Effect of Radio Frequency Electromagnetic Field on Cognitive Function of Children and Adolescents

Yue Xu*

School of Public Health, Zhejiang University, Hangzhou 310000, P.R.China

*Corresponding author: 3170104208@zju.edu.cn

Keywords: Electromagnetic field, Radiofrequency, Cognitive function, Nervous system, Child, Adolescent

Abstract: For decades, with the acceleration of technological development, a large number of children and adolescent are exposed to various kinds of anthropogenic electromagnetic fields (EMFs), so their caregivers are more concerned about the health impact caused by EMFs. EMF exposure is classified into several different type based on their wavelength, radiofrequency electromagnetic fields (RF-EMFs) (30 kHz to 300GHz) is emitted by mobile or cordless phones, smart devices, base station and Wi-Fi (Wireless Fidelity). According to International Agency for Research on Cancer (IARC), RF-EMFs is regarded as 'possibly carcinogenic to humans. However, the research on the impact of cognitive function caused by RF-EMFs in children and adolescents are not inconsistent and inadequate. This review summarizes the latest research on exposure to EMF of human, especially children and adolescents. EMF exposure sources, epidemiology of RF-EMFs impact related to cognition, animal researches, possible mechanism will be discussed in this review. As children and adolescents are at a critical stage of developing cognitive function, more rigorous prevention methods should be adopted before identifying the potential impact on physical and mental health.

1. Introduction

Over the past few decades, along with the increasing use of electronic devices, the young are more likely to be exposed to radiofrequency electromagnetic field (RF-EMF) that associated with Wi-Fi, cellphones and tablets, and those exposure might have impact on cognitive function in children and adolescents. According to World Health Organization (WHO), exposure to RF fields has made its effect on human health a topic of concern for scientist and the general public[1]. In 2011 yr, an International Agency of Research on Cancer (IARC) classified radiofrequency electromagnetic fields (RF EMF) as possibly carcinogenic to humans. As more researches on risks of cancers, benign tumors, gliomas and meningiomas, neurological and cerebrovascular diseases have been done, outcomes of studies including behavioral and neurological disorders and cancer are the top priority[1], especially studies on children and adolescents.

Among all, the potential impacts on recognition have already been investigated by scientists all over the world, especially possible impacts on cognitive function and nervous system. Since children have small heads and thinner skulls bones, higher absorption from radiofrequency radiation (RFR) than adults is associated than adults as well as their brain tissue has also higher conductivity[2,3]. Form a study on personal radiofrequency electromagnetic field exposure measurement suggests that the main contributor to total RF-EMF measurements of adolescents is their mobile internet use on the mobile phone[4].A study on the sleep habits of kindergarten children further confirms this view, it shows that the vast majority of the children slept in a bright environment, and there were electronic appliances in the room.[5] Another cross-sectional survey indicates that there are 63.5% of children who use display devices (TV, PC, tablets, smartphones, etc.) before bed when the percentage of children who have TV in their rooms is 39.9%[6]. All these directly or indirectly affect children's cognition, the potential impacts of the RF-EMFs might be more urgent than popular belief, and stricter methods should be taken to prevent cognitive functions on the young generation from damages.

2. Basic background of RF-EMF

2.1 Definition and Classification of RF-EMF

Electromagnetic fields (EMFs) are packets of energy that have no mass. They vary in frequency and wavelength and can be classified into two types: ionization EMFs and non-ionization EMFs. Different types of EMFs are shown in Figure 1. Ionizing EMFs are at the high end of the electromagnetic spectrum such as cosmic and X-rays have enough energy to cause ionization. Below in frequency and energy are ultraviolet, visible light and infrared EMFs. Below these forms of EMF are those used for telecommunications technologies (radiofrequency or RF-EMFs, 30 kHz-300 GHz) and those generated by electricity (extremely low-frequency or ELF-EMFs, 3 Hz-3 kHz). These EMFs do not have sufficient energy to directly cause ionization and are therefore known as non-ionizing EMFs [7].

