

Review

Controversies on electromagnetic field exposure and the nervous systems of children

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Summary. This paper reviewed possible health effects from exposure to low levels of electromagnetic field (EMF) in children, arising from electrical power sources and mobile phones. Overall, the information about effects on developmental processes and cognitive functions is insufficient and further research on children and adolescents is critically needed. New research approaches are required focused on the effects on the developmental processes of children exposed to electromagnetic fields, using consistent protocols. When the current data were considered in detail, it was noted that children's unique vulnerabilities make them more sensitive to EMFs emitted by electronics and wireless devices, as compared to adults. Some experimental research shows a neurological impact and exposure in humans may lead to the cognitive and behavioral impairments. Because of the proliferation of wireless devices, public awareness of these dangers now is important to safeguard children's future healthy brain development.

Key words: Electromagnetic field, Health risk, Mobile communication, Children

Introduction

EMF is invisible, and present everywhere in the environment. Humans are exposed to two types of EMFs, including extremely low frequency (ELF) EMFs generated by devices, such as electronic apparatus and power lines, and radio frequency (RF) EMFs generated by wireless devices, including cordless and cellular phones, and cellular and broadcasting transmission towers (Fig. 1). When terminology regarding this issue was considered, the term EMF was used to designate all of these electromagnetic fields, with RF and ELF referring to specific types of exposure. Exposure to EMFs, particularly with regard to children's nervous tissues, may lead to disturbances in other tissues activities that are controlled by the brain. These concerns have brought about controversial studies, evidence, and discussion in scientific publications about environmental risk factors, health policies and the recommendations of international agencies. Global advances in modern technology have increased the environmental risk factors on brain tissues, causing disorders such as interruptions in sleep patterns, migraines, and vertigo, as well as different types of cancer (Schüz et al., 2009; Khurana et al., 2009). Little information is available about the EMFs of cellular communication devices, like cell phones, regarding their safety guidelines in response to exposure. Therefore, great effort have been made by interested researchers to establish various techniques and international standard guidelines for testing these devices, and to provide clear information about quality assurance and the safety of human tissue exposure (Christ and Kuster, 2005).

The essential aim of this review was to raise awareness about children’s exposure to the low level EMFs emitted by electrical power sources and mobile phones. In light of this knowledge, any cognitive and behavioral impairment that occur after exposure may be prevented by early intervention.

Epidemiological evidence

Some researchers have reported that a population or individual, when exposed to EMFs for a long period of time, may undergo health threats, such as alterations in certain neurological activities and changes in the blood flow in particular areas of the brain, which can be reflected in the brain’s activity and function (AGNIR, 2003; Huber et al., 2000, 2002, 2003, 2005). With regard to the stages of a child’s growth, in terms of the increase in the number of tissues, higher conductivity was shown in the crania of children, with a higher specific absorption rate because of their smaller size, when compared with adult crania. This indicates higher exposure rates in children during mobile phone use, and shows that children are more vulnerable to EMFs than adults (Fig. 2). General attention and early precautionary alerts are necessary to prevent children from succumbing to the negative effects of EMF exposure. This may require limiting mobile phone usage in children (Gandhi et al., 1996; Gandhi and Kang, 2002; Peyman et al., 2001).

Most of the research on EMFs has been conducted

using experimental animals; therefore, further research into human brain tissue is required, especially in children. In addition, scientific evidence reported to the Health Council of the Netherlands (2002) must be gathered in order to apply preventive measures for children’s exposure to EMFs (Grigoriev, 2004; Van Rongen et al., 2004). Understanding this controversial issue is crucial to all sectors, including the government and those non-governmental agencies manufacturing cellular communication devices. Some researchers have revealed that EMFs emitted by mobile phones can interrupt and affect the brain activity of humans, thereby increasing the incidence of cancer after the prolonged use of cell phones (Khurana et al., 2009). Moreover, an increase in neurological symptoms, such as migraines and vertigo, has also been reported (Schüz et al., 2009). In contrast, some scientists have reported that the effects of mobile phones are not significant with regard to human health, which should be confirmed or disproven by further research studies (WHO, 2002).

