ISSN 2347-3487

EFFECT OF MAGNETIC FIELD FROM MOBILE PHONE ON CENTRAL NERVOUS SYSTEM

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ABSTRACT

Devices such as mobile phones, wireless internet modems, and radios and televisions, which occupy an important place in social life, produce electromagnetic fields (EMFs). Widespread use of these devices in daily life increases the intensity of exposure to EMFs on a day to day basis. Investigation of the effects on health of devices such as mobile phones used in close proximity to the body is attracting considerable interest from scientists. Mobile phones manufactured using the latest technology operate in a high frequency range (300–3000 MHz). This further heightens concerns regarding the effect of mobile phones on human health. Most Global System for Mobile Communications (GSM) operators in Europe, Asia, and Africa use a frequency of 900 MHz. With the rapid development of electronic information and communication techniques, exposure to electromagnetic fields (EMFs) has increased dramatically. Some studies have focused on the biological effects of electromagnetic radiation. Microwave radiation has been reported as producing adverse effects in the central nervous system (CNS), including headache, sleep disorders, anxiety, cognitive dysfunction and neurogenesis impairment in both humans and animals. However, the direct effects of microwave radiation on neurodevelopment and the underlying mechanisms for any such effects remain unknown. As per today's global scenario use of mobile phone is increasing day by day for communication. Due to its constant use, the electromagnetic radiation (EMR) emitted from the cell phone, base station and other household appliances cause adverse effects on human health. There is an increase concern about the interaction of EMR generated from mobile phones, with the human organs specially with brain because of its close and long proximity to human brain during the mobile usage. Concerns have shown whether these exposures could have effect on brain and central nervous system (CNS).

Indexing terms/Keywords

Magnetic field, Phone mobile, Health effects, Central Nervous system.

Council for Innovative Research
Peer Review Research Publishing System
Journal: JOURNAL OF ADVANCES IN PHYSICS
Vol.8, No.3
www.cirjap.com, japeditor@gmail.com

ISSN 2347-3487

INTRODUCTION

Some epidemiological investigations have shown that women and children, especially pregnant women and fetuses, are particularly sensitive to EMF exposure [1-3] and neurobehavioral disorders are increasingly prevalent in children [4]. In the developing nervous system, the brain tissue is more conductive than that of adults because it has a higher water content and a higher ion concentration, and young children have greater absorption of microwave frequency energy in the tissue of the head [5]. Therefore, the central nervous system (CNS) of the fetus is considered to be potentially susceptible. Even low doses of microwave exposures during fetal life would have a more profound and long-lasting effect than exposure as an adult. Thus, exposure to microwave radiation in utero may have a neuron developmentally toxic effect on the fetus. This situation has caused concern about a possible association between prenatal radiation exposure and cognitive dysfunction in children. Mice exposed in utero to 800-1900 MHz rated cellular telephone radiation (specific absorption rate (SAR) = 1.6 W/kg) were reported to have impaired memory and decreased anxiety, which may have been caused by altered neuronal developmental programming [3]. In addition, extremely low frequency magnetic radiation (ELF-MF) had significant effects on basic neuronal functions and synaptic plasticity in brain slice preparations of rats exposed either in the fetal or in the newborn period [2]. Thus, the studies have demonstrated that prenatal EMF exposure will induce behavior and neurodevelopmental injury in offspring; however, gender-specific effects have not been reported [6].

Some of study [7], showed that the adult human head absorbs approximately 80% of the radiation emitted by from the mobile [8]. Another study have reported contradictory results regarding effects of electromagnetic fields (EMF) of mobile phone on the nervous system. Many studies have showed that EMF emitted from mobile phone might affect brain activity; including sleep [9] attention [10] learning and memory [11] and cognitive performance[12] It has been suggested that the CNS harm from mobile phone might derive from the proven ability of EMF such as those from mobile phone to modify electrophysiological activity in human brain [13] and to alter neurotransmission [14]. Many preclinical evidence of oxidative damage was reported in the brain tissues when rats were exposed to radiation [15]. It has been concluded that EMF like the ones emitted from mobile phones influence normal brain and CNS physiology [16].

