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Effects of exposure to radio-frequency electromagnetic radiation emitted from mobile phones and mobile phone towers on sleep and cognitive performance in humans: A review

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Abstract

The electromagnetic radiations (EMR) are ubiquitous. The EMR is a combination of both electric and magnetic fields. It created by both natural and man-made sources. Man-made EMR sources could be ionizing and non-ionizing radiation. Ionizing radiation has a shorter wavelength and higher frequency thus higher energy. Non-ionizing radiation has a higher wavelength and shorter frequency. Mobile phones and its mobile phone towers contribute to man-made EMR sources. They operate in the radio-frequency electromagnetic radiation range and are categorized as non-ionizing radiation. From few decades, the extensive mobile phone usage has led to the deployment of several portable mobile phone towers in every nook of human habitation which raises community concerns. This review article presents the potential biological effects of radio- RF-EMR exposure. There is a lack of ubiquity regarding the adverse effects of electromagnetic radiation on human health. In general, the reported findings are conflicting, ranging from 'harmful impacts' to 'inconclusive impacts, through 'no impact.' While many studies reported RF-EMR-induced alterations in the sleep and sleep-wake patterns, others opposed it. Authors of many studies attributed cognitive impairment in humans to RF-EMR. Others did not agree with it. This implies that the claims and counterclaims regarding harmful impacts of RF-EMR in humans are plenty. We, therefore, recommend more intensive research with perfectly controlled protocols and follow up studies to be carried out with the focus to eliminate current controversies concerning the biological effects of RF-EMR.

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Electromagnetic fields (EMF) are present everywhere and are considered as one of the main factors that influence our environment[8, 37, 89]. All living beings including human populations are now exposed to EMF of various frequencies[37]. The exposure level will continue to increase with the advancement of telecom technologies[37]. In response to widespread concern of EMF exposure over potential human health effects, WHO formulated international EMF Project in 1996. One of the prime objectives of this project is to encourage and attracted biomedical scientists to emphasize and explore the effect of radiofrequencies (RF) generated by these sources on the human health. The broadband telecommunication system, *i.e.*, mobile phones' (MP) complex tele-network and its mobile towers (MT), generate and emit a considerable amount of radio-frequency electromagnetic radiations (RF-EMR)[73]. From past few decades, the extensive increase of MP usage has led to the mounting of MTs amid densely populated, occupational, and residential areas[61]. The radiation from MTs depends on several factors, such as the direction of signal transmission, power density, diffusion due to buildings & trees, and the distance from the source[95]. People with continuous exposure to RF-EMR showed physiological health symptoms[76], sleep disturbances[1], neuropsychological symptoms[67], and cognitive impairment[60].

On the contrary, several researchers documented that RF-EMR exposure did not produce significant adverse effects on human's health[12], sleep[36], and cognitive performance[57,72]. Hence the effects of RF-EMR on the human health perspective remain contradictory[82]. These human health-related anxieties have made this topic a concern for scientists and the general population, warranting extensive research. Therefore, in this review, we have explored the findings of former studies carried out to evaluate the effects of radio-frequency radiation emitted from mobile phones and mobile phone towers. However, the basis of this review article is demarcated mainly to the studies on sleep behaviour, and cognitive performance in humans, with reference to the effects of electromagnetic radiations from mobile phones and mobile phone towers.

Electromagnetic radiation (EMR) :

Electromagnetic radiation (EMR) is considered a property of space. The EMR is a mixture of both electric and magnetic fields. According to the WHO Regional Office for Europe in 1999, the "*Electric fields are created by differences in voltage: the higher the voltage, the stronger will be the resultant field. Magnetic fields are created when electric current flows: the greater the current, the stronger the magnetic field. An electric field will exist even when there is no current flowing. If current does flow, the strength of the magnetic field will vary with power consumption but the electric field strength will be constant*" (Excerpted from Electromagnetic fields published by the WHO Regional Office for Europe in 1999; Local authorities, health and environment briefing pamphlet series; 32). Some of the electromagnetic radiations with ample quantity of energy have ability to ionise the particles of matter and can break down the bonds between the different molecules are called ionising radiation[86]. These radiations include the X-rays, gamma radiations and cosmic radiations. While, other radiations

with low energy do not represent this property are called non-ionizing radiations[75,86]. Non-ionizing radiation includes ultraviolet (100-400 nm); visible light (400-760 nm); infrared (760-10^6 nm); extremely low frequency (ELF) band (1- Hz-300 GHz), and radiofrequency (RF)[51]. High-voltage electric lines, motors, generators, industrial and domestic appliances, home appliances, and home wiring etc. are known sources of Non-ionizing radiations[51,86]. In the present-day society major sources of these non-ionizing radiations to which all most all human being is likely to get exposed are telecommunication technology systems such as radio, television, internet, Wi-Fi, mobile phones and their base stations[51,66,75]. The growing man-made sources lead to higher EMR emission, often referred to as electromagnetic smog, result in greater exposure of the human individuals to EMR [9].

