Acta Neurophysiologica

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Review Article *Volume 4 Issue 5*

The Role of Non-Ionizing Electromagnetic Radiation in Altering Neurophysiology

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Received Date: March 16, 2023; **Published Date:** June 26, 2023

Abstract

Even before the wake of this of global pandemic and the associated social distancing norms, the lives of human beings cannot be imagined without cellular phones and electronic gadgets and the probability to be exposed to their harmful radiations is inevitable to an astounding extent in both adults, working from home and children, dependent on online classes and exams. Electro-pollution is skyrocketing and its impact can be perceived particularly as electro-hypersensitivity among human beings, penetrating even on deeper cellular and genetic levels. Advent of 5G technology will add on to the pre-existing radiation exposure at ambient and individual levels. Safety limits of exposure to electromagnetic radiation, as advised by responsible agencies/authorities, protects the industry and neglects human health and environmental homeostasis. This review critically analyzed the records of the development of mobile communication technologies, the associated electromagnetic fields and frequencies and the neuronal health issues emerging due to their sustained, yet, fluctuating presence throughout the three decades since inception. It highlights the precautions to be taken meanwhile and the need for extensive future research in this aspect to prevent such perturbations affecting our daily lives and the environment.

Keywords: Electrohypersensitivity; Electromagnetic Radiation; Neuron; Glioblastoma; Cognition; Behavior; 5G Technology

Abbreviations: 1G: First Generation; 2G: Second Generation; 3G: Third Generation; 4G: Fourth Generation; 5G: Fifth Generation; BBB: Blood-brain barrier; CDMA: Code Division Multiple Access; CNS: Central Nervous System; COVID: Corona Virus Disease; DNA: Deoxyribonucleic acid; EHF-EMR: Extremely High Frequency Electromagnetic Radiation; ELF: Extremely low frequency; EMF: Electromagnetic Field; FDMA: Frequency Division Multiple Access; GFAP: Glial fibrillary acidic protein; GSM: Global system for mobile communications; HIFEM: High-intensity focused electromagnetic technology; IARC: International Agency for Research on Cancer; ICNIRP: International Commission on Non-Ionizing Radiation Protection; ITU: International Telecommunication Union; LTE: Long Term Evolution; MOCA: Montreal Cognitive Assessment; mRNA: messenger Ribonucleic acid; NIR: Non-ionising radiation; NMDA: N-methyl-D-aspartate; OFDMA: Orthogonal Frequency division Multiple Access; PET: positron emission tomography; REM: Rapid Eye Movement; RF-EMF: Radiofrequency electromagnetic field; Sab: local absorbed

power density; SAR: Specific Absorption Rate; TDMA: Time Division Multiple Access; TRPC1: Transient receptor potential canonical 1; UTMS: Universal Telecommunication Mobile System; WHO: World Health Organization.

Introduction

Our world is enveloped in various classes of electromagnetic fields, collectively called "electrosmog", arising from both natural and artificial sources. There has been a rise in the intensity of electromagnetic radiation used for the benefit of humans in communicating over long distances in this decade. The electromagnetic spectrum currently being used for wireless communications are non-ionising in nature and varies between 300 Hz-300 GHz, involving mostly the radio waves and microwaves. However, reports are piling up that the elevations in the exposure to these radiations are taking a serious toll on human health.

The crucial electromagnetic factors that are responsible for the bioactivity of these non-ionizing radiations involved in wireless telecommunication systems are their intensities, frequencies, pulses, polarizations, modulations and durations of exposure. Cellular phones emit pulsed radiofrequency electromagnetic fields (RF-EMF) when in operation. The International Agency for Research on Cancer (IARC), under World Health Organisation (WHO), has already established both extremely low frequencies (ELF; 0-3,000Hz) and radiofrequency electromagnetic radiation (RF-EMR; 30 kHz-300 GHz) as 'possible' human (Group 2B) carcinogen and this evaluation was done in a meeting comprising 30 scientists during 24-31 May 2011 at Lyon, France [1,2]. However, subsequent research on biological toxic manifestations of RF radiation provides strong evidence to upgrade it as Group 1 human carcinogen [3]. RF or microwave carrier frequencies used in telecommunication systems always have concomitant ELFs to pulse and modulate the carrier continuous wave electromagnetic field (EMF) [4]. Moreover, ELFs evidently seem to be independently bioactive and the main notorious factor to inflict adverse effects on living organisms when exposed to telecommunication EMRs [5].