Several recently published studies suggest a potential link between occupational exposure to extremely low frequency (ELF) electromagnetic field (EMF) and neurodegenerative disease. In three studies, death from amyotrophic lateral sclerosis (ALS) was positively associated with occupational exposure to EMF, with relative risks ranging from 2 to 5 [17]. Some investigators have suggested that Alzheimer disease [18] and Parkinson disease may be induced by occupational exposure to EMF. Another disease possibly related to such exposure is multiple sclerosis; however, in a previous study we observed only a slightly increased risk among 31,990 employees of Danish utility companies [19]. These results indicate that exposure to EMF or to some other characteristic of electric cur-rent, such as electric shocks, may cause neuronal degeneration and subsequently various chronic neurological diseases. The observation in experimental animals of accelerated demyelination and neuronal death after exposure to electric shocks [20], suggest that repeated electric contusions may cause chronic neurological diseases. To the best of our knowledge, no other exposure experienced by utility workers has been associated with these diseases. Reporting of neurodegenerative diseases and other central nervous system (CNS) diseases as causes of death on death certificates is an imperfect reflection of the occurrence of the disease, and the quality of diagnosis of such conditions is severely limited [21]. To address further the hypothesis of an association between exposure to EMF and CNS diseases, we analyzed data from the same nationwide cohort of men and women employed in Danish utility companies that had previously been followed up for multiple sclerosis [19], mortality [17], and cancer incidence [22]. It assessed the incidences of a number of CNS diseases by data linkage to the nationwide, population based Danish National Register of Patients and compared the rates with the corresponding rates of these diseases in the general population. It also fit a multiplicative Poisson model to the data on utility workers, including duration of employment, age, calendar period, and estimated average level of exposure to EMF at work [23].

A cohort study found no indication of an increased mortality from motor neuron disease related to employment in electronic work [24]. The U.S. National Longitudinal Mortality Survey with 300,000 people followed up from the early 1980's was analyzed. Exposure assessment relied on job titles at baseline, with further classification based on a previously constructed job-exposure matrix. Causes of death were obtained from the National Death Index. Information on several potential confounders including race/ethnicity, education and income was available. Despite the large cohort size, only 40 deaths from motor neuron disease occurred during an average of 8.8 years of follow up. The crude hazard ratio was somewhat above unity, but after adjustment it indicated no excess among the quartile of population with the highest potential for ELF exposure. No gradient across exposure strata was found. The study was limited by the relatively crude exposure assessment, and low statistical power due to small number of events. A Danish registry-based case-control showed no association between residential exposure to power lines and risk of Alzheimer or Parkinson disease [25]. The cases (nearly 2000 with motor neuron disease, 8000 with multiple sclerosis, 16,000 with Parkinson disease and 20,000 with Alzheimer) were identified from the nationwide hospital discharge registry and matched controls population registry. Residential history was constructed for the past 20 years and distance from high voltage power lines was calculated using geographical information system for about 90% of the subjects. Information was also available on marital status, education and income (the latter two at small area unit level). No indication of increased risks were found for ever having lived 50 > m from a high voltage power line, nor for duration of such residency. Only in a sub group analysis of Alzheimer disease in the age group 65-74 years, an association was reported. The results did not confirm the findings of the Swiss cohort study reporting increased risks of Alzheimer disease for living 15 years within 50 m of a power line. A meta-analysis of 17 studies on occupational ELF exposure and amyotrophic lateral sclerosis found some evidence for an increased risk, but the findings were not consistent and indications of publication bias were detected [26]. The summary analysis showed elevated risk in case control studies, but not cohort studies. Similarly, increased risk was indicated in studies using clinical diagnosis of ALS, but not in those relying on death certificates. Asymmetric funnel plots and Egger's test indicated an

