school.

Introduction

Children's Electromagnetic Environmental Exposure

Almost all children are now exposed to very high levels of man-made electromagnetic fields (EMFs) compared with 150 years ago. However, few children, parents, teachers or clinicians are aware of this enormous change in their EMF environment. EMF exposures cover a spectrum of frequencies. Extremely low frequencies (ELF), along with time-varying electric and magnetic fields, are associated with electricity distribution through wiring. At higher frequencies there is electromagnetic radiation, such as visible light, along with ultraviolet, infrared, microwaves, and radiofrequency (RF) radiation as used for communication in radio and TV broadcasting, mobile phone signals, smart meters, Bluetooth, Wi-Fi and LiFi.

The first widespread application of electricity was with wired telegraphs in 1837. From the late 19th century industrialised countries built electricity distribution systems and by 1913 electrical appliances were common in homes. Radio broadcasts became common by 1920. From 1981 mobile phone networks were deployed in Sweden and from 1999 Wi-Fi, laptops and Bluetooth earpieces were first used. Wireless smart meters were introduced in 2008 and wristwatches from 2013. Smart glasses and voice assistants were available from 2014. 4G mobile phones were introduced in 2009, 5G in 2019 and LiFi in 2013.

In 2015, 75% of children in Korea used wireless devices by the age of 4 years [1]. Over the past two decades children have faced unprecedented levels of RF exposure at home, school and in public places, from conception to death [2]. Average environmental RF power density levels have increased in urban areas over the last 100 years by one trillion times (1,000,000,000,000-fold) with much higher peaks, and in 2012 Wi-Fi- equipped classrooms could average 10 to 100 μW/m^2 (microwatts per metre squared) [3]. The use of electricity and wireless has been related to "diseases of civilization" [4], and in 1881 Beard named symptoms now linked to EMF sensitivity as "American nervousness" [5]. Since most children, their parents and teachers now live in high levels of man-made EMFs, few have experienced a hygienic environment without EMFs or can make health comparisons between the two environments.

Children's greater sensitivity to EMFs than adults

Since humans are essentially bioelectrical, any part of the human body, including the mind and the five senses of perception, can be affected by EMF exposure. This includes both natural EMFs, to which the human body has mainly adapted, and harmful man-made or polarised EMFs [6].

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All humans, like other life-forms, are sensitive to natural environmental EMFs. Thus brain waves are partly entrained to the frequency of the Schumann Resonance [7, 8], and the cardiovascular system can be affected by geomagnetic disturbances [9], as revealed by the analysis of hospital admissions over many decades. The first association of environmental geomagnetic changes was with biological terrestrial effects caused by the 11-year sunspot cycle [10]. It has since been observed in humans for influenza [11], and also in heart rate variability, depending on the individual's sensitivity [12], including in elderly men [13], a group especially sensitive to EMFs. Children with asthma can also be affected by solar and geomagnetic activity [14], and this may also raise the risk of an increase in births of autistic children [15], while solar maximum periods were linked with reduced life-span and some fertility [16].

Adverse symptoms of human sensitivity to man-made EMFs were first recorded by a Fellow of the Royal Society of London in 1733 [17]. In 1932 adverse symptoms were described among electricity and radio workers [18], and more fully established by 1973 [19]. The mechanism of calcium flux was discovered in the 1970s [20], causing adverse health effects [21], along with oxidative stress [22], itself confirmed through an auto-immune response in a case study [23]. Other mechanisms have also been established [24], and disrupted ion-channel gating further analysed [25], although a quantum mechanistic approach is needed for some aspects [26].

Children have greater sensitivity to EMFs compared with adults in terms of the measured peak spatial Specific Absorption Rate (psSAR) [Table 1]. In fact, psSAR is of limited use because it measures average thermal power deposited over six or thirty minutes, not the primary and more bioactive electric and magnetic fields of pulsed signals used by mobile phones and FM radio. Studies from the 1990s onwards have shown a larger in-depth penetration of SARs for models of 5- and 10-year-old children as compared with an adult. The radiation was shown extending from the side of the head, against which the mobile phone was held, for up to 40% of the width of an adult's skull, but for 80% for a 5-year-old's skull and 70% for a 10-year-old's. The same effects apply to Wi-Fi, especially laptops and iPads held on the groin or chest.