There is an upsurge in the use of wireless telecommunications throughout the world, especially after the dawn of the COVID pandemic. The International Telecommunication Union (ITU) estimated the number of mobile phone subscriptions had increased globally from 68 out of 100 inhabitants in 2009 to 108 out of 100 inhabitants in 2019 [6]. The International Commission on Non-Ionizing Radiation Protection (ICNIRP) showcased the guidelines in 1998 and 2010 which are followed by most of the countries to implement wireless telecommunication technologies, but they are all based on the thermal or heating effects of the RF-EMR only [3], ignoring the extensively published data on the non-thermal effects of such radiations [7-10]. Since September, 2017, a group of more than 260 scientists and doctors of the United States of America and European countries have raised their voice against the deployment of 5G technologies as it will add a much more hazardous impact on top of the existing lower generation technologies [3].

They have urged for the revision of the obsolete guidelines and the safety limits prescribed by ICNIRP so that the policy makers and common people are not kept in darkness about the perils concerning the modern and emerging communications systems. The safe limits of specific absorption rate (SAR) values for head and torso region, as stipulated by ICNIRP are 4 W/kg for local public exposure and 10 W/kg for local occupational exposure, which remain unchanged since 1998 although it has been restricted for frequencies between 100KHz-6GHz [11]. The new guidelines published in 2020 have been updated extensively for frequencies above 6 GHz for which a new restriction standard has been formulated, called the local absorbed power density (Sab) that takes superficial absorption into account [11].

From the biological organ systems to biomolecules, all possess natural frequencies, which are close to the range of narrow frequency bands, especially the brain and circulatory system are in the ELF d (0-100Hz) range and cell membranes, DNA and blood ions are in the microwave range [12]. Therefore, resonances arise in biological systems in the presence of such altered and fluctuating electromagnetic fields that may affect them every instance.

Microwave Telecommunication System

The first generation (1G) fully automatic cellular phones arrived in 1981 with analogue signals [13]. Global system for mobile communications (GSM) operates with 900-1800 MHz carrier frequencies which are pulsed at 217 Hz [14] and a duty cycle of 1:8 [15]. It was introduced as a 2nd generation (2G) communication system in 1991 (Table 1) with Time Division Multiple Access (TDMA) and Frequency Division Multiple Access (FDMA) technologies and upgraded to Code Division Multiple Access (CDMA) in 1995. In 2000-2008, the 3rd generation (3G) was in use with periodic updates of CDMA technologies from Interim Standards-2000 to Universal Telecommunication Mobile System (UTMS-1.950-2.5 GHz) features [16].

4th generation (4G) was introduced in 2009 (Table 1) which covers a frequency band of 2-8 GHz and makes use of Orthogonal Frequency division Multiple Access (OFDMA) technology with Long Term Evolution (LTE) feature [13].

Generation	Technology	Feature	Frequency	Year of Introduction
1G	FDMA	NMT	Low frequencies	1981
2G	TDMA and FDMA	GSM	900-1800 MHz	1991
	CDMA	IS-95		1995
3G	CDMA	IS-2000	1.95-2.5 GHz	2000
	W-CDMA	UMTS		2001
4G	OFDMA	LTE	2-8 GHz	2009
5G	OFDMA	NR	1.95 -39 GHz	2018

Table 1: Chronological representation of different generations of telecommunication radio frequencies.
Table Abbreviations: 1G: First Generation; 2G: Second Generation; 3G: Third Generation; 4G: Fourth Generation; 5G: Fifth Generation; FDMA: Frequency Division Multiple Access; TDMA: Time Division Multiple Access; CDMA: Code Division Multiple Access; W-CDMA: Wideband Code Division Multiple Access; OFDMA: Orthogonal Frequency division Multiple Access; NMT: Nordic Mobile Telephony; GSM: Global system for mobile communications; IS-95: Interim Standard 95; IS-2000: Interim Standard 2000; UTMS: Universal Telecommunication Mobile System; LTE: Long Term Evolution; NR: New Radio; GHz: Giga-Hertz.