excess of small studies with increased risks, suggesting publication bias. The Swedish twin study [Swedish twin] with 216 cases (2/3 classified as Alzheimer's disease) showed elevated risks for occupational exposures exceeding 0.12 µT only for the subgroups with age of onset less or equal to 75 years and for manual workers but not the entire study population [27]. Furthermore, there was no exposure-effect gradient, i.e. the findings suggest a protective effect of low exposure. A meta-analysis covered 42 studies on occupational ELF exposure and neurodegenerative disease [28]. Only PubMed was searched, no other databases and only publications in English language were included. Of the 27 case-control and 15 cohort studies, only three employed measurements of ELF, five used classification by an industrial hygienist and 14 JEM or similar exposure tabulations. Twelve of the studies reported selectively only some of the findings. Total number of cases for various outcomes was not reported. Overall, occupational ELF showed associations with motor neuron disease and Alzheimer's disease, but not with Parkinson's disease, multiple sclerosis or all dementias. Studies with disease prevalence as outcome showed stronger associations than those addressing incidence or mortality [29].

ELECTRO MAGHETIC FIELD RADIATIDN

1. Electro Magnetic field Radiation

Electromagnetic field (EMF) radiation is the flow of photons through space. Each photon contains a certain amount of energy, and the different types of radiations are defined by the amount of energy found in the photons. The electromagnetic spectrum is the range of all types of EM radiation. X-rays used in hospitals or the radio waves from a radio station are all part of this spectrum [30].

2. Uses of Electromagnetic Radiation

Apart from the use in telephony, some other important uses of electromagnetic radiation as shown in Fig 1. below, in our day to day life are as follows:

- Conversion of electromagnetic radiation from Sun (solar energy) to chemical energy (food) by plants through the process of photosynthesis.
- X-ray used for bone structure imaging at hospitals.
- X-ray used in Security Scanner at Airports and shopping malls.
- Microwave used in microwave ovens and radars.
- Radio waves used in radio and television broadcasts.
- Visible light used for normal vision.
- Infra-red waves used in night vision goggles and in TV remote controls [30].

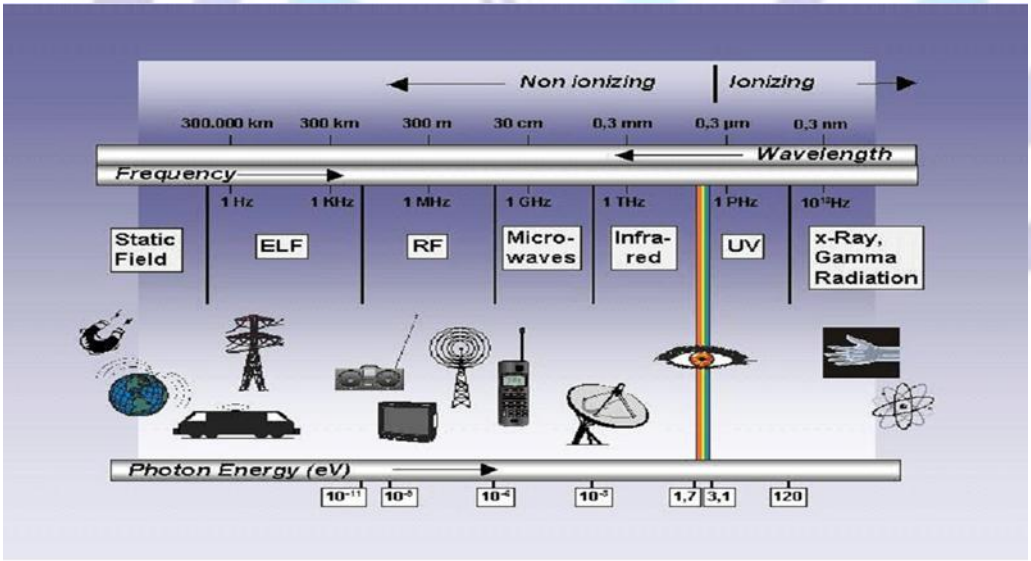

Fig 1: Complete Electromagnetic Spectrum

3. The most common sources of exposure

The most common sources of exposure as shown in table 1. below, include the FM/AM radio, TV transmission, Cellular networks using Global System for Mobile (GSM), Code division multiple access (CDMA), wireless local area network (WLAN), Bluetooth, Zigbee (ZigBee is an IEEE 802.15 standard, used to create personal area networks built from small low-power digital radios) , WiFi and WiMax technologies, which occupy the Very high frequency (VHF), Ultra high