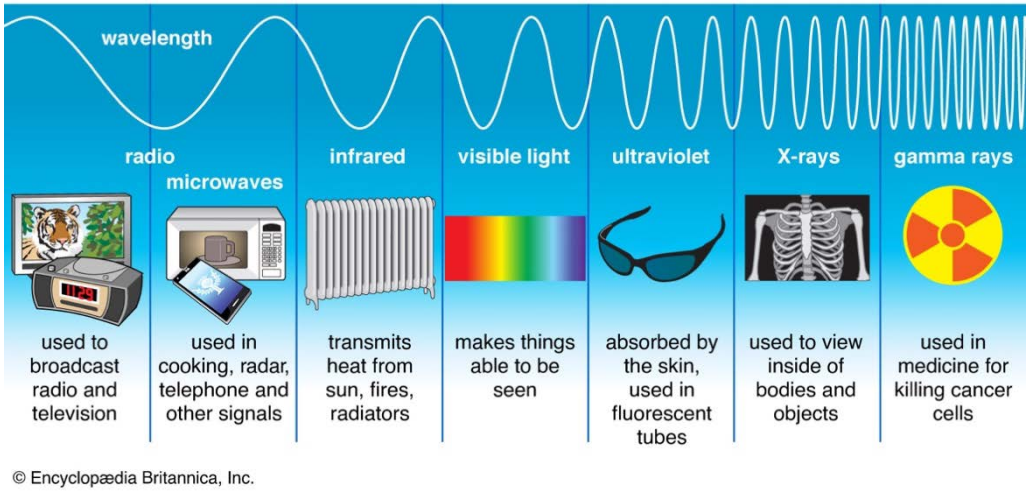

Figure 1. Types of Electromagnetic Radiation8

There are still other types expect RF-EMFs that have different impacts on health. Parts of them are ionizing radiations which are capable of changing the immune system[9], inducing circulatory and metabolic diseases and causing excess cancer risks even with lower doses[10,11]. Also, there are non-ionizing radiation which are similar to RF-EMFs such as extremely low frequency electromagnetic fields (ELF-EMFs) are evaluated as “the agent is possibly carcinogenic to humans”[12]. Association between ELF-EMFs and brain cancer, hemo-lymphoproliferative malignancies, leukemia and breast cancer have been studied and the results of them are inconsistent[13].

2.2 Sources of EMFs

Whenever current flows, an electric and magnetic field, or electromagnetic field, is generated. Electromagnetic fields are everywhere in our surroundings, for examples in thunderstorms, the accumulation of local charges in the air can produce electric fields. Also, the Earth's geomagnetic fields allows the compass to point north and south, and birds and fish use the magnetic fields to determine direction. In addition to natural sources, the electromagnetic fields also include electromagnetic fields generated by many anthropogenic sources from electrical lines, transmission towers, telecommunications, home appliances (televisions, computers etc.), mobile or cordless phones, Wi-Fi, and base stations， which are the key points we want to talk about in this review.

EMFs are categorized EMF frequencies, and those which has frequency of 30 kHz to 300 GHz are known as radiofrequency electromagnetic fields (RF-EMFs). RF-EMFs are emitted by smart devices (cellphones, tablets or laptops), television, radar, data transmission (WLAN, WI-FI, WiMAX) networks and so on.

3. Effect of Radiofrequency EMFs on Recognitive Function

Over the past few decades, it has been controversial whether children and adolescents are more vulnerable to RF-EMFs when they were widely exposed. The epidemiology on different facets of cognitive functions these years offer us some evidence to find out the relationship between exposure and the damages.