Advent of 5G Technology

Rolling out of 5th generation (5G) wireless communication technology has been initiated worldwide in recent times (Table 1) where East Asia, North America and Europe are ahead in the race of its implementation [17]. The implementation of such novel technology promises faster data transmission, Internet of Things (IoT), and autonomous mobility; however, without prior comprehensive risk assessment on human health and environment, it will seriously prove to be hazardous in the near future [3]. In its defense, the nature of the microwaves used in 5G technology should be better understood.

The highest bandwidth of 5G technology operates at 24-39 GHz frequency range, bordering the millimeter wave band (wavelength range: 10-1 mm) or extremely high frequency electromagnetic waves (EHF-EMR) [18] i.e. closing up to the infra-red waves. This high frequency spectrum reportedly will interfere with the accurate estimation of the water vapor concentration in the atmosphere while the satellite-based weather forecast [19]. The speed of transmission will be maximal (up to 100 folds higher than 4G) although to establish a strong connectivity constantly the 5G mobile towers should be implemented in even closer vicinity, as the 5G radiation can travel shorter distances effectively [20].

Facilitation of high bandwidth telephony and mobile data, machine to machine communication in real time (auto-pilot transport facility, etc.) will require broadband modulation schemes operating in pulsatile fashion, faster signals with steeper rise and fall times and therefore the need for close by radio towers generating higher frequencies [21].

The study by Neufeld and Kuster in 2018 highlighted the urgent need for revising the safety limits of 1000 duty cycles tolerated at present that generates irreversible tissue damage by unacceptable increase in the skin temperature [21]. Current guidelines state that the thresholds for frequencies above 10MHz are proposed to limit tissue heating, which are expressed in time-averaged quantities rather than continuous limits since such exposure is mostly transient and pulsed [11].

Manifestations in the Nervous System

Effects on brain

Tendency to put the mobile phone close to the ear while calling reduces the local cerebral blood flow in the inferior temporal cortex and increases that in the prefrontal cortex as observed in positron emission tomography (PET) images of humans [22]. Even the subliminal noise generated by the mobile phone's battery affected the regional cerebral blood flow in the auditory cortices bilaterally [23]. Similar PET scan study with radioactive fluorodeoxyglucose injection showed that healthy human participants had increased glucose metabolism at the orbitofrontal cortex and temporal pole, closer to the region where the antenna is placed externally on acute exposure to cell phone generated electromagnetic fields [24]. Numerous *in vivo* and *in vitro* experiments revealed that EMF generated from mobile phones or such simulations induces changes in the cell membrane permeability (electroporation), calcium efflux and neuronal excitability [25,26].

Simulation study with acute 900MHz exposure system for 24 hours, conducted by Fritze, et al. concluded that it induces minor stress response such as increasing hsp 70

transcript expressions in cerebellum and hippocampus after 7.5 W/kg exposure, and c-fos mRNA expression in the cerebellum, neocortex and piriform cortex at 0.3, 1.5 and 7.5W/kg groups of immobilized rats [14]. This was further substantiated in 2015 by Deshmukh PS, et al. [27] that heat shock protein levels are significantly elevated along with oxidative stress and DNA damage when exposed to chronic low-intensity microwave at 900, 1800 and 2450 MHz of frequencies. It is quite established that the permeability of the blood-brain barrier increases with continuous and pulse-modulated waves above 915MHz frequencies along with albumin leakage seen within few hours of exposure in 40% of the animals to GSM mobile phone electromagnetic fields of varying power densities [28]. This albumin may accumulate in the neuron and glial cells near the capillaries of the brain and have evidently caused neuronal damage in hippocampus, cortex and basal ganglia in rats [28]. RF-EMF also interferes with the electrical activity of the neuronal networks present in the brain and the peripheral neurons [29].