frequency (UHF), L, and S band of frequencies. The effects due to FM, AM and TV transmissions are localized to the areas around the location of towers and the Bluetooth, Zigbee applications operate at low power levels [30].

Table 1. Electro Magnetic Field (EMF) Sources

S. No.	EMF Source	Operating Frequency	Transmission Power	Number
1.	AM/FM Tower	540 KHz-108 MHz	1 KW – 30 KW	380
2.	TV Tower	48 MHz – 814 MHz	10 – 500 Watt	1201
3.	Wi-Fi	2.4 – 2.5 GHz	10 – 100 mW	
4.	Cell Towers	800, 900, 1800, 2100, 2300 MHz	20 W	~ 5 x105
5.	Mobile Phones	GSM-1800/CDMA GSM-900	W 1 2 W	900+ Million

4. Types of EMF radiation

EMF radiations are divided into two categories, ionizing and non-ionizing, depending on frequency and the power level [30].

Ionizing radiation is electromagnetic radiation whose waves contain energy sufficient to overcome the binding energy of electrons in atoms or molecules, thus creating ions. e.g. Ultraviolet rays, X-rays , gamma rays and cosmic rays as shown in figure (1).

Non-ionizing radiation refers to any type of electromagnetic radiation that does not carry enough energy per quantum to ionize atoms or molecules. e.g. low frequency radiations like radio waves, microwaves, and infrared radiations as shown in figure (1).

5. Effects of EMF exposure on human health

Effects of EMF radiation can be studied in two ways i.e. bio-effects and health effects are measureable responses to a stimulus or to a change in the atmosphere and are not necessarily harmful to our health. Biological effects can be two types i.e. Thermal and Non-Thermal effects.

Thermal Effects: Refers to the heat generated due to absorption of EMF Radiation. While using a cell phone, most of the heating effect occurs at the surface of the head, causing its temperature to increase by a fraction of a degree. Prolonged thermal effect may lead to increase in body temperature.

Non-Thermal Effects: Non-thermal effects are attributed to the induced electromagnetic effects inside the biological cells of the body which is possibly more harmful [31]. Health effects are the changes which may be short term or long term. These effects stress the system and may be harmful to human health. Mobile Service and EMF Radiation.

The EMF radiation in mobile services is primarily from two sources: radiations from base transceiver station (BTS) and radiation from mobile handsets both of which are at the relatively low end of electromagnetic spectrum. The energy carried by them is unable to break chemical bonds in molecules. Thus, they fall under the non-ionizing radiation category [30].

EFFECTS OF MAGNETIC FIELDS

Free radicals are essential for normal physiological processes, especially in relation to brain metabolism [32]. The brain is the highest consumer of oxygen in the human body and, most of the oxygen is converted into CO_2 and water with small amount of O_2 forming reactive oxygen species (ROS) [33]. The high metabolic rate and the composition rich in polyunsaturated fatty acids which are ROS targets in brain, makes brain more sensitive to oxidative damage [34]. Oxidative stress is a cellular or physiological condition of elevated concentrations of ROS that cause molecular damage to vital structures and functions [35].