Table 1. *The greater thermal sensitivity to EMFs of children compared with adults*

Area of body		psSAR higher in children than adults	Explanation for mobile phone held beside head	Reference
Whole head	5-year-old child	Radiation extends 2 times as far	Thinner skull of child, reduced skull dimensions, higher conductivity and electrical permittivity of child brain tissue	[27,28]
	10-year-old child	60% higher		
Hippocampus, hypothalamus		30-fold	Closer proximity to the cell phone antenna	[29]
Skull bone marrow		10-fold	Child's higher conductivity and electrical permittivity, allowing greater penetration and absorption	[30]
Eyes		5-fold	Closer proximity to the cell phone antenna	[31]
Brain		2-fold	Thinner skull of child 8-15 years	[32]

Children's physiological sensitivity to EMFs is especially acute neurologically in their early years while the brain develops. The brains of the fetus, infants and children have lower levels of myelin, the fatty sheath lacking conductive free ions. Therefore, their brains have comparatively higher levels of water with greater electrical conductivity and greater RF absorption [33]; myelin continues to develop through the mid-twenties [34]. Incomplete myelin sheaths can be damaged by RF, like the axons before being protected by myelin, leading to decreased action potential speed [35]. Children also experience two- to three-fold higher RF doses in the eyes and frontal lobe when a mobile phone is used to view virtual reality [31].

For children's sensitivity to EMFs, a study of 1979 found a dose-response relationship between increased incidence of childhood leukaemia and electrical wiring configurations [36]. Children's sensitivity to RF also had an odds ratio of 2.15 for leukaemia in children living < 2 km from AM radio transmitters compared with those living > 20 km away [37], and for children with leukaemia an odds ratio of 2.1 for increased mortality for children living close to TV masts [38]. Of 24 children living near a 1062 kHz transmitter, 54% suffered noise-induced hearing loss, where the electric fields inside the houses were 0.48-2.86 V/m and power density was 1,000 – 23,000 μW/m^2 [39]. Children's greater sensitivity to RF fields than adults was shown by Gandhi in 1996 [27], by Stewart's Report in 2000 for the UK government [40], and again subsequently [41,42]. A study of 2009 found five times the risk for brain tumours for using a mobile phone before the age of 20 [43]. Leukaemia remains the childhood cancer with the highest incidence, followed by central nervous cancers and brain tumours.

Children's hypersensitivity to EMFs

All children and adults are sensitive to EMFs. However, like other environmental perceptions, some people are hypo- or hyper-sensitive, as recognised for EMFs in 1885 [44].

The term "hypersensitivity" to EMFs is used in two ways. Firstly, it can mean "more sensitive" as opposed to average or less sensitive. Secondly, as with other environmental intolerances, it can mean "extremely sensitive" to a wide range of EMF exposures, sometimes defined as an exaggerated

response to a substance which is not consciously harmful for some other people. Most of the literature uses the term EMF "hypersensitivity" interchangeably for both senses, and this is continued here [Table 2]. It relates to EMF sensitivity to visible light or "photosensitivity", one of the five fundamental senses in all except the blind, although "photosensitivity" is sometimes also used for "hypersensitivity to light".

The triggering mechanisms include acute and intense exposure with cumulative effects, probably similar to other hypersensitivity conditions, such as for chemicals which can also involve mast cell sensitisation [45]. However, there is no single pathognomonic symptom [46], as expected from quantum photonic effects on neuronal tissue.

Table 2. *Sensitivity to EMFs (non-thermal): approximate percentages (general population)*

Level of Sensitivity			Cellular Sensitivity	Conscious Short-term and Subconscious Long-term Sensitivity	Ref.
Sensitive	Hypersensitive	Extreme	√	1.2 % - 3.6 %	[47]
		Above average	√	1.2 % - 29 %	
	Sensitive	Average	√	50 %	
	Hyposensitive	Below average	√	21 %	

Human hypersensitivity to EMFs was probably first recorded in 1746 for Professor Johann Doppelmayr of Nuremberg whose terrible suffering from electrical experiments led to him being named the first "Martyr of Electricity" [48]. It was again noted in 1750, when repeated electrical shocks for several weeks weakened Benjamin Wilson so much "that a very small quantity of electric matter" would cause uncommon pain [49].

Sensitivity to EMFs is often difficult to diagnose as the cause of adverse symptoms among adults, and much more so among children. One physician with 25 years' experience spent nine months researching before diagnosing hypersensitivity to EMFs [50]. Three out of the four cases in another study showed that it took from 3 to 17 years to identify EMF exposure as a cause of symptoms [51]. A former TV producer took 14 years to discover that the cause of her symptoms were EMFs [52]. A survey of 34 adults in the UK with electromagnetic hypersensitivity (EHS) showed that 7 (21%) were graduates of Oxford or Cambridge universities, an unusually high proportion given that these graduates form under 1% of the UK's adult population, implying the difficulty of identifying the cause of symptoms [46].

However, for some adults the onset of hypersensitivity to EMF is clearly caused by a sudden and unexpected acute exposure. Examples include exposure to RF transmitters [53], EHS symptoms after 2 hours' work in front of six active 1900 MHz transmitters (Case RG) or contact with a live wire (Case JJ) [54], or long-term occupational exposures by electrical and radio workers [18].