Several epidemiological studies are now emerging that clearly states the association of mobile phone usage with brain tumors (acoustic neuroma or vestibular schwannoma, meningiomas) [30] especially gliomas [31], which has a latency period (interval between causation and manifestation of clinically recognised symptoms) of greater than 20 years in human. Other types of benign and malignant tumors significantly associated with mobile phone usage over 10 years are facial neuroma and uveal melanoma [32]. There was a survival disadvantage in patients with gliomas and glioblastoma multiforme (WHO grade IV hazard) who have used mobile phones for greater than 10 years [31]. Moreover, a systematic review has found that children and teenagers have greater incidence of brain tumors in association with mobile phone use [33].

Changes in Neurons and their Micro-Environment

However contradicting it may seem, NIR can be absorbed by cells and can induce electric and magnetic fields in them. Genotoxic effects of NIR-EM radiation have been reported to be manifested by inducing oxidative stress and DNA breakage in neural cells [5,34]. Enzymatic activity of myeloperoxidase increased manifold and consequently levels of nitric oxide and glutathione transferase reduced [35,36]. Differential expression of heat stress protein is reported [37] on ELF-EMF exposure which can also cause changes in the enzymes involved in the reduction of free radicals [38]. Free radicals can cause damage to genetic materials as well as the proteins. NMDA receptors in the hippocampus are affected by extremely low frequency electromagnetic fields [39] and induced anxiety in rats [40].

Wang X, et al. [41] observed that the ELF field induced a drop in the counts of D2 dopamine receptors, which were induced by morphine. Many scientists claim RF EMF causes chromosomal instability, flux of expression, and mutation of genes which results in altered protein concentrations such as accumulation of GFAP [34,42]. EMF's exposure damages myelin structure by affecting the proteins associated with myelin formation and causes electro-hypersensitivity [43-45]. RF-EMFs increased molecules like malondialdehyde and glutathione in the nerve cells along with spinal cord atrophy, increased vacuolation, hypertrophy and formation of irregular myelin sheath were observed [34,46]. Even though mutations are known to perpetuate cancer, the correlation between cancer and EM waves is still debated [36,43].

Alterations in the physiology of cell membranes and ion concentrations affect the electrical activity of the brain. Ca^{2+} ion concentration has been reported to decrease in the hippocampus in mice upon RF EMF exposure [39]. These changes in the concentration of Ca^{2+} have dangerous implications as it acts as a secondary messenger in many signaling pathways and is involved in the release of neurotransmitters.

The concentration of ions like Na^{+} and K^{+} is of particular importance in terms of neuron for electrical signaling and ELF can inadvertently disturb the electrical activity by directly altering their concentrations [47]. The magnetic field of ELF affects the probability of ion-protein dissociation and quantum states of ions [48]. This interaction with the physical, non-linear mechanism of electrical and magnetic interferences, at particular ranges of frequencies and amplitudes, and cooperative process of the cell of a particular organism to manifest the biological effects is referred to as frequency 'window' phenomenon [49].

Cognitive Function and Behavioral Changes

Chronic low intensity of mobile phone microwave simulation in rats at a frequency range of 900-2450 MHz study showed that there was decline in learning and spatial memory [27]. Kalafatakis F, et al. [50] found that human subjects performed poorly in a working memory task after using a mobile phone for 5 minutes when compared to the controls. Effect on attention due to mobile phone usage was biphasic and complicated as divided attention remained unaltered whereas vigilance reaction time increased on using GSM 900 phones and decreased reaction time for selective attention in case of using WCDMA phones were observed [51]. The time of the day played a crucial role in improving the reaction time of the aforementioned cognitive tasks when compared to the duration of exposure to the exposure to the mobile phone

radiation [51].