Several studies demonstrated that radiation causes oxidative stress, which leads to activation of the apoptotic pathway. It has been reported that the effects of radiation on cell membranes induces apoptotic signal via lipid peroxidation [36]. Followed by its apoptotic effects by increasing oxidative stress [37]. An increase in free radical generation caused by radiations from mobile phones has also been reported in several other tissues [38]. One of the study demonstrated that mobile phones biochemically cause oxidative damage by increasing the levels of NO, malondialdehyde (MDA), xanthine

oxidase (XO), and adenosine deaminase (ADA) activities in rat brain used as a model for EMR exposure [38]. These continuously produced reactive oxygen species (ROS) are scavenged by superoxide dismutase (SOD), glutathione peroxidase (GSH-Px) and catalase (CAT) [37]. A study on ELF-EMFs exposure (50 Hz, 0.1–1.0mT) resulted to elicit redox and trophic response in rat cortical neurons ,[39] and also induce oxidative stress in mouse cerebellum [40]. As result, ELF-EMFs increase free radicals content with consequent lipid oxidative damage in brains mice and rats [41]. In both in vivo and in vitro rat cortical neurons cultures, ELF-EMFs are associated to oxidative stress, that arises both from field interaction with chemical bonds of biomolecules, thus giving ROS a higher concentration and activity,[42] and from un equilibrium in the enzyme-dependent scavenging ability [43].

EMF harmful effect on cognition, learning and memory in animals have been reported using an assortment of cognitive and behavioral tasks, tests and exposure conditions [44]. Behavioral and psychological studies states that exposure to EMF can affect human cognitive functions and behavior of animals [45]. In this context, a study showed that rats were exposed to 25 or 50 Hz fields for the short term (7 days) or long term (25 days) and examined in the Y form maze indicated that neither short term, nor long term exposure make any change in motor activity, but 50 Hz field exposure showed decrease recognition of new arm of the maze [45]. The researchers believed that extremely low frequency (ELF) EMF can make changes in calcium ion homeostasis in neuronal tissues. Hippocampal regions of mouse brain which has exposed to 50 Hz field for 90 days (50 and 100 mT) were isolated and compared with the control group. It was found that exposure to ELF EMF increased Calcium ions (Ca2+) levels in cells [46]. Some preclinical and clinical studies relating EMF-R & CNS have been summarized in Table 2. Studies demonstrated that exposure to RF EMF emitted by cell phones has an effect on brain physiology. Changes in Electroencephalography (EEG) power are manifested rapidly when exposure occurs during sleep [63].

Table 2. preclinical and clinical studies relating Electromagnetic Field Radiation (EMFR) and Central Nervous System (CNS)

S. No.	Subject	EMF exposure condition	Examined parameter	Result	Reference
1	Wistar Albino Male Rat	60 min /day for 2 month to a 900,1800,2450 MHz	Effect on brain	Structural changes in the frontal cortex and brain stem	Eser O.*et al.* 2012 [47]
2	Wistar Rat Brain	2 hour/day for 35 days,9.9/Hz/1.0 W/kg	Biochemical parameter	Increase in calcium ion efflux and or nithinine decarboxylase. A singnificant decrease in PCK activities was also recorded	Pulraj and Behari 2012 [48]
3	Wistar Albino adult male rats	900 MHz emitted from mobile for 2 hr/day for 10 month	RF effect on beta-amyloid protein, protein carbonyl and malondialdehyde	Increase in protein carbonyl	Dasdag *et al.* 2012 [49]
4	Male mice	90 min exposure to 8 mT EMF	Memory in mice	Hippocampus and basal ganglia impairement, effect on memory	Foroozandeh *et al* 2011 [50]
5	Wistar rat brain	Exposure 2 hr/day for 45 day,2.45 Ghz/0.11 W/Kg	Exposure 2 hr/day for 45 day,2.45 Ghz/0.11 W/Kg	Biochemical change induce oxidative stress. A significant increase in apoptosis cells and decrease protein kinase C activity in hippocampus	Kesari *et al* 2011 [51]
6	Male Wistar rat	RF-EMR for 1 hour per day for 4 week GSM(0.9 GHz/1.8 GHz)	Passive avoidance and hippocampal morphology	Alter passive avoidance and hippocampal morphology	Narayanan *et al* 2010 [52]
7	Male and Female rat	3 hr/day exposure to a 840 MHz	Behaviour locomotor activity, grooming	Change in behaviour activity, decrease, locomotor activity,increase grooming, freezing behavior	Daniels *et al* 2009 [53]
8	Male Wistar rat	50 missed call/day for 4 week from GSM (900/1800 MHz)	Spatial memory performance	Affected spatial memory perform	Narayanan *et al* 2009 [54]
9	Wistar rat	900 MHz/2 W/kg (2hr/day for 4 week)	Effect of EMF on newborn rats	Induces pyramidal cell loss in hippocampal	Bas *et al* 2009 [55]

