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Aaron Skaist
Touro College

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The Effects of RF-EMF on the Child Brain

Aaron Skaist

Aaron Skaist will graduate in June of 2020 with a Bachelor of Science degree in Biology.

Abstract

It has long been debated whether or not cell phones have a deleterious effect on the brain. Recent studies indicate that the electro-magnetic field emitted by cell phones called RF-EMF is linked to cancer. Guidelines created to limit the exposure have not been changed since 1981 and do not consider children. The mechanism thought to cause cancer is reactive oxygen species (ROS), which cause the creation of micronuclei. RF-EMF poses a greater threat to children than adults. This is due to the major anatomical differences between the head of a child and an adult. The skull of a child is much thinner than that of an adult. Additionally, the marrow in the skull of a child is much more vulnerable to RF-EMF. Another difference is the presence of myelin in the brain of a child. Until the age of two production of myelin sheath occurs at a frenzied pace. After age two production slows but continues into adulthood. The uncompleted myelin sheaths, as well as the unprotected axons, can be easily damaged by RF-EMF. This can lead to axonal degeneration and decreased action potential speeds. Another difference is the presence of neural stem cells. Neural stem cells differentiate from neuroepithelial tissue. These cells then commit to oligodendrocytes or astrocytes and undergo cell division to form immature glial cells. Research shows that children contain a substantial amount of these stem cells, whereas adults do not. RF-EMF inhibits cell division resulting in a decreased number of immature glial cells. Because of these anatomical differences, parents should be wary of the amount of "screen time" they provide their children. The guidelines of acceptable SAR should also be changed to take the risks to children into account.

Key Abbreviations

ROS- Reactive Oxygen Species.

RF-EMF- Radio Frequency Electro Magnetic Fields.

ELF-EMF- Extremely Low Frequency Electro Magnetic Fields

SAR- Specific Absorption Rate

SAM- Standard Anthropometric Mannequin

GSM- Global Systems for Mobile communication

MWF- Myelin associated Water Frequency

Introduction

It has been estimated that as of the end of 2017 there have been more cell-phone subscriptions than humans (International Telecommunication Union 2016). Cell phones use radio-frequency waves to carry information from one phone to another via base towers. As of May 2011, the IARC officially recognized RF-EMF as a Group 2B human carcinogen (International Agency for Research on Cancer 2011). This means that RF-EMF is now classified as a "possible human carcinogen". There are those who believe that it should be moved up to the "known carcinogen" category due to the studies done on rats that show a positive correlation between cell-phones, and cancer (Belpomme et. al 2018). With the arrival of 5G networks and the ever-increasing dependency on cell-phones the potential risks of these networks must be determined. One area of study that has not been as defined is the potentially greater hazards of RF-EMF to children than adults.

It is thought that there are two mechanisms in EMF that cause cancer. The first is thermal radiation and the second non-thermal. Thermal radiation is due to the friction caused by polar molecules as they move along with the electromagnetic field. This effectively heats up the brain the same way a microwave heats up food. This can cause denaturing of DNA. Non-thermal radiation is the emitting of a particle that denatures DNA or splits ROS (reactive oxygen species) creating free radicals that are detrimental to human health. It is now being discovered that even ELF-EMF, such as those that provide electricity, can

cause cancer when one is exposed long-term. This is also seen in RF-EMF, as studies show that one who uses a cell phone for ≥ 10 years will double his chances of getting acoustic neuroma (Khurana et. al 2009)

Another factor that must be considered is the intensity of the radio-wave. The average GSM (Global Systems for Mobile communication) phone operates on a wavelength of 800 MHz to 1900 MHz. This is broadcasted at different strengths depending on the signal strength and how hard the phone has to work to connect to the closest base station. There are guidelines in place to limit the amount of radiation emitted by a phone. This is limited to 1.6 W/Kg in a 1-gram cube of tissue. It is estimated that up to 80% of the radiation emitted by the phone is absorbed by the head when one is talking on the phone normally. The aim of this paper is to explore the potential effects RF-EMF waves emitted by a cell-phone have on a child's brain.