The electromagnetic spectrum :

Electromagnetic spectrum (EMS) consists of electromagnetic radiation frequencies of different wavelengths and energies. EMS covers the frequencies ranging from below 01 Hz to above 10^{25} Hz. This frequency range is divided into separate bands such gamma rays, X-rays, ultraviolet; visible light; infrared; radio wave /frequency (30 KHz to 300 GHz) [{microwave (300 MHz-300 GHz): extremely high frequency (EHF); super-high frequency (SHF); ultra-high frequency (UHF)}; very high frequency (VHF); high frequency (HF); medium frequency (MF); low frequency (LF)], voice frequency (VF); very low frequency (VLF); and extremely low frequency (ELF)[39].

Sources of electromagnetic radiation :

Electromagnetic radiation is created by both natural and man-made sources. Natural sources include earth (terrestrial sources) and space (extra terrestrial origins)[86,88]. Terrestrial sources include the earth's magnetic field that makes a compass to orient in a North-South direction, lightning/thunder-storms, and visible light[37]. The earth's atmosphere, solar radiations, and cosmic radiation are included in the extra terrestrial origins[27].

There are different man-made sources of electromagnetic fields include electricity and electrical appliances, X-rays, radio communications devices including mobile phones and their base stations, TV antennas, transformers, alternators, electric hardware and equipment of arc- and resistance-soldering and radio stations[51,75,88]. The most common man-made sources in the RF range are listed below; Radio and television broadcasting; Cellular (mobile phone) networks; Wireless networks; Industrial applications; Medical applications; Domestic sources; Security and safety applications including radar and navigations; Other systems include those used for monitoring weather, traffic speed, collision avoidance with vehicles and ground penetration[27].

Mobile phones and mobile phone towers :

A mobile phone towers (MT) is a setup of telecommunication industries composed of towers, radio channels, transmitters, and receiver antennas[40]. Mobile phone towers are two types, *i.e.*, ground-based towers and rooftop towers. MTs are mainly installed on tall trees, water tanks, or tall commercial and residential buildings to provide the best possible

network services[61]. The main task of a MT is to enable a transfer and reception process between mobile stations. MT and mobile phones are among the main sources of RF-EMR[24]. Radio Frequency (RF) generated by cell phones usually depends on the number of base stations around the area, the cell phone network traffic, and how far is a cell phone from base stations. The amount of power sent from a base station could vary from one cell phone to another even within the same area, depending on the interference from obstacles, such as buildings and trees[5]. Mobile phone towers/ base transceiver stations (BTS) transmit in the different frequency ranges[84]. Associated frequency ranges are as follows: With the use of a sensible meter we can record how a great deal of RF-EMR is gotten at a specific point/spot. RF-EMR strength may not be uniform around a tower. The energy by a tower receiving wire, like other media transmission radio wires, is facilitated toward horizon (corresponding to the earth surface), with some plunging disseminate[5]. Mobile phones transport by transmitting radio-frequency radiation over an arrangement of fixed receiving wires called base stations[5]. Distance is considered as a modest/ moderate factor that modulating the effects of electro-magnetic field exposure proxy with respect to mobile phone base stations[5]. Mainly, power density (W/m^2), electric field (V/m), magnetic field (A/m) and specific absorption rate (SAR) are used in the measurement of radiations emitted from these base stations. SAR is the estimation of rate by which a body absorbs vitality when the body is exhibited to radio frequency electromagnetic radiation (RF-EMR). It is expressed as power held per mass of tissue and its unit is watts/kilogram[50]. According to the ICNIRP regulations, in India, the limit for open introductions is 1.6 W / kg for 1 gram volume which is the center estimate of SAR [38].

Effects of radio-frequency electromagnetic radiation on
Overall health :