10	Fisher rat brain	900 MHz/0.6 W/Kg, 2 hr/week for 55 weeks	Cognitive impairement Neuro behavioural effects	Reduced the memory function by albumin leakage	Nittyby *et al* 2008 [56]
11	Inhabitant	Mobile phone base		Increase neuro-behavioural effect	Rassoul *et al*2007 [57]
12	Rat	24 and 48 hr exposure to a0.01-mt,60 Hz magnetic field	DNA strand breaks in brain cell of rat	Increase single and double strand breaks	Lai and Singh 2004 [58]
13	Human endothelial cell line EA hy 926 cells	900 MHz for 1 hr	Proteomics analysis	Changes in protein expression involved in the structure of cell	Nylund and Leszczynsk 2004 [59]
14	Male and female rats	EMR exposed for 2 hr to GSM	Nerve Cell damage	Neuronal damage in the cortex	Salford *et al* 2003 [60]
15	Male Sprague Rat	Acute 2 hr exposure to a 60 Hz magnetic field	DNA strand	Break in brain cells	Lai and Singh 1997 [61]
16	Human being	high-frequency electromagnetic fields of digital mobile radio telephones	Sleep	shortening of sleep onset latency	Mann and Roschke 1996 [62]

They outlast exposure by at least15 min when RF EMF is applied during waking prior to sleep [64]. Simulations of the SAR distribution within the brain support the interpretation that sub cortical structures may be responsible for the observed effect on the sleep Electroencephalography (EEG) [63]. A study showed that radiation also causes memory loss, concentration difficulties, fatigue, and headache, in a dose response manner, headache, discomfort, nausea [65].

RESULTS AND DISCUSSIONS

Studies report that exposure to toxic substances and environmental agents that may have toxic effects compromises the development of organs and systems. For example, one study reported that exposure to non-steroidal anti-inflammatory drugs in the prenatal period affected the development of the sciatic nerve [66]. Another study reported that anti-inflammatory drugs administered in the prenatal period reduced the number of cells in the hippocampus and led to dysfunction in the development of the nervous system [67]. The effects of the EMF emitted by the mobile phones that are frequently used in social life as technology progresses have recently attracted considerable attention from researchers. For example, Sonmez et al. [68], reported that many GSM operators used a frequency of 900 MHz and that there was a marked decrease in the number of Purkinje cells in the cerebellum of adolescent female rats exposed to EMF at that frequency. Another study reported that EMF applied at a low frequency led to changes in hematological parameters [69]. One study reported genotoxic effects in cells associated with chromosomal aberration and structures such as micronuclei in mature and immature rats exposed to long-term application of an 1800-MHz EMF [70]. Şekeroğlu et al. [70] showed the irreversible effects of cytogenotoxic damage, especially in immature rats. In growing rats, EMF at a frequency of 900 MHz has been reported to lead to moderate desquamation and vacuolization in the epithelium of testicular seminiferous tubules, while at a frequency of 1800 MHz it led to pathological findings such as severe vacuolization, necrosis, and desquamation in the seminiferous tubule epithelium [71]. Odacı et al. [72] determined a decrease in granular cell numbers in the dentate gyrus of rat pups exposed to a 900-MHz EMF in the prenatal period. Another study investigating the effects of EMF in the prenatal period reported a decrease in testicular seminiferous tubule diameter [73]. All these studies clearly show that EMFs applied in the prenatal period have adverse effects on various organs [74]. However, the effects on the liver of EMF applied in the prenatal period are still unknown, due to the lack of sufficient studies on the subject. Gokcimen et al. [75], reported in their study of young male rats that a magnetic field led to sinusoidal dilatation in the parenchyma and periportal area of liver tissue. Sinusoidal expansion and vacuoles surrounded by membrane in light microscopy and TEM findings were reported in rabbit liver sections exposed to a 650 MHz EMF for 12 months in another study. In the group exposed to EMF for 18 months in that study, irregularity was observed in sinusoidal lumen diameters, the cell cytoplasm was empty and replaced by granules, chromatin was less condensed, and the space between the interior and exterior nuclear membrane expanded [76]. Another study referred to EMF altering mitochondrial structures, particularly in hepatocytes [77]. EMF applied to chicken embryos was reported to lead to cytoplasmic degenerations in liver cells [78]. Similar to Lahijani et al.'s [78] findings, necrotic hepatocytes with an irregular nucleus and irregular cytoplasm structure were also observed in experimental group mothers (EGMR) pups in study [79]. Histopathological findings such as expansions in endoplasmic reticulum, vacuoles in mitochondria, and active stellate cell fibrosis observed in EGMR sections in the study show the adverse effects on the liver in the postnatal period of 900 MHz EMF applied in the prenatal