3.1 Brain Cancer

Both epidemiology and laboratory studies which use the Bradford Hill viewpoint show that glioma is caused by RF radiation (OR = 2.80, 95% CI = 1.13–6.94)[14]. In 2011, IARC classified mobile phone radiation RF-EMFs to be one of the agents of Group 2B, that is "the agent is possibly carcinogenic to humans"[12]. The reason may be some mutation on central nervous system might impaired cognitive functions like intellectual disability (or low intellectual functioning), impaired speech and language[15,16].

This view has also been verified in animals; possible mechanism of brain cancer caused by electromagnetic radiation is investigated by an experimental study on rat brain. The study suggests that electromagnetic radiation is affective to the oxidant-antioxidant system and causes to structural changes in the frontal cortex, brain stem and cerebellum and impair the oxidative stress and inflammatory cytokine system. This deterioration might lead to disease including loss of these areas function and cancer development[17].

3.2 Sleep Problems

A community-based prospective cohort study in Amsterdam indicates that when sleep duration scores associated with the level of RF-EMFs form base station, sleep onset delay, night wakenings, parasomnias and daytime sleepiness were not associated with the exposure level to RF-EMF from base stations. Also, the use of cordless phone was related to less favorable sleep duration ($p<0.001$), night wakenings and parasomnias, and also with bedtime resistance (mobile phone use at age 5 vs. bedtime resistance: $p<0.001$) ,but not sleeping scores[18].

Another cross-sectional study from Spanish investigates the association between telecommunication and other screen devices use and sleep measures in adolescents and shows that frequency of cordless phone calls (PR=1.30,95%CI:1.04-1.62),mobile phone dependency(PR=1.55,95%CI:1.09-2.56), and tablet use were related to an increase of subjective and objective sleep problems in adolescents[19]. However, currently, there is still an interesting dichotomy on sleep problems caused by RF-EMFs. A cohort study on people aged 18-65 does not support the hypothesis that RF-EMF from mobile phone use has long-term effects on sleep quality since it is not capable of precluding the possibility of other factors associated with mobile phone use unless mobile phone call-time is above 258 minutes (OR= 1.24, 95% CI:1.03–1.51)[20]. As for the different views ， more evidence is needed to draw a conclusion on the impact caused by RF-EMF.

Animals study also indicates that the internal clock of organisms are very sensitive to the exposure of weak RF-EMF[21], and the changes of internal clocks are able to affect the circadian rhythm and the behaviors of sleeping will be further influenced.

3.3 Structural Changes

Whole-brain RF-EMF dose from mobile communication devices for screen activities while wirelessly connected to the internet was associated with smaller caudate volume. Overall brain volumes are not associated with whole-brain and lobe-specific RF-EMF doses[22].

A cross-sectional study investigated the relationship between screening time of preschool children and brain white matter integrity in preschool children， which draws a conclusion that higher use of screen-based media was associated with lower microstructural integrity of brain white matter tracts which also relate to some cognitive function like supporting language, executive functions, and emergent literacy skills through three different standardized assessments ($p<0.01$; $p<0.01$; $p<0.01$)[23].

Several researches on animals also investigate the structural changes in an individual's brain. t 900 MHz EMF may lead to cellular damage in the hippocampus and the cerebellum[24]. Additionally, RF-

EMF exposure may inhibit the development of neuronal synapse formation in the young brain and affect physiological functions[25].

There are also some studies on mechanism to investigate the possible reason of how the EMF can change brains structurally. Rats were exposed to 1800 MHz EMF and the results showed that exposure cause neurochemical and pathophysiological damage by initiating the inflammatory process in various brain regions which might leads to a huge risk of induction of brain damage[26]. Also the study shows the health impacts are additionally associated with a remarkable elevation in the genotoxicity of neurons[26].

Different MHz（900-, 1800-, and 2100-MHz） have certain effects on rats, leading to oxidative stress, increase lipid peroxidation, as well as increase oxidative DNA damage formation in the frontal lobe of the rat brain tissues. In addition, 2100-MHz RFR may cause formation of DNA single-strand breaks[27] which can further leads to changes in biological tissues. However, the impact of different MHz on the mechanism needs to be further discussed.