Since studies concerning the effect of mobile phone usage on cognitive functions are inconsistent require more sensitive and validated tools, a recent study conducted a cognitive analysis in Saudi- Arabian population using Montreal Cognitive Assessment (MOCA) questionnaire protocols and they found that participants who used their mobile for more than 2 hours daily scored less in MOCA when compared to those who use it for less than one hour and their performance dwindled when they kept their phones near their head [52].

A recent study found that base station radiation caused marginal delay in the peak timings of the rest-activity rhythm in people residing at a distance of 300-500 m or in between two towers [53]. Electro hypersensitivity and tinnitus independently affects the sleeping pattern and induces disturbances [54]. Moreover, a cross-sectional study emphasized that mobile phone usage in 1967 students for over 8 hours per day, especially using it for at least 30 minutes before going to sleep and after the lights are switched off and keeping them near the head while sleeping bears positive correlation with longer sleep latency, sleep disturbances and increased tendency of daytime sleepiness [55] and these results are consistent with a similar study conducted in Japanese adolescents in 2011 [56].

Synaptic plasticity is a crucial phenomenon for formation of long-term memory and learning. During formation of synaptic plasticity, microwave radiation exposure influences both pre-and postsynaptic neurons [57]. The presynaptic neurotransmitters in the vesicles either accumulate or clear out, inflicting damage to mitochondria whereas in postsynaptic neurons, membranes are punctured and therefore results in impairment of learning and memory functions. Furthermore, decline in immature dendritic cell number and activities, reduction in dendritic spine and dendritic length were also observed [58]. Less pyramidal cells in the hippocampus were noted in radiation exposed groups [59] and in some cases, loss of cells is accompanied with darkened nuclei, vacuolated cytoplasm and scattered cells [60]. It is claimed that exposure to NIR affects the cholinergic system, which has a critical role in memory acquisition and process in learning, in the hippocampus [61] and in major regions of cerebellum and cerebral cortex [10].

In epidemiological studies, neurological and cognitive disorders like rage, loss in memory, reduced concentration, headache, and disturbed sleep patterns due to EM waves have also been reported [62-64]. Long-term exposure to mobile phone signals exerts adverse effects on attentiveness and working memory [65], and spatial learning in animals [34,66] RF energy absorbed by the sympathetic nervous system can alter its activity and affect the eating behavior [67]. On the contrary, therapeutic effects of High-intensity focused electromagnetic technology (HIFEM) were also observed as reduction in obesity [68]. ELF-EMF includes changes in locomotor activity [69] induces anxiety [40], depression-like behavior [70], altered emotional state [71], and perception [72]. All these symptoms collectively belong to ‘‘microwave sickness” otherwise known as neurasthenia [73].

Electrohypersensitivity

Electromagnetic hypersensitivity or electrohypersensitivity (EHS) is a conflicting term which includes a collection of the following symptoms—itching, smarting, pain, heat sensation, redness, papules, pustules, and unrelated to general hypersensitivity symptoms like headaches, fatigue, sleep disruption, nervousness, irritability, emotional lability, and concentration deficit in association with exposure to mobiles phones and other electronic devices [74,75]. Sweden has already established EHS as functional impairment rather than a disease although WHO still doesn’t recognise it as a diagnosis and often linked it to psychosomatic manifestation [74].

Interference in Molecular Interplay

Signaling pathways: 1.6W/kg triggered ERK-survival signaling however strong SAR of 4.0 W/kg activated JNK-apoptotic signaling pathways in Drosophila [76]. Apart from activating stress response pathway via hsp 27/MAPK (Figure 1) as in human endothelial cells by 900 MHz EMF [77], hsp 16 in *Caenorhabditis elegans* by 750 MHz EMR [78] and generation of ROS in rat and rabbit brains [79], mobile phone radiation can bolster overeating tendency by deviating brain energy homeostasis [80] via elevation of hypothalamic ghrelin and diminution of hexokinase levels [81].