period. Our microscopic evaluations also confirm this study findings, because significant hydropic degeneration was determined in the per central area in slides from the EGMR group [79].

Research is still in progress over the recent years to investigate mobile phones and the risk of cancer [80]. Researchers are studying tumors of the brain and central nervous system and other sites of the head and neck because mobile phones are typically held next to the head when used [81]. Research studies have not shown a consistent link between mobile phone use and cancer [82].

In some of study [23] show that a nationwide cohort of approximately 31,000 employees in Danish utility companies employed between 1900 and 1993, It observed increased risks for senile dementia, demyelinating diseases in central nervous system (CNS), and motor neuron diseases compared with the population of Denmark. In an internal comparison between the groups of average workplace exposure to50 Hz EMF, It observed an increased risk of epilepsy, motor neuron diseases, and senile dementia in the higher exposure groups compared with the background EMF exposure group. In all analyses the incidences of Parkinson disease, presenility, including Alzheimer dis-ease, and other CNS diseases, were essentially unrelated to exposure to EMF. My finding of an increased risk of motor neuron diseases is in agreement with those of previous epidemiologic cohort studies of amyotrophic lateral sclerosis (ALS) in which duration of employment in jobs with exposure to EMF was associated with an increased risk for ALS [83,84]. A case-control study of 28 ALS patients and 32 controls showed that the cases with greater exposure to 50 Hz EMF had a 2.5 fold increase in risk in comparison with controls [85], and the authors concluded that long-term occupational exposure to EMF increases the risk for ALS. One hypothesis that may explain the increased risk for ALS among utility workers is related to exposure to electric shocks. In an earlier case-control study of ALS in the United Kingdom, case patients had had more episodes of electric shocks before development of the disease than controls [86]. This result was corroborated in a case control study in the United States in which higher risks for ALS were seen among persons who had experienced electric shocks resulting in unconsciousness and among persons at risk of occupational exposure to electric current [87]. An association between working in electrical jobs and development of ALS is also indicated by the results of a Swedish case-control study, which showed a sevenfold increase in the risk for motor neuron diseases, including ALS, among employees in electrical occupations [88]. A population-based case control study from Washington state of risk factors for ALS in 174 cases found an increased risk for ALS associated with electrical shocks resulting in unconsciousness [89]. In this study of mortality in the same cohort of utility workers, we observed an increased rate of death from accidents among employees who had received electric shocks, particularly among employees with medium and high exposure to EMF [84]. We concluded that the excess number of deaths from ALS might have been due to repeated electric contusions rather than to heavy exposure to EMF. The results of the present study and other epidemiologic studies thus indicate that electric utility work may be associated with an increased risk for ALS, due either to EMF or to electric shocks. A review of the 20 medical records of patients discharged with a motor neuron disease from neurological departments revealed 15 patients with a diagnosis of ALS. Four patients who received an initial diagnosis of motor neuron diseases were later found to have ALS; the last patient received a diagnosis of non-specific motor neuron disease. One patient reported a head trauma, another reported two episodes of electric shocks 19 and 26 years before the diagnosis of ALS, and familial ALS was diagnosed in one patient. As I validated the diagnoses of ALS and other motor neuron diseases from medical records, I included only the observed cases of these diagnoses. No attempt was made to validate the number of expected cases, and the calculated the ratios of observed