3.4 Other Cognitive Function Changes

Both epidemiological and animal researches imply the association between certain cognitive functions and RF-EMFs. A cross-sectional study shows that higher brain exposure to RF-EMF is related to lower non-verbal intelligence, but not to other cognitive function outcomes[28]. Auvinen A et al. (2019) reported a prospective cohort study carried by in Sweden and Finland on individual aged 18-66 suggests that occurrence of headache is strongly associated with call-time, while observing no association with occurrence of tinnitus and hearing loss[29].

Animals studies carried by researches also indicates the other aspects of cognitive function changes such as memory performance, emotional behavior and behavioral change. Zhang J-P et al.(2017) suggests that RF-EMF exposure do not affect the spatial memory and brain histology in adolescent male mice[30]. The research also suggests that RF-EMF exposure do not lead to depression-like behavior, but it may however increase the level of anxiety[30]. Research conducted by Hutchison ZL et al. (2020) on marine dwelling creatures demonstrates a striking increase in exploratory or foraging behavior in Little skates in response to human-made EMF[31].

A study indicates that long-term exposure to RF-EMF might exert beneficial effects on hyperactivity-like and anxiolytic behaviors of the 5xFAD mice, a kind of Alzheimer's disease (AD)-transgenic mice.[32] But the studies on mechanism, animals and epidemiology still cannot reach a consensus. Further investigation is needed to provide a solid base to determine the association between cognitive function and RF-EMFs.

4. Conclusion

Though the lack of clear conclusions, especially the limited research on children more surveys conducted in recent years show that there is some correlation between the two. RF-EMFs are associated to cancers when cancers on nervous systems are not the exceptions, such as glioma. And the mechanism might be the change of oxidant-antioxidant system.

Sleeping status and duration of children or adolescents probably related to the exposure to RF-EMFs emitted by base stations and cordless phones when the internal clocks might by a possible affecting route from the exposure to the sleep performance. Nevertheless, the relationship between sleep and exposure is still unclear.

The function-related structural changes play a role in changes of cognitive functions as well. Caudate volume, white matters, hippocampus and cerebellum have been observed changes in different studies, which can partly indicate the possible causes of impacts by exposure to RF-EMFs.

Cognitive function can be evaluated in different aspects, such as intelligence, hearing, memory, etc. and the general cognitive function change might be even harder to draw the conclusions. Thus, more studies can be involved to examine the possible impacts on youngsters.

According to above studies that showed a number of drawbacks and inconsistency of in these studies, no firm conclusion can be drawn on the association between RF-EMFs and cognitive

functions. However, when evidence of children and adolescents have more vulnerable cognitive functions than adults as well as the investigations are still inadequate and inconsistent, more attention should still be paid on preventive methods to protect the underage since the brain continue developing during these periods.

This review cannot simply ignore inconsistent and insufficient results, because according to previous studies, children and adolescents are more likely to be exposed to electronic and intelligent devices, and should pay attention to the exposure of children and adolescents to RF-EMFs electromagnetic fields. In addition, some potential effects of emerging smart devices and emerging telecommunications devices, especially children and adolescents, on cognitive function should be carefully evaluated.

References

[1] E. van Deventer, E. van Rongen, R. Saunders, WHO research agenda for radiofrequency fields. Bioelectromagnetics. 32, 417–421 (2011).

[2] J.-H. Moon, Health effects of electromagnetic fields on children. Clin. Exp. Pediatr. 63, 422–428 (2020).

[3] L. Hardell, Effects of Mobile Phones on Children's and Adolescents' Health: A Commentary. Child Dev. 89, 137–140 (2018).

[4] K. Roser, A. Schoeni, B. Struchen, M. Zahner, M. Eeftens, J. Fröhlich, M. Röösli, Personal radiofrequency electromagnetic field exposure measurements in Swiss adolescents. Environ. Int. 99, 303–314 (2017).