The effect of radio-frequency electro-magnetic radiations (RF-EMR) emitted from mobile phone towers (MT) on overall human health is a general public concern. The reported biological effects of RF-EMR on humans are physiological[15], biochemical or behavioural[51], and neuropsychological[67] changes. Several studies documented that exposure to RF-RFR from mobile phone towers gives rise to adverse health effects[2,81]. It has been reported that from continuous exposure to RF-EMR, people experience many health symptoms such as nausea, loss of appetite, visual disturbances, irritability, depressive tendencies, lowering of libido, feeling of discomfort, anxiety, and phobic nervousness[14,15,76]. A study[27] on cancer incidence in the human population exposed to Sutton Coldfield television (TV) and frequency modulation (FM) radio transmitter revealed that the risk of different types of cancer, like adult leukemia, skin cancer, bladder cancer varies as a function of distance from the location of the transmitter. Besides, it has been documented that living in the vicinity of mobile phone base stations has increased the frequency of 8 different types of cancers within one year[50,64,96]. The findings[35] revealed that regional cerebral blood flow (rCBF) was increased in dorsolateral prefrontal cortex on the only ‘handset-like’ RF-EMF exposure side but not the ‘base-station-like’ RF-EMF exposure

affected rCBF. Meo and Al-Drees[59] revealed that RF-EMR can cause hearing and vision complaints. Another study conducted by Mjøen *et al.*,[62] on birth defects of two paternal groups' offspring was most likely and medially exposed to RFR. A study conducted in Finland has reported that the RF-EMF alters protein profiling in females[41]. Fattahi-asl *et al.*,[26] and Shahbazi-Gahrouei *et al.*,[80] suggest that radiofrequency electromagnetic radiation may lead to oxidative stress and rapid diffusion of the human ferritin and chorionic gonadotropin level in an in vitro enzyme assay and enzyme activity. More importantly, radiofrequency radiation exposure increases the risk for brain tumors' development in humans has always been a concern[8,37]. Another study's findings demonstrated that continuous 24x7 electro-magnetic exposures caused genetic-damage in the nearby vicinity population to MTs[28]. Meo *et al.*,[61] reported that exposure to LF-EMR emanated from mobile towers is associated with elevated levels of HbA1c and risk of type 2 diabetes mellitus in the students. Altun *et al.*,[4], Kesari *et al.*,[43], Singh *et al.*,[83] reviewed the possible effects of LF-EMR on infertility and reproductive health. Lasalvia *et al.*,[48] reported that RF-EMR exposure affects the enzyme activity in human lympho-monocytes.

However, some studies are opposing the effect of RF-EMR on biological processes[91]. Some studies reported that RF-EMR exposure was not significantly associated with adverse effects on human health[7,12,77]. One study carried out in the UK showed exposure to mobile phone signals increased blood pressure though it was not significant[11]. A significant association could not be validated in a case-control study between cancer risk and RF/MW radiation exposure[6]. Besides, no significant EMF exposure associations with plasma estradiol, melatonin, HSP70, HSP27, and TET1 were found[94]. No association was found between measured exposures from towers with self-reported non-specific or insomnia-like symptoms[58].

Sleep :

Sleep is an endogenously generated self-sustained cerebral process under the central nervous system's control. We spent about the third part of our life sleeping. Sleep is important for the relaxation of our body and mind. Sleep is vital for life and for all biological processes such as immune, metabolic, and brain-related functions, including cognitive, memory, and performance-related functions[45,92]. Findings from different emerging studies reflect that exposure to radio-frequency electromagnetic radiations emitted from mobile towers may affect humans' sleep-wake cycle. Abelin *et al.*,[1] reported that exposure to RF-EMR increased the difficulties in falling asleep and maintaining sleep, and consistent prolongation of sleep onset latency was recorded in few volunteers[49]. It has also been reported that the higher resting alpha activity in young adults, but not in adolescents and elderly, is modified following exposure to (2G) GSM[18, 32]. Exposure to RF-EMR increased electroencephalogram power in the spindle frequency range[79]. Further, Schmid *et al.*,[79] showed that both delta and theta activities (non-rapid eye movement sleep) and alpha and delta activities (rapid eye movement sleep) were affected following EMF exposure conditions.

Lustenberger *et al*.,[55] reported an increase in event-related EEG spectral power and phase changes in men's slow wake activity range. A study conducted by Liu *et al*.,[52] revealed that daily exposure to occupational EMR altered sleep quality, while during the same experimental period, no changes in sleep duration were documented. Saxena *et al*.,[78] reported that the exposed group (>2 hours/day of mobile usage) experienced sleep disturbances and day dysfunctions as compared to the control (≤ 2 hours/day of mobile usage). Further, females and evening users of MP showed deterioration of sleep quality[78]. Bhatti *et al*.,[13] reported shorter average sleep duration in individuals exposed to mobile phone upgraded versions with advanced applications. It was found that the exposure to 900 MHz RF-EMF increased the delta-theta frequency range in several frontocentral electrodes does not alter differences in spindle frequency ranges[56]. Danker-Hopfe *et al*.,[20] reported that females had a shorter awake time within the sleep period under RF-EMR exposure than males. It has been reported that alteration in sleep wake-cycle affects our quality of life and wellbeing, individual's daily performance, and overall health[65].