One epidemiological study reported by Bellieni et al. (2003) showed a relationship between EMFs and ELF and/or RF exposure with some health conditions, such as childhood leukemia, neurodegenerative diseases, allergic and inflammatory reactions, adult brain cancer, and breast cancer. When the causes of childhood central nervous system (CNS) tumors were evaluated, genetic and environmental factors were pointed out, as well as unknown reasons. While gliomas and astrocytomas comprised nearly 50% of all pediatric CNS and primitive

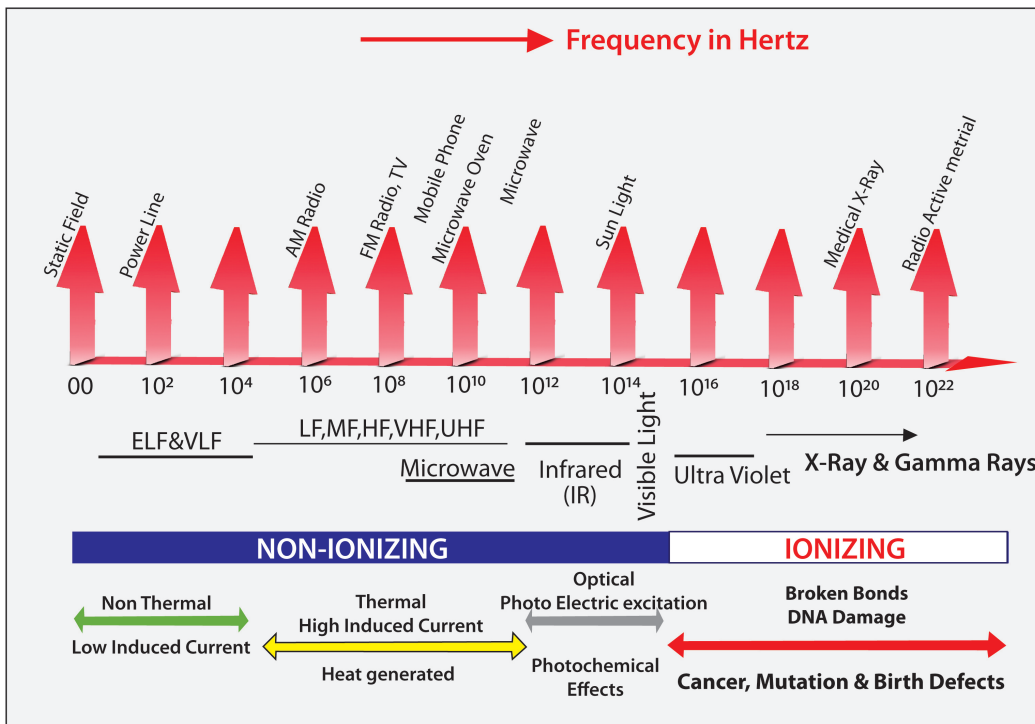


Fig. 1. Entire electromagnetic spectrum, with a partition between nonionizing and ionizing radiation. The main sources at the different frequencies have been added (redrawn from Consales et al., 2012).

neuroectodermal tumors, ependymomas occurred mainly during childhood. In addition, CNS tumors showed a difference between children and adults with respect to the proportion of all cancers (20% in children, less than 2% in adults). Their cellular origins, classification scheme, proportions of pathological subtypes, and anatomical sites are important in explaining these differences (McKinney, 2005); therefore, it is necessary to design specific research to determine the causes of CNS tumors in children. With the presence of benchmarks showing the sequence of human development, starting with the prenatal and fetal periods, the sensitivity to environmental factors and EMF exposure can be determined, especially during the periods of cell proliferation and migration in the last two periods of development. Since the CNS is formed during the third week of development, its tissue is highly sensitive to exposure (Edwards et al., 2003; Rodier, 2004; Saunders and McCaig, 2005).

EMFs and the nervous systems of children

Electromagnetic fields arising from power installations are known to pose risks, but there is no quantitative scientific data related to this. Furthermore, some epidemiological studies have reported that residences located near electric power lines and other high voltage installations have been attributed to increased risks of cancer in childhood (Olsen et al.,

1993; Linet et al., 2003; Wrensch et al., 2012).