[5] Y. Durduran, S. Pekcan, B. Çolpan, Sleep habits and related factors in kindergarten children. Niger. J. Clin. Pract. 22, 1218–1223 (2019).

[6] P. Brambilla, M. Giussani, A. Pasinato, L. Venturelli, F. Privitera, E. Miraglia del Giudice, S. Sollai, M. Picca, G. Di Mauro, O. Bruni, E. Chiappini, Sleep habits and pattern in 1-14 years old children and relationship with video devices use and evening and night child activities. Ital. J. Pediatr. 43, 7 (2017).

[7] D. Belpomme, L. Hardell, I. Belyaev, E. Burgio, D. O. Carpenter, Thermal and non-thermal health effects of low intensity non-ionizing radiation: An international perspective. Environ. Pollut. Barking Essex 1987. 242, 643–658 (2018).

[8] electromagnetic spectrum | Definition, Diagram, & Uses | Britannica, (available at https://www.britannica.com/science/electromagnetic-spectrum).

[9] K. Lumniczky, N. Impens, G. Armengol, S. Candéias, A. G. Georgakilas, S. Hornhardt, O. A. Martin, F. Rödel, D. Schaue, Low dose ionizing radiation effects on the immune system. Environ. Int. 149, 106212 (2021).

[10] S. Tapio, M. P. Little, J. C. Kaiser, N. Impens, N. Hamada, A. G. Georgakilas, D. Simar, S. Salomaa, Ionizing radiation-induced circulatory and metabolic diseases. Environ. Int. 146, 106235 (2021).

[11] M. Hauptmann, R. D. Daniels, E. Cardis, H. M. Cullings, G. Kendall, D. Laurier, M. S. Linet, M. P. Little, J. H. Lubin, D. L. Preston, D. B. Richardson, D. O. Stram, I. Thierry-Chef, M. K. Schubauer-Berigan, E. S. Gilbert, A. Berrington de Gonzalez, Epidemiological Studies of Low-Dose Ionizing Radiation and Cancer: Summary Bias Assessment and Meta-Analysis. JNCI Monogr. 2020, 188–200 (2020).

[12] List of Classifications – IARC Monographs on the Identification of Carcinogenic Hazards to Humans, (available at https://monographs.iarc.who.int/list-of-classifications).

[13] K. A. Diab, The Impact of the Low Frequency of the Electromagnetic Field on Human. Adv. Exp. Med. Biol. 1237, 135–149 (2020).

[14] M. Carlberg, L. Hardell, Evaluation of Mobile Phone and Cordless Phone Use and Glioma Risk Using the Bradford Hill Viewpoints from 1965 on Association or Causation. BioMed Res. Int. 2017, e9218486 (2017).

[15] A. P. L. Marsh, D. Heron, T. J. Edwards, A. Quartier, C. Galea, C. Nava, A. Rastetter, M.-L. Moutard, V. Anderson, P. Bitoun, J. Bunt, A. Faudet, C. Garel, G. Gillies, I. Gobius, J. Guegan, S. Heide, B. Keren, F. Lesne, V. Lukic, S. A. Mandelstam, G. McGillivray, A. McIlroy, A. Méneret, C. Mignot, L. R. Morcom, S. Odent, A. Paolino, K. Pope, F. Riant, G. A. Robinson, M. Spencer-Smith, M. Srour, S. E. M. Stephenson, R. Tankard, O. Trouillard, Q. Welniarz, A. Wood, A. Brice, G. Rouleau, T. Attié-Bitach, M. B. Delatycki, J.-L. Mandel, D. J. Amor, E. Roze, A. Piton, M. Bahlo, T. Billette de Villemeur, E. H. Sherr, R. J. Leventer, L. J. Richards, P. J. Lockhart, C. Depienne, Mutations in DCC cause isolated agenesis of the corpus callosum with incomplete penetrance. Nat. Genet. 49, 511–514 (2017).