Methods

To complete this study, online scholarly databases were searched for relevant articles. Databases included Google Scholar, as well as ProQuest, EBSCO, and EMF-PORTAL. Key words included "head," "child," as well as "cell phones" among many others. While most of the material found is available to the public, many of the articles needed special access that was provided by Touro College for the use of this paper.

Background

In 1982 the IEEE (Institute of Electrical and Electronic Engineers) was commissioned to find a level of intensity of RF-EMF exposure that could be considered safe. It is worthwhile to keep in mind that the IEEE is an organization dedicated to "advancing technology for the benefit of humanity" according to the mission stated on their webpage. They are also not a group whose main focus is health sciences. Their studies resulted in a near unanimous conclusion of 1.6 W/kg to be safe for non-occupational use (IEEE, 1982), however no rationale was provided for

this number. These guidelines have remained unchanged since a remodeling of the guidelines in 1991 to a two-tier system based on a “controlled environment,” i.e. workers in a profession who are aware of the potential hazards of the job, and an “uncontrolled environment,” i.e. the general population.

Cell phone compliance with these guidelines are tested through SAM (Standard Anthropometric Mannequin), a model head with dimensions based off of the 90th percentile of U.S. military recruits in the year 1989. The corresponding body of the head would be a six foot, two inches, 220 lb. male. The model is filled with dielectric material of similar composition to that of brain tissue. A phone is then positioned next to the head and the model is subjected to a phone call. A probe is inserted between the mannequin’s head and the cell phone, which measures the radiation levels emitted and calculates it as W/kg based off of 1-gram of tissue. This is referred to as the psSAR (peak spatial Specific Absorption Rate), or the SAR of a cell phone. It must be noted that this method can only measure the effects of thermal radiation.

There is another way of calculating SAR called the FDTD (Finite Difference Time Domain) method. This method is a computational program in which a magnetic field is arranged as a three-dimensional grid. The permeability, permittivity, and conductivity are then entered into the program for the material contained in each specific cube. Through this the program can compute based off of all the materials in the cubes how much radiation was absorbed by each specific tissue.

There have been multiple experiments done to prove the hazards of RF-EMF. One of the more popular studies exposed rats to a GSM-like frequency and monitored long-term and short-term effects. The most recent study exposed rats to RF-EMF to monitor long-term effects and found a positive correlation between these waves and cancer (National Toxicology Program 2018). One of the disadvantages of this study was the inability to expose rats in the same manner that a human is exposed. Additionally, the SAR that was used for this experiment was higher than that of normal cell phone use.

Another study that has gained popularity in recent years is the computer simulation of an RF-EMF. This involves studying the characteristics of the electromagnetic field and the specific features of the tissues being exposed. The researchers will then create virtual models and simulate exposure to an RF-EMF. The shortcoming of this type of study is that one can only monitor the effects of thermal radiation. The FDA uses a four-member family for all their simulations consisting of male and female adults and children. Both the SEMCAD program, which monitors EMF, and the virtual family are available to the public.

Potential Effects

These studies, as well as most other recent experiments conducted by experts in the field, yield results that indicate that

RF-EMF’s are potentially hazardous to one’s health. The question remains as to whether RF-EMF causes cancer. Most recent studies find a positive correlation between RF-EMF and malignant glial cell tumors (Falcioni et al 2018). This study is unique as the researchers projected a lower SAR over a longer period of time. This suggests that long-term exposure may in fact be the cause for concern and not the SAR. If this is the case, it would render today’s safety standards useless, as they are based on SAR. Another study found that there was an increased risk for glioblastoma and acoustic neuroma in heavy cell phone users (Hardell et al. 2013). The tumors observed were usually ipsilateral to the preferred side of cell phone use. These results are extremely important. Acoustic neuroma is a benign tumor on the vestibulocochlear nerve, just inside the inner ear. This is the closest organ to which one holds the cell phone while talking on the phone. While acoustic neuroma is not malignant, it can cause deleterious effects by putting pressure on the brain stem. The mechanisms by which RF-EMF potentially causes cancer are unclear. It is highly unlikely that RF-EMFs have enough energy in them to significantly heat up brain tissue to the point that would cause denaturing of DNA. It is highly debated whether they have enough energy to break a strand of DNA. However, even if there is not enough energy to denature or break strands of DNA, there would be enough energy to create ROS which can lead to genetic damage in the long term.