Most of the research has been conducted in limited laboratories, and with a small number of children, for a short duration of time; therefore, further research is required, using child and adult volunteers, as well as experimental animals, for the comparison and correlation of the data. Studies like these may provide some qualitative information, but reliable estimates regarding risk cannot be obtained (Sienkiewicz et al., 2005). In contrast, because of the lack of individual and further investigations of electromagnetic field exposure, it has not been reported as a remarkable health issue (with regard to ELF) by the World Health Organization Research Agenda (WHO, 2002). As advanced technology, competition among electronics manufacturing companies, and our social demands for these devices increase, the exposure to EMFs increases the risks to human tissue. Additionally, ionizing radiation may be considered an environmental risk factor in CNS tumors and leukemia (Linet et al., 2003; Wrensch et al., 2012); however, some studies have shown that ionizing radiation has no effect on the CNS (Little, 1999).

Extremely low frequency electromagnetic fields

In 2004, the NRPB released a detailed data analysis of ELF, finding that an increased risk of childhood leukemia was consistent with exposure to EMFs;

How the diffusion of radiation among different ages in the brain

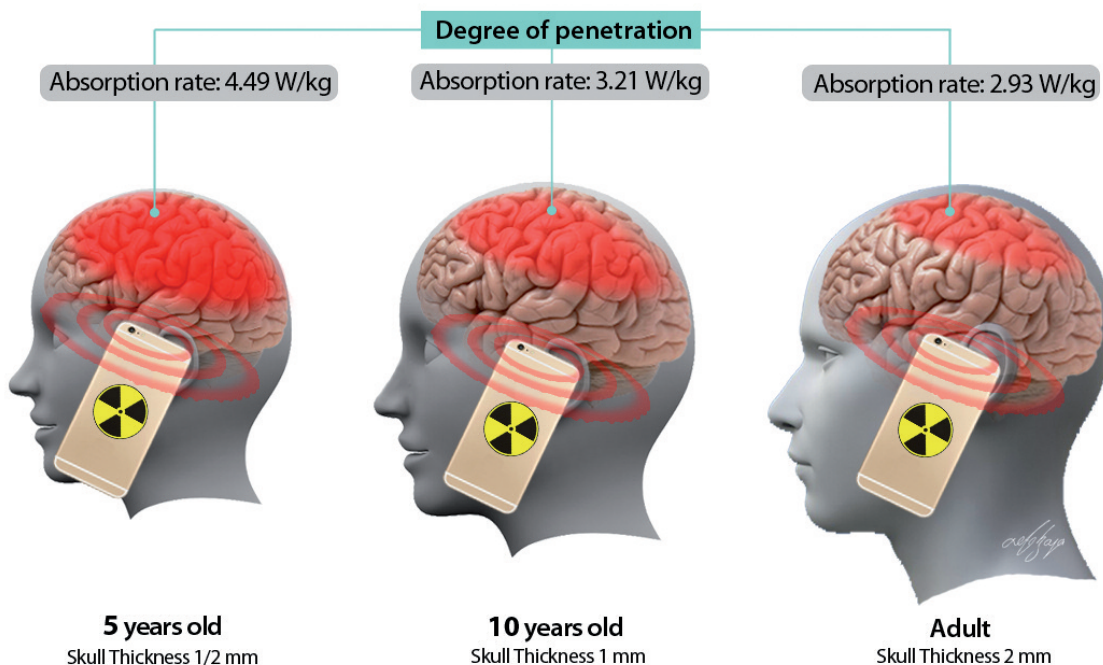


Fig. 2. Absorption of mobile phone radiation in a 5-year old child, a 10-year old child, and in an adult, at 900 MHz (redrawn from Gandhi et al., 1996).

however, the sample size was small with relation to childhood CNS tumors. In addition, childhood CNS tumors have been separately evaluated as a diagnostic group, among others (including leukemia), in several documents (Feychting and Ahlbom, 1993; Olsen et al., 1993; Verkasalo et al., 1993; Tynes and Haldorsen, 1997). However, other studies have been dedicated to the investigation of CNS tumors (Gurney et al., 1996; Preston-Martin et al., 1996; Schüz et al., 2001). Incidentally, none of these studies had adequate sample sizes to subdivide the heterogeneous CNS tumors into diagnostic subgroups, and there was no evidence on the correlation between CNS tumors and other cancer types. The possible risk of CNS tumors in adults, depending on mobile phone usage, was evaluated by the Interphone Study, which was conducted in 13 countries (Cardis and Kilkenny, 1999). The power frequency output of mobile phones, the duration of use, and the model of phone in relation to the geographical location (urban/rural) may be related to the possible risk of CNS tumors in adults. However, in childhood, comprehensive research studies with appropriate study designs are required (Cardis and Kilkenny, 1999).