Different properties of NIR affect the molecular interplay in different ways. EMR exposure with lower SAR value (1.6W/kg) triggers the cell survival mechanism via the ERK signaling pathway and 4.0 W/kg SA value initiates the stress response via JNK associated pathway. The heat shock proteins are expressed in excess on exposure to 900MHz RF in human endothelial cells (hsp 27) which activates the MAPK pathway and 750 MHz RF induces the upsurge of hsp 16 in *C elegans*.

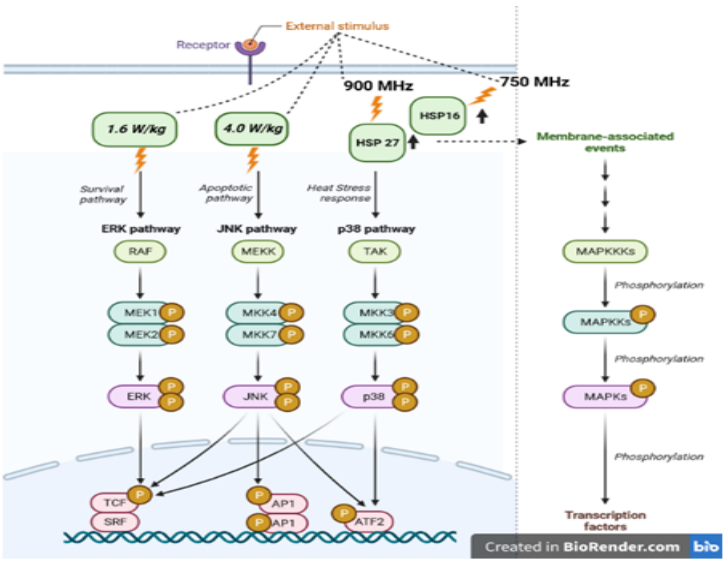

Figure 1: The signaling pathways affected by RF-EMF exposure.

Induction of Epigenetic Modification: A recent study showed that maximum energy generated by mobile phones at the highest frequency (2450 MHz) for six months had a significant reduction in the DNA methylation and hypermethylation of histone (H3K9) in the hippocampus of Wistar rats [82] which is indicative of cognitive impairment and memory deficits when such epigenetic modulations occur around gene promoters [83].

Apoptosis: The neural stem cell differentiation and formation of neurospheres were severely affected by exposure to the GSM 900 MHz RF-EMF although it had no effect on the cell viability, apoptosis and differentiation of astrocytes [15]. In contrast, 1900 MHz RF exposure for 2 hours on neurons and astrocytes cell cultures up-regulated the expressions of Asc (apoptosis-associated speck-like protein containing a card), caspase-2 and caspase-6 [84]. Similar observations were documented in a study published in 2021 that show inhibited Eph receptors 5 expressions and the critical downstream factors like CREB and Rho-A were affected on 1800 MHz RF-EMF exposure, thereby impairing neurite outgrowth and neuronal differentiation [85]. Nonetheless, ELF-EMF facilitates neuronal differentiation and neurite outgrowth by promoting transient receptor potential canonical 1 (TRPC1) expression *in vitro* [86]. Extensive study should be initiated to check any changes in expression of other factors involved in apoptosis in various regions of the nervous system.

Autophagy: Recent studies have shown evidence of autophagy in the brain in response to NIR. Rats exposed to electromagnetic pulsation uninterruptedly showed a significant increase in the expression of the chief autophagic protein, LC3-II, in the hippocampus [87]. In addition, exposure to ELF-EMF in human neuroblastoma cells (SH-SY5Y) has shown an increase in autophagy activation factors along with phagophores and double-membrane autophagosomes [88].

The autophagic activity increases with a longer exposure (4-12 weeks) to RF-EMF observed in the nerve cells of mice. The cerebral cortex of mice showed a remarkable increase in the expression of autophagy-related proteins and heightened activity of LC3B-II [45]. Initiation of autophagy was also exhibited in the hypothalamus and striatum of mice on exposure to RF-EMF [89]. RF-EMF also triggered the expression of p62 in the hippocampus, a protein that has a significant role in autophagy, with a fourfold increase in autophagic structures compared to the controls [34]. However, the autophagic activity in the brain stem is sedentary [90].