Another adverse effect that RF-EMFs can have is on memory. It has been reported that RF-EMF impair memory, cognitive function, and learning. Experiments show that rats that have been exposed to RF-EMFs for four weeks have performed poorly on inhibitory avoidance tests. The suggested mechanism for learning and memory impairment is that RF-EMF stimulates the opioidergic system in the amygdala, hippocampus and other areas crucial for memory consolidation. This may in turn impair the release of NO, which plays a role in memory consolidation (Ahmadi et al. 2018). Despite this, many researchers have not found RF-EMF to impair memory, learning or cognitive function (Klose et al. 2014).

RF-EMF has been blamed for many other conditions that are not associated with the brain, such as hypofertilization and cancers of the eyes and glands. These are extremely broad fields and are beyond the scope of this paper. Researchers are of the opinion that the mechanism that causes all these ailments is long-term exposure to RF-EMF. However, RF-EMFs do have the energy to potentially create ROS. ROS can be created by transfer of energy from the EM wave to the oxygen molecule or the transfer of a free electron. This has been shown to cause the creation of micronuclei (Kesari et al 2014). A micronucleus contains a chromosome or part of a chromosome that is not included in the daughter nucleus after the nuclear envelope forms around the chromosomes during mitosis. This part of DNA that has been left out of the nucleus is enclosed in its own nuclear

envelope and is attached to the nucleus. Formations of micronuclei have also been associated with DNA double-strand breaks that lead to the incorrect copying of the chromosomes and formation of the nuclear envelope around them. Micronuclei have been used as markers for researchers and healthcare providers to reveal DNA damage and potential cancerous cells. If these micronuclei are a direct consequence of the EMF, then we can see a definite link between RF-EMF and DNA damage. However, even if the mechanism of the formation these micronuclei is not DNA damage, research has shown that the chromosomes inside the micronucleus have reduced functioning (Hatch et. al 2013). Eventually, due to the close proximity of the micronucleus to the nucleus, the contents of the micronucleus will be released into the nucleus. This often results in incorporation of non-functional DNA into functional DNA which can cause the cell to turn cancerous. Thus, even if the mechanism for micronuclei formation is not DNA damage, it is almost inevitable that the formation of micronuclei will lead to DNA damage.

Each of these effects is highly debated amongst researchers. It is not clear whether the cause is the cell-phone or perhaps some other environmental stressor. However, there is overwhelming evidence that cell-phones have a negative effect on the brain of a child.

**Discussion:
Bone Thickness and Density**

The head of a child differs anatomically in multiple ways from the head of an adult. These anatomical differences cause the brain to be more vulnerable to cell-phone radiation. One example is the thickness of the skull. The skull vault is comprised of two flat compact bones with a diploe or spongy bone sandwiched in between. The average skull of an adult is between 6 to 8 mm thick depending on the location on the skull. A study conducted measured the thickness of the cranial vaults of children (birth-18) using CT scans. It was found that skull thickness increases as a child grows older (Smith et. al 2012). Not only does the thickness of the skull develop over time, but so does the cranial capacity. This is to accommodate for the ever growing and developing brain of the child. Additionally, the skull of an adult is completely ossified. The skull of a fetus, however, is made of cartilage and it slowly ossifies until birth. Even after birth there are areas that are not ossified called fontanel. One of these fontanel or soft spots do not ossify and close until six years after birth. One advantage of the incomplete ossification is to assist the baby in descending through the birth canal. Skull thickness increases throughout development due to the remodeling of osseous tissue by osteoclasts and osteoblasts. This is particularly