Changes in the nervous system and brain dunction

Exposure to RFs and EMFs affects many brain

activities, such as sleep, memory, and learning (Diekelmann and Born, 2010). Interestingly, Global System for Mobiles (GSM) mobile phones (900 to 1800 MHz) can affect the cognitive functioning area of the brain; therefore, further research should focus on how electromagnetic fields influence cognitive functions (Barth et al., 2008). Many cognitive studies regarding electromagnetic field exposure have been conducted, but only a limited number are related to children (Lin, 2003, 2004). Exposure to EMFs and ELF is also related to an increased risk for Alzheimer’s disease via the reduction of the pigment melatonin, which protects the brain. In addition, exposure to ELF for a long duration of time may cause calcium (Ca²⁺) level alterations in nervous system cells and neurons, and induce oxidative stress (Fig. 3) (Hardell and Sage, 2008).

Discussion

Mobile phones are usually held close to the cranium during conversation; therefore, the brain is exposed to an EMF. Following a certain exposure period, a variety of health problems can occur in children, including those in the nervous system. Here, it was reported that EMF exposure from ELF and EF creates negative effects in several types of neurodegenerative diseases, including adult and childhood brain tumors, as shown by the

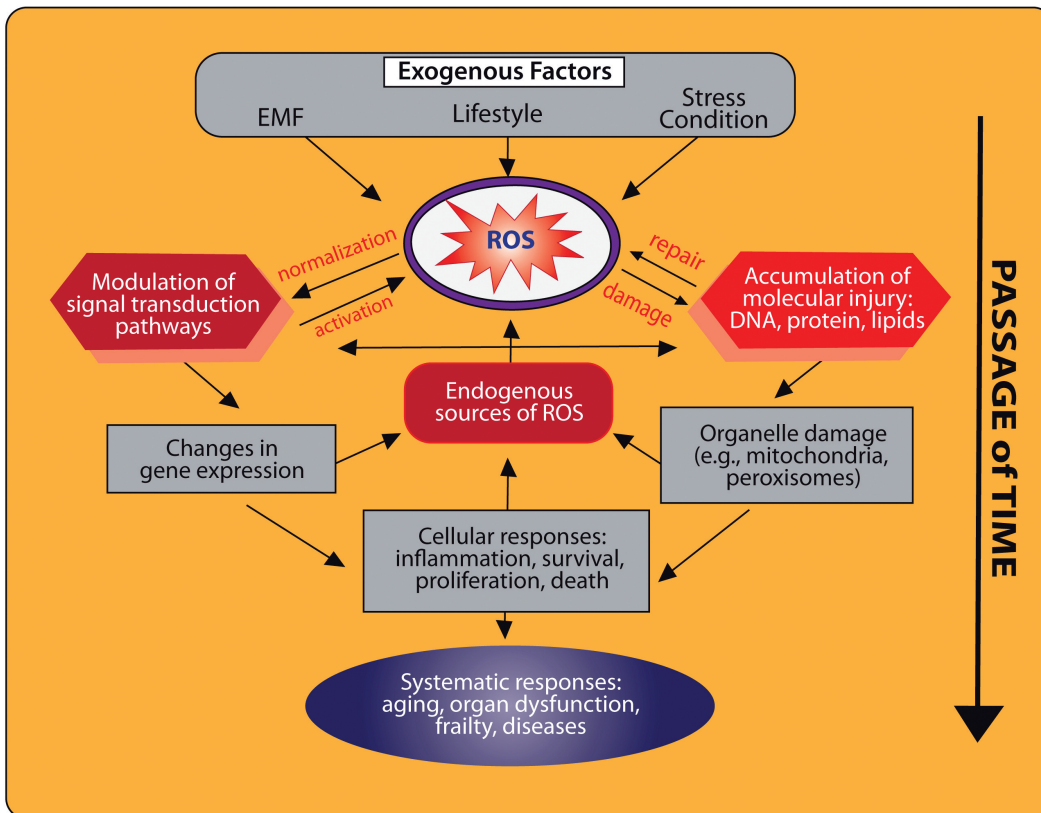


Fig. 3. Schematic summary of the mechanisms of reactive oxygen species (ROS) and oxidative stress (redrawn from Kregel and Zhang, 2007).