For children, as with adults, the onset of hypersensitivity can also be caused by the sudden introduction of RF exposures. Convincing examples include the installation of (a) wireless smart meters, and (b) 5G antennas.

(a) In a survey of 92 subjects reporting EHS symptoms from the installation of wireless smart meters at their homes or their neighbours', five (5%) were children. Their five most common symptoms were insomnia, headaches, tinnitus, lethargy and cognitive disturbance [55].

(b) Seven case studies cataloguing EHS symptoms in previously healthy people after the installation of 5G antennas near to their homes or places of work showed that the symptoms abated when those affected moved away [56]. Three children, aged 4, 6 and 8 years, who spent three nights in a cottage near a mast with three 5G antennas, had sleeping problems, like the two accompanying adults. However, the children also became emotional and irritable, with two experiencing involuntary diarrhoea and abdominal pains, while one had skin rashes [57]. In a family of three exposed to two 5G antennas 70 m away, the daughter aged 19 years had the most severe health issues. These included sleeping problems, headache, concentration and memory problems, skin disorders, irregular heartbeat, photosensitivity, involuntary diarrhoea, anxiety and panic attacks [58].

Diagnosing electromagnetic hypersensitivity (EHS) in children is even more challenging than for adults for at least three reasons, as discussed below: (a) Insufficient knowledge of EMF sources and symptoms; (b) Insufficient remission time in EMF-free areas for a difference in symptom pattern; (c) Insufficient use of genetic tests and other biomarkers.

Insufficient Knowledge of EMF Sources and Symptoms

Few parents, teachers or doctors have sufficient knowledge of both the EMF sources and their symptoms for diagnosing EHS in children. In Case 1 in a study from Sweden it took 10 years for physicians and therapists to establish that the child had EHS [59]. In the UK, the father of a nine-year-old pupil, who suffered from headaches, extreme tiredness, and rashes on her legs, noted the worst occurrences were on the afternoon when the class used laptop computers. This enabled him and their general practitioner to diagnose the cause as the Wi-Fi router next to which the child was sitting in the classroom and the symptoms stopped when the child was removed from this environment [60]. In Case History # 3 in a study from Canada, it took three years to identify the cause of a 14-year-old boy's depressive and aggressive symptoms as the electrical wiring supply next to his bed [51]. For a baby and small child, it took a university researcher to link their skin rashes and one later case of absence seizure with visiting or living near over-head power lines [61].

Sadly, some children have died as a result ignorance or misinformation about sensitivity to EMFs. One 13-year-old

died of leukaemia after sleeping for three years next to an electricity meter, despite complaining of "pressure in the head" within six months of moving to the house [62]. This followed a study of 232 children for whom the odds ratio for the risk of leukaemia was 2.15 close to certain wiring configurations, compared with controls [63]. Over-head power cables were linked with brain tumours in 14- and 15-year-old children in legal cases against the electricity provider in 1994 [64]. A 15-year-old pupil in the UK, who was highly allergic to EMFs from Wi-Fi, committed suicide in 2015 after the headteacher of her school which deployed Wi-Fi refused to read scientific information on the effects of its EM radiation, instead mistakenly claiming that it was "safe" [65].

Few general physicians know much about the effects of environmental EMFs or have received appropriate training. Some 54% of doctors in Switzerland accepted that EMF exposure could cause ill health [66], but in Germany only 8% had taken part in EMF training [67]. However, German physicians recommended protective measures in 46% of 253 consultations, advocating the removal of electrical devices or moving to a different apartment or town. In France, 79% of 600 physicians accepted that living near power lines or regularly using a mobile phone or Wi-Fi increased the risk of illness [68].

Insufficient Remission Time in EMF-Free areas for a Difference in Symptom Pattern

If the cause of EHS is Wi-Fi or similar exposures at both home and school, a child suffering EHS may rarely be long enough in remission, free of the EMFs, for the child or parents to notice any significant difference in symptoms. However, one case study of a boy aged 8 years used remission to diagnose EHS. He developed severe headache, some fatigue and dizziness at school after the installation of a 5G mast close to the school, but was generally symptom-free at his home which had considerably lower EMF levels [69].

In comparison, it can be easier for a teacher, whose EHS has been caused by a school's installation of Wi-Fi in the classroom, to spend time away from the Wi-Fi in the classroom and thus realise the difference in symptoms This was true in Case 3 from Sweden [59] of a teacher who "recovered and felt well again" during a week's sick-leave, and for a teacher in the UK who "felt completely normal" over the weekend away from the classroom [70]. Another teacher, Dr Andrew Tresidder's Case Study 2 [71], became so ill with EHS that she had to resign from her work, only subsequently discovering that the cause was the school's Wi-Fi after she experienced the remission of symptoms in areas free from Wi-Fi.