interesting since remodeling of bone is usually due to stress on the bones. Subsequently, the bones restructure themselves to create new lines of stress. Yet the cranium undergoes little to no stress from the weight of the body as many of the other bones do. Remodeling of osseous tissue in the cranium has been shown to continue until age 18. The thickness of the skull of a child under the age of 1 has been shown to be between 3 and 4 mm (Table 1). The skull of a 20-year-old, on the other hand, has an average thickness of 6 to 8 mm depending on the location on the skull (Delye et. al 2004). This is a significant increase in the protection provided to the brain. Additionally, the bones have been shown to increase in density as the child gets older. The density of the skull of a child under the age of 1 is between 750 and 850 mg/cm³ (Table 2), whereas the density of a 20-year-old is around 1000 mg/cm³.

The added thickness and density of the skull during the development of the cranium is likely due to an increased compact bone formation and decreasing amount of spongy bone tissue. Thus, when a child is exposed to RF-EMF the compact tissue which is the protective covering is not as thick. This not only exposes the brain to RF-EMF, but it also exposes the vulnerable red bone marrow contained in the diploe in between the trabeculae to these waves. This could account for the correlation of leukemia and RF-EMF observed in children in Rome that were within a 2 km radius of base towers that communicate via RF-EMF (Michelozzi et. al 2002). Other studies found the same results in different communities, although the biological mechanism is still unclear. Yet, perhaps since the compact bone

| Age | Mean Thickness (mm) | Standard Deviation (mm) | Age | Mean Density (mg/cm ³) | Standard Deviation (mg/cm ³) |
|---------------|---------------------|-------------------------|---------------|------------------------------------|--|
| 0-6 (months) | 3.4 | 0.3 | 0-6 (months) | 777.1 | 35.9 |
| 7-12 (months) | 4.1 | 0.5 | 7-12 (months) | 822.5 | 39.9 |
| 5 | 5.2 | 0.7 | 5 | 935.5 | 65.9 |
| 10 | 5.9 | 0.8 | 10 | 973 | 33.1 |
| 15 | 6.2 | 1 | 15 | 999.2 | 59.4 |
| 20 | 7.3 | 0.9 | 20 | 1013 | 60.6 |

Table 1 and 2 (modified from Delye et. al 2004))

is not fully developed, it leaves the marrow exposed. These waves could then potentially damage the marrow cells, creating cancerous white blood cells that interfere with the production of red blood cells. The lack of red blood cells carrying oxygen in the blood results in the devastating symptoms of leukemia. Another potential hazard of RF-EMF that can come about due to lack of bone protection is damage to the brain itself. The less radiation that the skull absorbs results in more radiation hitting sensitive brain tissue.

Myelin

A major anatomical difference between the brain of children and adults is the amount of myelin surrounding a neuron. Myelin is a fatty substance which surrounds neurons in the CNS and PNS. Its functions are to insulate neurons to allow action potentials to propagate quickly, as well as to provide protection for the neuron. Among other components, myelin is mainly comprised of sphingomyelin, long hydrocarbon chains, and sphingolipids. It is produced by Schwann cells in the CNS and oligodendrocytes in the PNS. Demyelination has been associated with many diseases such as MS. It is also associated with many psychiatric disorders such as developmental disorders and schizophrenia. Demyelination leaves neurons vulnerable to toxins. It also increases the internal resistance of the membrane, which leads to the decreased velocity of an action potential and less of a chance of this potential propagating into a post synaptic potential (PSP). When demyelination proceeds past a given value, axon degeneration occurs.