Independent Expert Group on Mobile Phones in 2000. Contrarily, some researchers have obtained no evidence regarding the negative effects of EMF exposure, or any disruptions in the brain activities (Skinner et al., 2002). A few studies have reported possible behavioral effects on postnatal development; however, new studies about the effects on pre and postnatal development after exposure to EMFs are required to increase our knowledge regarding this issue (Juutilainen, 2005).

Researchers have conducted experimental studies on animals and, to some extent, humans, to measure the sensitivity changes in brain functions and behavior from ELF and RFs, after using cell phones. The activity waves of the brain, at levels as low as 0.1 watts per kilogram (W/Kg), can cause alterations in humans exposed to cell phone radiation. Therefore, mobile phone radiation shows effects on cognitive memory and learning. Alterations in the brain and nervous system are related to specific risks; however, there are no studies describing short time exposure in childhood comparing the morphology and size of the cranium and the surrounding tissues (Hardell et al., 2007). Childhood brain tissues have greater EMF penetration, with a longer lifetime exposure than adults (Kheifets et al., 2005). Moreover, it has been clearly demonstrated that EMF exposure may alter brain functions and the nervous system. Overall, the significance of long-term exposure has not been widely studied in either adults or children (Hardell and Sage, 2008); but there are a few studies regarding subjective symptoms in children.

The effects of EMFs on human tissues, and the risk factors, have been discussed in the literature, especially over the last few years, coinciding with the increase in advanced technology devices, such as cellular phones (Fedorowski and Steciwko, 1997; Braune et al., 1998; Mashevich et al., 2003). The Global System of Mobile Communications (GSM standard; 902 MHz/pulsed at 217 Hz) focused on the transmission of pulsed RFs, and reported them as a health hazard. In recent years, the effects of EMFs on the nervous systems of humans, specifically related to the use of mobile phones, has been the subject of a large number of experimental studies.

The evidence of spontaneous electroencephalogram (EEG) type signals, especially sleep EEG signals, showed the effects of exposure to the GSM; however, these results are variable. They also indicated that various radiofrequency sources at home and work were involved in alterations in brain activities, such as in cognitive performance, hearing, and balance, including a wide range of symptoms, like migraines, headaches, fatigue, and itching. Furthermore, a causal relationship between EMF exposure and symptoms has not been established by pre-determined studies. In addition, it has been reported that headaches and fatigue are common symptoms following mobile phone usage; in this context, Van Rongen reported a possible relationship between EMFs and these symptoms (Van Rongen et al., 2009). Overall, the effects of electromagnetic field exposure on brain functioning and symptoms have been reviewed by several national and international expert groups (Cook et al., 2006; Krewski et al., 2001, 2007; Valentini, et al., 2007).

Dynamic changes in brain development take place in the *in utero* environment, and continue from the postnatal period to adolescence (Giedd, 2004). These developmental changes are reflected on the brain functions of children in different age groups, as well as the duration of exposure to EMFs; but this correlation has only been made in a few studies (Van Rongen et al., 2009). The effects of prolonged exposure on children's nervous systems through late adolescence are unknown, but there are reports of adverse health impacts with exposures at very low levels (far below public safety standards). This could have serious implications on human health and society's exposure to both ELF and RFs (Lai and Singh, 2004).

Haarala et al. (2003a) made comparisons between two teams of male and female children, with ages ranging from 10-14 years. One team was exposed to GSM phones with a maximum power average of 0.025 W, while the second team was not exposed to GSM phones. They concluded that there was no significant difference between the two teams. However, this requires further study, with greater exposure duration, since the sensitive age of children ranges between 6 and 12 years. In addition, there are ethical concerns about how to involve children in such a study (Haarala et al., 2003b; Martens, 2005). Overall, it is a public health responsibility to lower the limit of exposure to RFs, and