It is also challenging for teachers to identify children hypersensitive to EMFs, although one secondary school teacher linked the cognitive agitation of an able pupil who suddenly called out "I can't think" to a mobile phone switched on at the back of the classroom unseen by the pupil. In another case, during an outdoors sports session, he noted that about 15% of two teams of teenagers suddenly became ill at the same time and were unable to continue playing in a match. The game was on a sports pitch located near the top of a hill. He subsequently linked these adverse symptoms, which he too experienced but to a milder extent, with numerous mobile phones simultaneously activated about 900m away in one direction, while the nearest mast was about 500m away from the sports pitch in the opposite direction, leaving the pupils and teacher in the middle, caught by the radiation. A similar case occurred in a primary school where each year children in a particular classroom suffered more nosebleeds than usual, and surveys with meters later revealed a narrow beam of radiation through that classroom from a distant mast. In another case, secondary school pupils sitting in one row of seats were more likely than others to suffer nosebleeds; a power cable was later discovered under the floor along the line of these desks. Other cases are individual, with one teenager, unable to sleep, eagerly reporting the following day that he had slept exceptionally well after following advice to switch off his mobile phone which he kept under his pillow.

Insufficient use of Genetic Tests and Other Biomarkers for Children's EHS

Genetic tests and other biomarkers are rarely used to help confirm a child's hypersensitivity. The genetic variants (null) GSTT1 + (null)GSTM1 are nearly ten times more prevalent in EHS people than others [72]. Similarly, DNA repair genes with diminished repair capacity, such as the XRCC1 Ex9+16A allele, were possibly associated with childhood leukaemia near electric transformers and power lines [73]. The primary sensor Piezo1 can affect myelin repair [74], while demyelination, sometimes a result of RF exposure [75, 76], has also been associated with EHS. Reduced myelin applies to children, from fetus through to the mid-20s years, as explained above [34,] and also the elderly.

Other tests to support diagnoses of EHS in adults may also be rarer for children. These include scans, such as MRI to show brain damage [77], and ultrasonic cerebral tomosphygmography to show compromised brain blood flow [78, 79]. However, despite a wide range of indicators there is no single biomarker [80], as expected for the transient impact of photons on a bioelectrical body.

Short-term conscious health effects

Most short-term adverse symptoms caused by EMF exposures have been known for over 200 years, as evident from symptoms in the 18th century [81] compared with those in the 21st century [82]. Among highly exposed people, the younger aged under 40 years reported more inflammation than the older. The symptoms of anxiety, headache, and impaired concentration, memory and problem-solving related to the level, not the duration, of exposure [83].

A survey specifically on children involved 357 controls living elsewhere and 609 aged 9-18 within 20 km of the Skrunda radio location station. For residential locations at 3.7 km the mean exposure was 3,205 $\mu W/m^2$. The reaction time to sound and visual stimuli was longer for the Skrunda group than controls, especially aged 9-13 years. For the Skrunda

group subdivided into exposed and unexposed, memory and attention were considerably less for the exposed group living in front of the transmitters, along with decreased neuromuscular endurance, and with delayed reactions in girls but not boys [84]. In other studies, ten-year-old boys living in areas with higher RF exposure showed lower verbal scores and higher internalizing and total problems [85], while longer duration of mobile phone calling (>40 min/week) had higher concurrent total behavioural problems [86]. Children aged 5 exposed to higher RF-EMF levels from mobile phone base stations showed a higher risk of 1.82 for emotional symptoms [87]. For 293 school children in Poland aged 7 years, higher levels of RF-EMF were associated with mental health difficulties and emotional problems [88]. Higher smartphone use was linked to shorter sleep duration and increased sleep disturbances in 292 Swiss adolescents aged 11-15 [89].

Cognition and memory are also affected by EMFs. For 217 boys aged 13-16 at two schools near masts with different exposure levels of similar radiation, those at the more exposed school had impaired motor skills and spatial working memory compared with the less exposed school [90]. Memory problems among Swedish children increased nearly 60 times between 2006 and 2024 and nearly tripled between 2019 and 2024 in Norwegian children aged 5-14 years. Since 2019 5G with its high exposure levels was deployed [91].

Long-term subconscious health effects

The long-term effects of EMFs are relevant to children who may be exposed to high levels of EMFs for all their lives. Long-term effects including cancers and neurological harm can also be linked to conscious short-term symptoms for some EHS people with specific sensitivities. Long-term non-thermal EMF effects have been known since 1948 when microwave irradiation caused testicular degeneration [92]. In 1953 a doctor's survey of radar workers found, in addition to short-term headaches, long-term brain tumours, leukaemia and internal bleeding [93]. In 2002 and 2011 the IARC classified EMFs as class 2B possible carcinogens. A recent review found high certainty of evidence that RF causes cancer [94], and experts now state that there is enough evidence to reclassify RF as a class 1 known carcinogen, the highest category [95]. RF transmitters can cause both short-term and also long-term symptoms, such as an increased incidence in childhood leukaemia [96] and increased leukaemia, brain, bladder, male breast and skin cancers within 2 km [97], while the risk of cancer was three times higher near a mast [98], and the risk for women over ten times higher [99].