Production of myelin begins in the brain at the fourth month of gestation and continues rapidly until the age of two. This rapid myelination relates to the rapid development of cognitive skills, showing the importance of myelin in the brain development. The production then slows; however, myelin is continually being synthesized throughout adulthood. One way to be able to quantify the amount of myelin in the brain is to differentiate between white and gray matter. While myelin is contained in the gray matter, it is most heavily concentrated in white matter. MRI imaging is used to create an MWF (Myelin associated Water Fraction). MWF is a scale that measures the movement and volume of water molecules that are trapped between the lipid bilayer of the myelin sheath. Calculating the water content can provide a quantifiable measure

of the amount of myelin structure above these water molecules. Units are given in mean VFM, or mean myelin water fraction on a scale of zero through twenty-five on a Gompertz curve. Studies using MWF show that the fastest myelination occurs in the first two years after birth (Dean III et. al 2015). MRI images from this same study show a clear progression of myelination throughout the first five years of life (Figure 3).

This study also established a direct association between cognition scores and myelination. It is not by coincidence that the most rapid development in cognition, learning and motor skills occurs during the fastest rate of myelination.

RF-EMF can be a risk for demyelination in children whose myelin development has not been completed. Even adults whose myelin sheaths are fully developed are at risk of demyelination due to RF-EMF. The risk exists because formation of free radicals by RF-EMF can cause lipid peroxidation. This can then cause the myelin to be oxidized, resulting in the formation of a free radical chain. The demyelination results in an exposed axon that risks further damage by RF-EMF, which could potentially degenerate the axon. Demyelination can also result in slower action potentials and the decreased likelihood of PSP propagation in the post-synaptic membrane. This may be the mechanism for the lower cognition scores observed by (Dean III et. al 2015) in children with lower VFM. Lower myelination levels can also result in the plaques of dead neurons associated with MS as demyelinated neurons die. Children whose myelin is still not fully developed in certain areas in the brain are at an increased risk of myelin and axonal degeneration. The more RF-EMF that is absorbed by the brain in a child, the more exposed the neurons can become as demyelination progresses.

Neural Stem Cells

When a child is born, most of the neurons needed are already differentiated from their stem cells. Development of the brain consists of axonal growth as well as formation of new synapses. Another area of development is the differentiation of glial stem

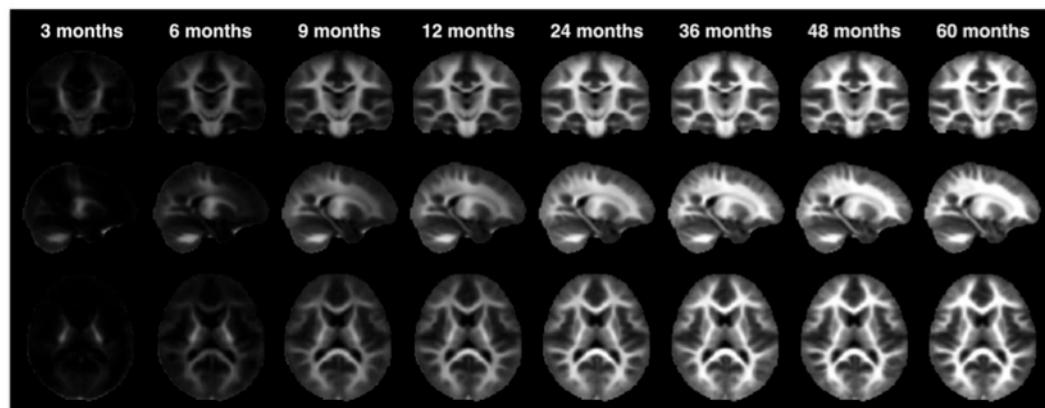


Figure 3

cells into immature glial cells. Studies show that the number of mature oligodendrocytes and astrocytes significantly increase in the first three years after birth (Kjær et al. 2017). In this study, researchers found that while there was an insignificant increase in neurons in the first three years of life, there was almost a threefold increase in the number of glial cells from birth until age three. Oligodendrocytes added an average of 6 million new cells per month, which is about two new oligodendrocytes per second. After the age of three, addition of new oligodendrocytes declined, adding only another 10 million from the age 3 until adulthood, whereas addition of new glial cells is negligible.