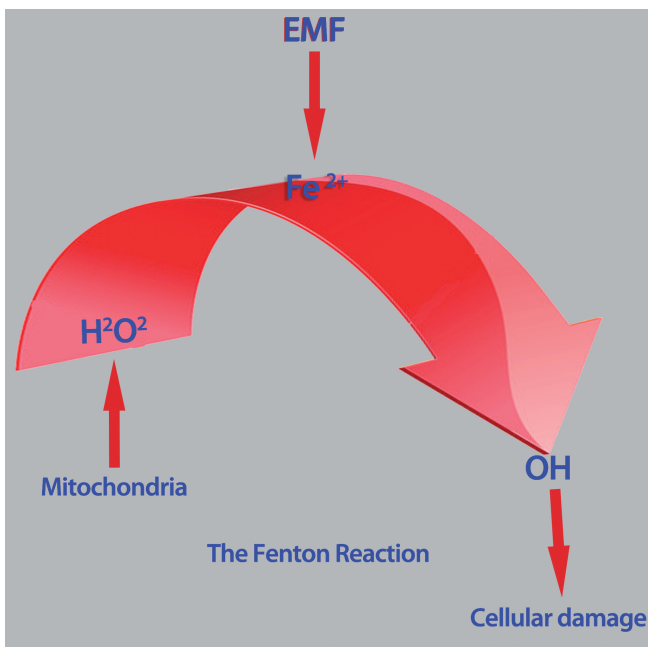


Fig. 4. Representation of the Fenton reaction and its role as a mediator in EMF-induced bioeffects (redrawn from Phillips et al., 2009).

set guidelines for the places where people live and work, such as institutions and schools. Instead of Wi-Fi technology, wired alternatives should be implemented, particularly in schools and libraries, so that children are not subjected to elevated RF levels.

In contrast, the report by the UK Advisory Group on Non-Ionizing Radiation (Agnir, 2012) concluded that no clear scientific evidence indicated that exposure to RFs causes negative health effects in adults or children. Based on European standards, the microwave exposure emitted by mobile phones is 2 W/Kg for the brain. This is based on the thermal effects using cataract development in animal eyes, induced at 100 W/Kg, with a safety factor of 50 for the standard setting. The risks of brain tumors, gliomas, and acoustic neuromas increase with the increasing the use of mobile phones (Scinicariello and De, 2007; Hardell and Sage, 2008).

The EMF exposure in the tissues and, particularly, inside the cells reveals the effects of carcinogenesis on macromolecules, such as DNA, via free radical damage. Some researchers assume that exceeding the EMF safety standard leads to biological damage via heating, but studies have shown that the cell damage can occur in the absence of heating as well. EMFs increase the free radical activity of the cells, as a result of the Fenton reaction, which is a catalytic process of iron that converts it to hydrogen peroxide. This occurs as a product of oxidative respiration, which is very potent, and creates toxic free radicals in the mitochondria (Fig. 4). Any exposure from prolonged low-intensity ELF and RFs results in increased free radical production, and may be considered to be a possible biological mechanism for carcinogenesis (Lai and Singh, 2004; Hardell and Sage, 2008).

Some reports have attributed congenital birth defects (CNS, heart, respiratory system, etc.) to the effects of EMF exposure (Blaasaas et al., 2002, 2003; Cardis and Kilkenny, 1999). In contrast, the evaluation of these defects showed no clear significantly increased or decreased risks from EMFs (Blaasaas et al., 2004).

Generally, public health authorities and international health organizations, including the environmental protection nongovernment sectors, have agreed that the EMF safety standards should be based on scientific evidence, and not on the assumption that the EMF safety standard levels are not applicable or effective. However, there are many examples of scientifically based early warnings about the potential risks to public health. Essentially, the aim has been to establish preventative and precautionary measures against these environmental hazards over a long period of time (Hardell et al., 2007). The use of cordless phones might be a standard preventative method to decrease the effects of mobile phones on biological systems, and RF emitting devices with ELF fields may require different limits in their ranges in the future, as scientific technology advances. Overall, this review paper observed few studies about the general and particular effects of EMFs on the nervous systems of children. In addition there is

insufficient information about the effects of EMF exposure on adolescents and children (Martens, 2005).

Conclusion

This review may add to the creation of different safety measures for children exposed to electromagnetic fields, especially with regard to the effects of the electromagnetic fields emitted by wireless devices. Until now, it has not been reported that children exposed to the RF electromagnetic radiation emitted by wireless devices are more or less sensitive than adults. Most scientific studies on children exposed to electromagnetic radiation from wireless devices do not provide adequate data regarding the negative effects on developmental processes and cognitive functions. In this context, ongoing studies may elucidate the exposure mechanisms and these negative results. New approaches are required, which are focused on the effects on the developmental processes of children exposed to electromagnetic fields, using consistent protocols.

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Conflict of interest. The authors declare that they have no conflict of interest

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