to expected number of hospitalizations were based on comparable observed and expected numbers as identified in the National Register of Patients. Although the medical review changed the observed numbers of ALS and other motor neuron diseases, I did not include this information in the analyses. My finding of an increased risk of senile dementia is consistent with the results from a Swedish case control study which reported that workers exposed to magnetic fields during their last occupation before disease onset were at higher risk of dementia than workers in occupations with low exposure to EMF [90]. The number of cases of senile dementia in that study was rather small and the majority of the cases were diagnosed with vascular dementia [90]. Study finding [23] of a decreased risk for epilepsy among the utility workers compared with the Danish population is probably due to the “healthy worker effect.” Most cases of epilepsy are diagnosed during childhood, and this condition is not compatible with employment in electric utilities. Contrary to this result, in the high EMF exposure group, it observed a twofold increased risk of epilepsy in the analyses that compared risk among the EMF exposure groups. Head traumas, cerebrovascular diseases, and degenerative diseases are among the most common causes of epilepsy in adults. it cannot exclude the possibility that EMF exposure may be another risk factor for epilepsy. The present study is the first to suggest an increased risk of epilepsy associated with EMF exposure. it observed no increased risk for other neurological diseases that have been linked in previous reports to above-average exposure to EMF, including presenility (Alzheimer disease). The risk for Parkinson disease was also not increased in this study, in accordance with the results of the U.S. study of neurodegenerative diseases among utility workers [83]. As the National Register of Patients contains data for the entire population of Denmark, practically all hospitalized cases of CNS diseases among utility workers occurring after 1977 were identified. In addition, patients with symptoms of these diseases are all clinically verified in neurological departments. The files of the workers were established years before the neurological event reported to the register, and the completeness of the employment files and of the register reduces the likelihood of selection or information bias [23].

CONCLUSIONS

Only a few new epidemiological studies on neurodegenerative diseases have been published since the previous Opinion. They do not provide support for the previous conclusion that ELF magnetic field exposure could increase the risk for Alzheimer's disease or any other neurodegenerative diseases or dementia. Health effects of EMF regarding neurophysiological studies, due to methodological weaknesses, these studies are not useful for drawing meaningful conclusions. The same is true for the results concerning behavioral outcomes and cortical excitability. Largely consistent

with earlier results, recent in vivo studies have reported that exposure to magnetic fields has no effect on activity or locomotion, but may affect the performance of spatial memory tasks (both deficits and improvements have been reported) and engender subtle increases in behavioral anxiety and stress. There is some evidence that these effects may be greater with higher intensity fields and with longer durations of exposure, but the magnitude or direction of effect cannot be defined with accuracy. In vivo studies that have investigated potential molecular and cellular mechanisms have not identified any mechanism that operates at levels of exposure found in the everyday environment. Animal studies that have suggested that magnetic fields may offer potential therapy against neurodegenerative diseases require confirmation and clarification. No additional insights regarding the effects of electric fields are possible, due to the almost complete absence of new data. As in the previous Opinion, the few available in vitro studies do not provide any support for drawing conclusions on the possible effects of ELF on the nervous system and neurobehavioral disorders.

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