Impaired Auditory Functions

The EM radiation alters sensory perception. Extensive and repeated use of mobile phones on the same ear reported worst cases of ipsilateral tinnitus [91]. There seems to be an association between subjective electrohypersensitivity and tinnitus which may have been perpetuated due to overactivated cortical distress networks in the vulnerable human population [64]. Humans and animals hear clicks or other sounds when exposed to short pulse (1-20 μsec) microwave RF [92]. A study in 1962 revealed that different types of field are perceived as different sounds like buzzing, ticking, hissing, or knocking sounds [93]. One of the contributory factors to the change of perception may be by virtue of the thermoelastic effect i.e the reduction of elastic or oscillatory properties of fluids and tissues in the head

resulting due to hyperthermia caused by exposure to EMR [94,95].

Alterations in Electrophysiology of Brain

Many studies in humans have reported changes in electrical activities in the brain, particularly at 2G and 3G mobile signals which affect the alpha waves of EEG [96], but it may be due to thermal effects [97]. Pulsed NIR can increase rapid eye movement (REM) [98], disrupt EEG of REM sleep in rats [99] and increase brain activity at the end of the duration of sleep [100]. Cell phone RFR affected the y-inter hemispheric functional synchronization of neural signals and their further progress of signals by EEG coupling between the two hemispheres [101] although it improved efficiency of neurons in cortices [102,103].

Changes in the Blood-Brain barrier

The blood–brain barrier (BBB) vascularizes the central nervous system (CNS). Any movement between the brain and blood is tightly regulated by this barrier. This in turn protects the neural tissue from infection. Changes in the permeability of the barrier expose the brain to toxins and antigens. With the hike in temperature, the permeability of the blood-brain barrier increases [104]. Thermal effect of radiation also causes an increase in uptake of albumin in the brain owing to the enhanced permeability of the BBB [105]. This in turn increase the uptake of albumin bound drugs into the brain [106], for instance, hydrophilic drugs like domperidone and methylatropine, antagonist of dopamine and acetylcholine respectively, increasing the absorption of chemotherapeutic drugs on microwave exposure [107]. Different pulse characteristics of the EMR caused different levels of uptake. Exposure to thermal effects of microwaves makes the brain more vulnerable to infections [107]. Scientific records are present even in rat models that states 20 minutes of RFR exposure of 900 and 1,800 MHz increases the permeability in the male rats, however, there was no change in female rats. The scientific evidence on RFR safety or harm remains inconclusive. More studies are needed to demonstrate the effects of RFR on the permeability of BBB and the mechanisms of their breakdown [108].

Effects on Neuronal Development

Since we all are surrounded by EMF all the time, the effects of EMF on the development of embryos is an absolute crucial priority. Some reports of *in-utero* exposure to EMF unveiled hyperactivity and memory impairment in mice progeny. The reason may be altered neuronal wiring during development [109]. Nervous systems in children can also be affected by postnatal exposure which results in their developmental anomalies. The radiation absorption rate for children can be very different from adults [110]. One popular belief is that children have thin skulls; therefore, more energy is absorbed, making them more susceptible to radiation effects though evidence to support this claim is sparse. Sun et al. reported that, chicks that have been exposed to ELF-EMF, in ovo, exhibited memory insufficiency and stress [111] while Lahijani MS, et al. [112] described the changes in histological architecture of the brains of the chicks.