A special concern for long-term symptoms in children is prenatal and postnatal exposure where both were associated with behavioural difficulties such as emotional and hyperactivity problems in 13,159 children around the age of school entry [100]. Other studies have proposed a pathophysiological link between EMF exposure and autism through oxidative stress and other mechanisms [101, 102]. In addition, pre- and post-natal exposures have been linked with children's headaches [103], cognition [104], and DNA damage has been found close to masts [105], as has unrepairable chromosomal aberrations [106].

Long-term EMF exposure at home and school is also relevant to specific children genetically susceptible to particularly long-term EMF damage. Thus children with genetic traits linked with thyroid cancer should avoid RF [107], as should those with disrupted CACNA1C gene expression perturbing l-type voltage-gated calcium channels [108], leading to increased anxiety [109]. Girls with hereditary breast cancer predispositions are recommended sunglasses to block blue light from digital screens [110], and older boys with a genetic disposition to infertility should avoid Wi-Fi and mobile phones [111], while, pupils with unfavourable toxicokinetic variations in antioxidant genes linked with chemical sensitivity, long associated with electrical sensitivity, should be removed from EMF environments like Wi-Fi [112]. Other studies link EMF exposure with neuron impairment [113], and kidney diseases [114], while all may be susceptible to Wi-Fi effects on the fibrous elements of the large vessel wall leading to cardiovascular disorders [115].

Adverse psychological effects from wireless addiction

The psychological distress arising from digital and wireless addiction [116] is becoming more widely recognised [117]. Two results of RF are anxiety and depression [118]. These emotional problems can be related to alexithymia, the inability to recognise, understand or describe emotions [119]. Girls were more affected than boys by depression through social media use and suffered poor sleep [120], both features of the effects of the RF radiation itself. High levels of smart phone use were associated with reduced short-term memory and reduced spirituality [121]. Another study found headache as the prime effect, along with tinnitus and depression [122].

Since anxiety, depression, disturbed sleep and headaches, key elements of wireless addiction, are all established RF-EMF effects, it is possible that they are less results of psychological addiction than physiological RF-EMF exposure. Studies are needed to assess how far the two causes overlap.

Children's rights against involuntary EMF exposure

At present, almost all children's man-made EMF exposure is partly or wholly involuntary. This presents ethical as well as health challenges, given the evidence for adverse effects. Some experts have likened it to an experiment without informed consent in contravention of the Nuremberg Code [123], since any testing of humans with a classified carcinogen like EMFs is unethical and 5G radiation was deployed in areas with children without full prior safety testing.

Although a school's EMF environment is the responsibility of the head teacher as regards Wi-Fi and mobile phones, external sources such as masts depend on the local planning authority. In the year 2000 the UK's Stewart's Report advised that schools should be consulted over masts where the main

beam fell on their premises [40]. The Report recognised that children will be exposed to EMFs for their lifetime, that their nervous systems are developing, and that their moisture content and thus conductivity and their energy absorption are higher than an adult's. Therefore, the UK applied the precautionary principle in its recommendation of 2004 [124], followed by Chief Medical Officers' advice in 2011 that children under 16 "should be encouraged to use mobile phones for essential purposes only, and to keep calls short" [125].

Likewise at home parents have only partial control of children's EMF exposures. They can use wired ethernet connections in place of Wi-Fi, but are usually powerless to prevent nearby masts, neighbours' Wi-Fi and mobile phone use, or wireless smart meters, all of which can impact their children's health. Even if the parents move home to protect a child who is hypersensitive to EMFs, there is no guarantee under present laws that the new accommodation will remain EMF-free. Similarly, some countries prohibit new buildings near overhead cables, but others do not and do not apply the precautionary principle. One commentator claimed that to remove all buildings within 300 m to reduce magnetic fields near overhead power lines to under 0.1 μT "is simply unaffordable" [126], although safety outweighs cost in air and car travel, and in the removal of tobacco smoke, asbestos and lead in petrol. Insurance risks are also challenging [127], since most underwriters from the 1990s onwards have refused to cover EMFs [128] except as high risk like asbestos.

The International Declaration on the Human Rights of Children in the Digital Age was promulgated in 2023. One of the three rights it promotes is that children should not be exposed to harmful wireless radiation [129]. Some countries have already banned Wi-Fi in nurseries and elementary schools.