[16] L. S. Blok, J. Rousseau, J. Twist, S. Ehresmann, M. Takaku, H. Venselaar, L. H. Rodan, C. B. Nowak, J. Douglas, K. J. Swoboda, M. A. Steeves, I. Sahai, C. T. R. M. Stumpel, A. P. A. Stegmann, P. Wheeler, M. Willing, E. Fiala, A. Kochhar, W. T. Gibson, A. S. A. Cohen, R. Agbahovbe, A. M. Innes, P. Y. B. Au, J. Rankin, I. J. Anderson, S. A. Skinner, R. J. Louie, H. E. Warren, A. Afenjar, B. Keren, C. Nava, J. Buratti, A. Isapof, D. Rodriguez, R. Lewandowski, J. Propst, T. van Essen, M. Choi, S. Lee, J. H. Chae, S. Price, R. E. Schnur, G. Douglas, I. M. Wentzensen, C. Zweier, A. Reis, M. G. Bialer, C. Moore, M. Koopmans, E. H. Brilstra, G. R. Monroe, K. L. I. van Gassen, E. van Binsbergen, R. Newbury-Ecob, L. Bownass, I. Bader, J. A. Mayr, S. B. Wortmann, K. J. Jakielski, E. A. Strand, K. Kloth, T. Bierhals, T. D. Study, J. D. Roberts, R. M. Petrovich, S. Machida, H. Kurumizaka, S. Lelieveld, R. Pfundt, S. Jansen, P. Deriziotis, L. Faivre, J. Thevenon, M. Assoum, L. Shriberg, T. Kleefstra, H. G. Brunner, P. A. Wade, S. E. Fisher, P. M. Campeau, CHD3 helicase domain mutations cause a neurodevelopmental syndrome with macrocephaly and impaired speech and language. Nat. Commun. 9 (2018), doi:10.1038/s41467-018-06014-6.

[17] O. Eser, A. Songur, C. Aktas, E. Karavelioglu, V. Caglar, F. Aylak, F. Ozguner, M. Kanter, The effect of electromagnetic radiation on the rat brain: an experimental study. Turk. Neurosurg. 23, 707–715 (2013).

[18] A. Huss, M. van Eijsden, M. Guxens, J. Beekhuizen, R. van Strien, H. Kromhout, T. Vrijkotte, R. Vermeulen, Environmental Radiofrequency Electromagnetic Fields Exposure at Home, Mobile and Cordless Phone Use, and Sleep Problems in 7-Year-Old Children. PLoS ONE. 10, e0139869 (2015).

[19] A. Cabré-Riera, M. Torrent, D. Donaire-Gonzalez, M. Vrijheid, E. Cardis, M. Guxens, Telecommunication devices use, screen time and sleep in adolescents. Environ. Res. 171, 341–347 (2019).

[20] G. Tettamanti, A. Auvinen, T. Åkerstedt, K. Kojo, A. Ahlbom, S. Heinävaara, P. Elliott, J. Schüz, I. Deltour, H. Kromhout, M. B. Toledano, A. H. Poulsen, C. Johansen, R. Vermeulen, M. Feychting, L. Hillert, COSMOS Study Group, Long-term effect of mobile phone use on sleep quality: Results from the cohort study of mobile phone use and health (COSMOS). Environ. Int. 140, 105687 (2020).

[21] P. Bartos, R. Netusil, P. Slaby, D. Dolezel, T. Ritz, M. Vacha, Weak radiofrequency fields affect the insect circadian clock. J. R. Soc. Interface. 16, 20190285 (2019).