Thermal and Non-Thermal Effects

Some portions of EM waves can be absorbed by our body which results in the generation of heat, induces perception of warmth and slows down the sensation of warmth [94]. This may be due to induced EMF electricity [94]. Temperature increase stimulates the temperature receptors that might account for the warmth sensation. These receptors are dependent on the frequency of exposed radiation-with increase in frequency, the threshold energy decreases [113]. This heat is usually dispersed by increasing blood flow. Eyes lack this type of heat dispersing system, and therefore are affected by EM waves in the form of cataracts or retinal injury [114]. RF-EMF causes rotation of the polar molecules that subsequently generates heat [115]. The rate of absorption of EMR energy and the diffusion of the same is an important factor influencing the thermal effects of EM waves in an organism [116]. Other factors on which the thermal effect of EMR depends are the dielectric constant of tissue, size of target tissues with respect to the wavelength, size and shape relative to the wavelength of EMR, geometry and alignment of target tissue, and spatiality of the radiation [117]. The dielectric ability (electricity conducting property) of tissues is dependent on the amount of water in the tissues. Less energy is absorbed by tissues with lesser water content e.g. bone [118]. Threshold energy of 10.8 W/kg is required to raise the temperature of the brain by 0.931°C [119].

The non-thermal effects are possibly harmful for the biological cells and even for the human body. The absence of correlation between experimental and control samples in this study indicates that the rate of non-thermal effects is almost independent of the magnetic flux density and absorbed frequency [70]. Even though it is difficult to distinguish whether the manifestations of EMR on biological tissues or cells are of thermal or non-thermal origin, modulation (with constant frequency and intensity) of EM waves can be a reliable measure to assess the non-thermal biological effects [63].

Conclusion

In all probability, it is the combined effects of components present in the mobile phones and not the EMF itself. All the proofs of these hazards associated with non-ionizing electromagnetic radiation arise due to their exposure

within the safety limits as stipulated by ICNIRP guidelines since 1998. Some scientists claim that the members of the ICNIRP are biased to ignore the harmful effects of non-ionising electromagnetic radiation because of their ties with telecommunication or electric companies that will raise a conflict of interest [3].

It is an absolute necessity to evaluate the risk of cancer associated with being irradiated during mobile phone usage or being amidst EHF-EMF by initiating investigatory projects and recruiting a competent panel of oncologists and other scientists. The short-term effects of these radiations are so inconspicuous yet significant to initiate the hazardous impact that wreaks havoc in the long run and therefore human epidemiological studies to assess such long-term effects of mobile phone usage and to be present in the upcoming EHF-EMF are tremendously necessary. On the other hand, the governments of the respective countries globally should awaken to the cause of improving human health by taking the impact of non-ionising EMR from the widespread source seriously after considering the IARC's classification of carcinogens.

Cognitive-behavioural therapy can be targeted as a treatment strategy to alleviate the underlying cortical distress network over activation due to excessive exposure to mobile phone radiation [54]. Other than that, the public can now only be made aware if every nation focuses only on upgrading the speed of communication by jeopardizing public health and adding more to the electro-pollution. The younger generation should refrain from prolonged usage of mobile phones and other EHF-EMR radiating gadgets. In case of extended calls, headsets or speakers should be encouraged to maintain a safe distance between the mobile handset and our body. Even when the phone is in standby mode, it should be kept away from the body. To ensure quality sleep at night, latenight phone usage should be avoided as blue light interferes with the secretion of melatonin and hampers our regular sleep pattern [120]. Until the government takes any action to prevent their citizens from the wrath of these ubiquitous electromagnetic fields and their radiations, we have to care for our own safety and cautiously select mobile phones bearing lower SAR values while browsing other specifications when procuring them or use anti-radiation shields if and when available in the market.

Acknowledgement

The authors acknowledges the financial support from Department of Science and Technology, and Biotechnology, Government of West Bengal [845/(Sanc.)-ST/P/S&T/1G-39/2016; Dated:12/02/2021] to the corresponding author, the DST-FIST Programme [Grant No.SR/FST/LSI-560/2013(c), dated 23-06-2015] and DBT-BUILDER [BT/INF/22/SP45088/2022 dated 17.02.2022] of Department of Life Sciences, Presidency University, Kolkata.

Conflict of Interest

The authors declare that there is no conflict of interest.

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