The dangers of adverse health, social and psychological effects have led to many bans on children's use of mobile phones in schools. In Europe they are banned as in 2025 in France, Greece, Italy, Luxembourg and parts of Switzerland, and many schools in the UK, while Denmark is developing a law and Belgium and the Netherlands advise against them.

A few individual pupils and teachers who are hypersensitive have won legal cases or been helped practically in several countries and had Wi-Fi and mobile phone radiation removed from their school environment. Most countries have health & safety, equality, safeguarding, duty of care and precautionary legislation, which require accommodations. Sometimes EHS is specified as requiring assistance, as in the US. Some adults have received compensation for injuries from mobile phone radiation, or been granted ill-health early-retirement pension rights, or phone masts have had to be removed. People with EHS or with implants have been classified by some legal systems as interested parties in the siting of masts, because of their need for protection.

Protecting children from man-made EMF exposure

To protect children from adverse effects of EMF it is first necessary to determine the lowest known threshold of harm, the "No observed adverse effect level" (NOAEL). This must then be reduced, where relevant, to allow for interspecies and intraspecies differences and the higher sensitivity of groups such as children [Table 3]. In addition, extra reduction may be necessary for extreme individual sensitivity, unusual toxic synergies or existing health conditions. Some experts state that, as for stochastic risks like X-rays, there is no safety threshold for man-made EMFs. The human body has already adapted to natural low levels such as the eye reacting to a single photon of visible light or two infrared photons, and living cells emitting low levels of biophotons to aid communication and homeostasis.

Children's higher sensitivity requires greater protection than healthy adults, as also for the elderly and ill, pregnant women and hypersensitive persons. Protection includes long-term and non-thermal effects along with modulated exposures, such as the dangers of Wi-Fi [130]. Selye proposed his general adaptation syndrome in 1950, with its triphasic responses of alarm, resistance and exhaustion [131]. After years of cumulative exposure, many children could react with mitochondrial resistance to, or exhaustion from, the oxidative stress of environmental EMFs, as with asthma and neurodevelopment [132].

A problem for children's EMF protection is that many

Table 3. *No observed adverse effect level (NOAEL), safety and sensitivity reductions, RF EMF. (a) Non-thermal, long-term, modulated. (b) Thermal, short-term, unmodulated*

Human, Animal	Harm	No observed adverse effect level (NOAEL)	Safety reductions (or thermal increases)	Sensitivity reductions	Ref.
(a) Non-thermal, long-term, modulated					
mice, rats	cardiomyopathy, neoplasms	0.2-0.4 W/kg	2 x 10-fold reductions: interspecies and intraspecies. whole body, adults: 0.002-0.004 W/kg	10-fold reduction children: 0.0002-0.0004 W/kg	[133]
humans	brain effects: beta 2	0.003 W/kg	*[2 x 10-fold safety reductions: 0.00003 W/kg]*	*[10-fold sensitivity: 0.000003 W/kg]*	[134]
humans, animals	median, 165 results SAR	< 0.0165 W/kg	10-fold reduction: 0.00165 W/kg		[135]
humans	adverse health effects	500 μW/m^2	*[2 x 10-fold safety reductions: 5 μW/m^2]*	[10-fold sensitivity: 0.5 μW/m^2]	[136] [137]
(b) Thermal, short-term, unmodulated					

Table 3. *No observed adverse effect level (NOAEL), safety and sensitivity reductions, RF EMF. (a) Non-thermal, long-term, modulated. (b) Thermal, short-term, unmodulated*

rats	altered brain cholinergic activity	0.6 W/kg (2.45 GHz)	*[not used for ICNIRP's thermal guidelines]*		[138]
8 male rats	1^0 increase in temperature and disrupted behaviour	2.5 W/kg (1.28 GHz) 4.9 W/kg (1.28 GHz)	*[used for ICNIRP's thermal guidelines]*		[139]
5 male monkeys		81,000,000 μW/m^2 (225 MHz) 570,000,000 μW m^2 (1.3 GHz) 720,000,000 μW/m^2 (2.45 GHz)	*[used for ICNIRP's thermal guidelines]*		[140] [141]
ICNIRP formally recognized by WHO: thermal limits	100 kHz – 300 GHz	core: 4 W/kg	core (whole body average): 0.08 W/kg aver. over 10g, 30 min	"children ... might have a lower tolerance .. than the rest of the population ... it may be useful to develop separate guideline levels ... some guidelines may still not provide adequate protection for certain sensitive individuals"	[142] [143]
	100 kHz – 6 GHz:	head and torso: 20 W/kg limbs: 40 W/kg	head and torso: 2 W/kg averaged over 10g, 6 min limbs: 4 W/kg averaged over 10g, 6 min		
	6 – 300 GHz	head and torso: 200,000,000 μW/m^2	head and torso: 20,000,000 μW/m^2 averaged over 4 cm^2, 6 min		
	30 – 300 GHz	limbs: 400,000,000 μW/m^2	limbs: 40,000,000 μW/m^2 averaged over 1 cm^2, 6 min		