All neural cells including neurons and glial cells are originally derived from neuroepithelial cells of the neural tube. The neuroepithelial cells that will eventually become glial cells differentiate into precursors of oligodendrocytes and astrocytes, and then migrate toward the neurons. These precursors then differentiate into immature oligodendrocytes or astrocytes. The differentiation of the neuroepithelial cells into oligodendrocyte precursor cells is accomplished on three distinct waves of proliferation. The waves are initiated by sonic hedgehog signaling (SHH), a signal that controls differentiation of cells in an embryo. These signals cause the formation and migration of precursors from neuroepithelial tissue in both the CNS and PNS in the early days of gestation. Less than 3% of the precursor cells do not differentiate and remain as precursor cells in the adult brain. Once the precursor cells have reached their destination, they differentiate into immature glial cells. The precursor cells will then express certain sequences of transcription factor codes that will determine whether this cell will be an astrocyte or an oligodendrocyte. If the cell undergoes genetic commitment to oligodendrocytes, it will develop a PDGFRα receptor that will be sensitive to platelet derived growth factor (PDGF), a key component in the differentiation of a precursor into an oligodendrocyte. Upon stimulation from PDGF the cell will then undergo chromatin condensation and will form heterochromatin. This will cause silencing of certain genes and the activation of specific sequences of transcription factor, which results in the formation of an immature oligodendrocyte (Goldman, Kuypers 2015).

Exposure of glial cells to RF-EMF results in a decreased conversion of precursor cells to immature glial cells. A recent study found that long-term exposure to RF-EMF resulted in a dramatic decrease of proliferation (Eghlidospour et al 2017). One must keep in mind that in this particular study a higher SAR (2.287 W/kg) was used than that of a cell phone. Despite this, the RF-EMF was not found to induce apoptosis of these cells which had been previously suggested. However, the results did show an inability of precursor cells to undergo proliferation into immature oligodendrocytes, which resulted in a lower number of available oligodendrocytes to perform myelination of the neurons. The brain of a child contains many more of these precursor cells than an adult brain does. The development of a neuron, including

its axonal growth and formation of new synapses, depend on the myelination by the oligodendrocytes. If oligodendrocytes are withheld from differentiation, a lower number of mature cells available for neuron myelination can result. The lack of myelination can affect action potential speeds and cause axonal degeneration. Additionally, the inability to differentiate not only results in less immature oligodendrocyte cells, it will also result in less immature astrocytes. This is because astrocytes and oligodendrocytes share the same precursor cell.

Conclusions

Both biologically and socially, the early years of development are extremely sensitive to environmental factors of a child. The SAR guidelines have still not been changed to accommodate the developing brain of a child. There has been little effort to monitor how children get phones or how long they use them. As technology roots itself deeply in our lives and society depends increasingly on its conveniences, there must be an understanding of the potential effects that they can have on children. While the effects of exposure continue to be debated amongst researchers, it is clear that the guidelines are not sufficient when it comes to children. The current methods of testing SAR do not take into account many variables that change from children to adults. Additionally, the guidelines have not been changed since 1981 despite the upgrade to the “known carcinogen” category. The difference between the brain of an adult and that of a child, as well as the importance of the development of the brain, should warrant a difference in guidelines.

One may question the relevance of these studies, as they all discuss the brain and the normal method of talking on the phone. In current society talking on the phone has been replaced by texting and using phones for virtual reality gaming. Therefore, one may question whether the studies done are relevant to modern society. Yet studies show that while the head absorbs 80% of the radiation while one is talking on the phone, the head absorbs 50% of the radiation during gaming (Fernandez 2018). This is still a considerable amount. Especially with the current culture of letting children use cell-phones to stream movies and play games online. The effects of cell-phones, whether socially or biologically, clearly affect children. While the purpose of this paper is not to suggest that society abandon cell-phones entirely, there should be some sort of regulation for giving a cell-phone to a child, the same way there are rules regarding giving a minor tobacco or alcohol.

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