[22] A. Cabré-Riera, H. E. Marroun, R. Muetzel, L. van Wel, I. Liorni, A. Thielens, L. E. Birks, L. Pierotti, A. Huss, W. Joseph, J. Wiart, M. Capstick, M. Hillegers, R. Vermeulen, E. Cardis, M. Vrijheid, T. White, M. Röösli, H. Tiemeier, M. Guxens, Estimated whole-brain and lobe-specific

radiofrequency electromagnetic fields doses and brain volumes in preadolescents. Environ. Int. 142, 105808 (2020).

[23] J. S. Hutton, J. Dudley, T. Horowitz-Kraus, T. DeWitt, S. K. Holland, Associations Between Screen-Based Media Use and Brain White Matter Integrity in Preschool-Aged Children. JAMA Pediatr. 174, e193869 (2020).

[24] G. Altun, S. Kaplan, O. G. Deniz, S. E. Kocacan, S. Canan, D. Davis, C. Marangoz, Protective effects of melatonin and omega-3 on the hippocampus and the cerebellum of adult Wistar albino rats exposed to electromagnetic fields. J. Microsc. Ultrastruct. 5, 230–241 (2017).

[25] Exposure to RF-EMF Alters Postsynaptic Structure and Hinders Neurite Outgrowth in Developing Hippocampal Neurons of Early Postnatal Mice, (available at https://www.ncbi.nlm.nih.gov/pmc/articles/PMC8159076/).

[26] A. Sharma, S. Shrivastava, S. Shukla, Exposure of Radiofrequency Electromagnetic Radiation on Biochemical and Pathological Alterations. Neurol. India. 68, 1092–1100 (2020).

[27] M. E. Alkis, H. M. Bilgin, V. Akpolat, S. Dasdag, K. Yegin, M. C. Yavas, M. Z. Akdag, Effect of 900-, 1800-, and 2100-MHz radiofrequency radiation on DNA and oxidative stress in brain. Electromagn. Biol. Med. 38, 32–47 (2019).

[28] A. Cabré-Riera, L. van Wel, I. Liorni, A. Thielens, L. E. Birks, L. Pierotti, W. Joseph, L. González-Safont, J. Ibarluzea, A. Ferrero, A. Huss, J. Wiart, L. Santa-Marina, M. Torrent, T. Vrijkotte, M. Capstick, R. Vermeulen, M. Vrijheid, E. Cardis, M. Röösli, M. Guxens, Association between estimated whole-brain radiofrequency electromagnetic fields dose and cognitive function in preadolescents and adolescents. Int. J. Hyg. Environ. Health. 231, 113659 (2021).

[29] A. Auvinen, M. Feychting, A. Ahlbom, L. Hillert, P. Elliott, J. Schüz, H. Kromhout, M. B. Toledano, C. Johansen, A. H. Poulsen, R. Vermeulen, S. Heinävaara, K. Kojo, G. Tettamanti, COSMOS Study Group, Headache, tinnitus and hearing loss in the international Cohort Study of Mobile Phone Use and Health (COSMOS) in Sweden and Finland. Int. J. Epidemiol. 48, 1567–1579 (2019).

[30] J.-P. Zhang, K.-Y. Zhang, L. Guo, Q.-L. Chen, P. Gao, T. Wang, J. Li, G.-Z. Guo, G.-R. Ding, Effects of 1.8 GHz Radiofrequency Fields on the Emotional Behavior and Spatial Memory of Adolescent Mice. Int. J. Environ. Res. Public. Health. 14, 1344 (2017).

[31] Z. L. Hutchison, A. B. Gill, P. Sigray, H. He, J. W. King, Anthropogenic electromagnetic fields (EMF) influence the behaviour of bottom-dwelling marine species. Sci. Rep. 10, 4219 (2020).

[32] Y. Son, J. S. Kim, Y. J. Jeong, Y. K. Jeong, J. H. Kwon, H.-D. Choi, J.-K. Pack, N. Kim, Y.-S. Lee, H.-J. Lee, Long-term RF exposure on behavior and cerebral glucose metabolism in 5xFAD mice. Neurosci. Lett. 666, 64–69 (2018).