western countries still use ICNIRP's unprotective guidelines. As the table illustrates, these were based on studies limited to thermal, short-term effects, with unmodulated exposures. They derived from animal studies in the 1970s and 1980s, determined by the core temperature rise of 1^0 associated with disrupted behaviour in finding food. The threshold was given as 4 Watts per kilogram (W/kg), with guidelines reduced by 50 to 0.08 W/kg, but with 2 W/kg allowed for the head and torso, and 4 W/kg for the limbs. Thermal guidelines are "fundamentally flawed", unlike DNA stress responses [144]. Guidelines based on non-thermal or long-term health effects derive from a threshold in the range of 0.003 W/kg to 0.0165 W/kg, giving a safety level for children in the range of 0.000003 W/kg, or 0.0002 W/kg based only on animal studies.

Since the ICNIRP guidelines do not protect children, they are inappropriate for locations like homes and schools where children spend long periods of time. Instead, non-thermal, long-term, guidelines are needed, such as Bioinitiative, EUROPAEM or IGNIR. Most classify children as sensitive, in comparison with adults. Some also define exposure levels by duration or sleeping or working areas, or by modulation and frequency [Table 4]. The electric field, in Volts per metre (V/m), is more appropriate for assessing health harm from EMF environments than the heating metrics, such as specific absorption rate (W/kg), or power density (μW/m^2).

To assess children's EMF environment, parents, head teachers and general practitioners need EMF meters. They are easy to use and quickly indicate problems. Although conscious reactions are very variable and influenced by innumerable biophysical factors, hypersensitive people often experience adverse health above 0.05 V/m, as supported by some ecological studies. Mobile phones can receive at < 0.02 V/m, although replacing them with a wired system would be much better for children's health. If 0.05 V/m is used as the NOAEL for RF-EMF, a safety factor of 10-fold gives a limit of 0.005 V/m (0.06 μW/m^2) [145].

Some 1.2 % – 29 % of all children are likely to be hypersensitive to EMFs, with 1.2 % – 3.6 % extremely sensitive, as explained above. This also applies to parents and teachers. This sensitivity is an issue of growing concern. The statement on EHS by the International Commission on Biological Effects of Electromagnetic Fields (ICBE-EMF) describes it as a "humanitarian crisis" requiring an urgent response. This is particularly relevant to sensitive children in schools: "Many of these exposures are involuntary and now inescapable. Common outcomes of this are job, school and home loss, separation from family and friends, inability to access medical care and general lack of access to all areas of the public domain. The unmitigated, neglected widespread disruption of lives is inhumane and deeply troubling." [146]

An important document relating to children with EHS is the Scientific Consensus International Report on EHS by thirty-two worldwide experts, published in 2021 [147]. This confirmed that EHS is a distinct neuropathological condition and not the different condition, a psychological nocebo response [148]. The latter is obviously irrelevant to most younger children hypersensitive to EMFs. They have

Table 4. *RF-EMF guidelines specifically including children: Non-thermal, long-term, modulated.*

<table>
<tr><th>Guidelines</th><th>Children, Sensitive</th><th>Electric Field V/m</th><th>Power Density μW/m^2</th><th>Notes</th><th>Ref.</th></tr>
<tr><td rowspan="2">BioInitiative</td><td>children</td><td>0.03 V/m</td><td>3 μW/m^2</td><td rowspan="2">For chronic exposure to pulsed RF</td><td rowspan="2">[149]</td></tr>
<tr><td>adults</td><td>0.05 V/m</td><td>6 μW/m^2</td></tr>
<tr><td rowspan="5">EUROPAEM
> 4 hours</td><td rowspan="4">children, sensitive</td><td>0.006 V/m</td><td>0.1 μW/m^2</td><td>GPRS (2.5G) with PTCCH (8.33 Hz pulsing),
DAB+ (10.4 Hz pulsing),
Wi-Fi 2.4/5.6 GHz (10 Hz pulsing)</td><td rowspan="5">[150]</td></tr>
<tr><td>0.02 V/m</td><td>1 μW/m^2</td><td>GSM (2G) 900/1,800 MHz, DECT (cordless phone), UMTS (3G), LTE (4G)</td></tr>
<tr><td>0.06 V/m</td><td>10 μW/m^2</td><td>TETRA, DVBT</td></tr>
<tr><td>0.19 V/m</td><td>100 μW/m^2</td><td>Radio broadcast (FM)</td></tr>
<tr><td>non-sensitive</td><td></td><td></td><td>Night: 10 x sensitive
Day: 100 x sensitive</td></tr>
<tr><td rowspan="3">IGNIR</td><td>children, sensitive</td><td>< 0.02 V/m</td><td>< 1 μW/m^2</td><td>Average: 0.006 to < 0.001 V/m; 0.1 μW/m^2</td><td rowspan="3">[151]</td></tr>
<tr><td rowspan="2">non-sensitive</td><td>< 0.06 V/m</td><td>< 10 μW/m^2</td><td>Night. Average: 0.02 V/m, 1 μW/m^2</td></tr>
<tr><td>< 0.19 V/m</td><td><100 μW/m^2</td><td>Day. Average: 0.06 V/m, < 10 μW/m^2</td></tr>
</table>