Other studies have found no significant effect of radio-frequency radiations on the human sleep-wake cycle irrespective of these findings. Wagner *et al*.,[91] recorded no significant effect of GSM cellular mobile phone 900 MHz pulsed with a frequency of 217 Hz, pulse width 577 µs on REM sleep. Further, Huber *et al*.,[34] recorded similar findings as Wagner *et al*.,[91]. Another finding revealed that GSM frequency exposure and mobile phone usage's daily duration were not associated with sleep quality[31]. Hinrichs *et al*.,[32] noticed no significant effect of exposure to EMR on humans' sleep stages. The study conducted in Austria reported that low exposure to HF-EMR has no significant effect on sleep quality[36]. Mohler *et al*.,[63] found that excessive daytime sleepiness & sleep disturbances are not associated with mobile phone usage duration & environmental far-field radiofrequency electromagnetic field. Lowden *et al*.,[53] noticed that radiofrequency exposure has no change in sleep stages than a sham, while power spectrum analyses showed a reduced activity within the slow spindle range. Also, no differences were found for health symptoms, Stroop color-word test performance during exposure, or sleep quality[53]. No association between mobile phone use with most of the sleep parameters at baseline, but insomnia was slightly more common among mobile phone users in the highest call-time category[87]. Although the effects of radio-frequency electromagnetic radiation on sleep parameters are still under debate, and results across these studies are not entirely consistent.

Cognition :

Living organisms perceive both evident and subtle inputs from the environment through inherent attributes that they are endowed with. Those attributes are collectively called "cognition." Cognition is the central nervous system's scientific study, including learning, memory, attention, perception, performance, conceptual development, and decision making. Much contemporary evidence proves that exposure to RF-EMR emitted from mobile phone base stations affects humans' cognition-related processes. However, some

other studies did not find any significant effect of RF-EMR on cognitive performance. Several studies reported that exposure to RF-EMR harms human cognitive performance. The study findings showed the negative impact of exposure to RF-EMR by mobile phones on human brain physiology[25,30], reaction time task[68], attention[22], and memory performance[46]. The cellular phone radiation exposures have been shown to alter cognitive functions, including central nervous system activity[9,23,54]. It has also been reported that digital mobile phone exposure altered information processing speed in trail-making tasks and simple choice reaction time tasks[42]. In a cross-sectional study, inhabitants living in proximity to mobile phone base stations showed alteration in neuro cognitive tasks' performance, *i.e.*, visuomotor speed, problem-solving, attention, and memory[70]. Meo *et al.*,[60] suggested that radiation emitted by mobile phone base transceiver stations associated with impaired cognitive performance in-school adolescents. Further, mobile phones' excessive use can cause cognitive function impairment in adults[3]. Cabr´e-Riera *et al.*,[16] suggested that higher brain exposure to radiation is related to lower non-verbal intelligence but not other cognitive function attributes. Furthermore, 902 MHz mobile phone exposure produced minimal auditory and visual memory tasks[10]. Another study suggested that some of the effects of exposure to EMR on memory and brain function have been illustrated to be dependent on the modality of exposure, *i.e.*, Pulsed versus Continuous Wave[47], exposure dose, and side of exposure of head[71] and gender of the individuals[85].

Some studies negate the adverse effect of RF-EMR radiation exposure on different cognitive parameters, such as performance tests, oddball tasks, reaction time, false reactions, attention and memory tasks[44,74,90]. Haarala *et al.*,[29] also did not observe 902 MHz mobile phone radiation exposure on righthanded Swedish volunteers' short term memory. Findings of a double blind study showed no effect of exposure to RF-EMR from cellular phones on simple reaction time, sensitivity, and accuracy in children[69]. Similarly, Cinel *et al.*,[17] and Riddervold *et al.*,[72] did not find any effect of radiation exposure on different cognitive tasks, including trail making B test following other exposure conditions. Furthermore, Curcio *et al.*,[19] also evidence that exposure to RF-EMR does not change BOLD (blood-oxygen-level-dependent) response in humans. Wallace *et al.*,[93] reported that TETRA base transceiver station signal exposure was not affected by cognitive performance and physiological reactions. No statistically significant difference was recorded between the exposure and sham exposure towards cognitive performance and physiological parameters[33,57].

Overall from the ongoing discussed review and literature emerged from the different studies, the effect of radio-frequency electro-magnetic radiation on human sleep behaviour and cognitive performance is still a concern needing careful investigation. People inhabiting around the mobile base stations have been proposed as constructive target populations to investigate the effect of radio-frequency electromagnetic radiations on human sleep and cognitive behaviour. Therefore, we recommend more intensive research with perfectly controlled protocols and follow up studies to be carried out with the focus to eliminate

current controversies concerning the biological effects of RF-EMR in humans.

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