not experienced prior cognitive conditioning necessary for a psychological response. This is also true for many unaware adults who become EHS before discovering its cause.

Nevertheless, some children especially sensitive to EMFs fail to receive the help they need in the removal of the EMFs causing their ill health. One reason is the misleading and illogical confusion between the two different conditions of electromagnetic hypersensitivity (EHS), known since 1746, and "electrophobia", known since 1903. This confusion was introduced arbitrarily in 2004 without any proof by the United Nations' agency, the World Health Organization (WHO). Similarly, in 1972 the WHO arbitrarily rejected without any proof the non-thermal effects on the nervous system already established by expert scientists in California and elsewhere in the US, and in the USSR and other European and eastern countries [152]. The ICNIRP, formally recognized by the WHO, still publishes thermal and short-term guidelines which are unprotective for children. These "captured" agencies [153] are aligned with the military-industrial complex [154], effectively promoting a "conspiracy" to invalidly deny non-thermal effects like EHS [155]. In contrast to the problems with the WHO [156] and to bias in studies sponsored by governments and industries [157], the independent viewpoint, represented by the International Commission on the Biological Effects of Electromagnetic Fields (ICBE-EMF), supports the Scientific Consensus International Report in accepting the reality of EHS rather than the false suppositions and erroneous assumptions behind the short-term thermal myth and psychological hypothesis [158]. "National and international bodies, particularly the WHO, will bear major responsibility for failing to provide specific science-based guidance" to protect children [159]. In fact, a court in Italy rejected evidence supplied by the ICNIRP and similar groups with conflicts of interest and instead preferred independent experts [160], and the ICNIRP'S 2020 Guidelines can be seen as failing on "fundamental scientific quality requirements", rendering them unprotective of children's health [161].

The safeguarding of children's health requires a different theoretical basis from the socio-economic argument behind thermal limits, where often legal action is necessary for the removal of, or compensation for, EMF harm [162]. For children, like many adults, who have no power to control their physical environment, any socio-economic benefits of the military-industrial complex are irrelevant if their health is harmed in the short or long term. Children's health should not be harmed through unsafe economic exploitation, if the WHO's definition of health is followed as "a state of complete physical, mental, and social well-being, and not merely the absence of disease or infirmity" [163].

Conclusion

All children are more sensitive than adults to the EMFs in their environment and need greater protection at home and school from short-term and long-term effects. Children who are hypersensitive to EMFs need particular protection, and all children need protection from being exposed so much that they become hypersensitive. Parents and teachers need to provide children with an environment which has safe levels of EMFs below the threshold for adverse health. However, many parents and teachers lack the necessary information, since "the media, the responsible organizations (World Health Organization) and the governments are not transmitting this crucial information to the population, who remain uninformed." [164] The greater information and appropriate actions outlined above and elsewhere [165] show how children's health can be protected, and how their electromagnetic environment can be made safe.

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Conflicts of Interest:

The author declares no conflict of interest.

Abbreviations

EHS	Electromagnetic Hypersensitivity
ELF	Extremely low frequency
EMF	Electromagnetic Field
EUROPAEM	European Academy for Clinical Environmental Medicine
GHz	gigahertz frequency
Hz	Hertz (frequency, number of cycles per second)
IARC	International Agency for Research on Cancer
ICBE-EMF	International Commission on Biological Effects of Electromagnetic Fields
ICNIRP	International Commission on Non-Ionizing Radiation Protection
IGNIR	International Guidelines on Non-Ionising Radiation
kHz	kilohertz frequency
MHz	megahertz frequency
MRI	Magnetic resonance imaging
ms	milliseconds
μT	microTesla (magnetic flux density)
μW/m^2	MicroWatts per metre squared (power density, for Radiofrequency)
NOAEL	No observed adverse effect level
psSAR	peak spatial Specific Absorption Rate
RF	Radiofrequency
SAR	Specific Absorption Rate
V/m	Volts per metre (electric field)
WHO	World Health Organization
W/kg	Watts per kilogram (the rate at which RF energy is absorbed, as in SAR)

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