Review

Electromagnetic Safety of Children Using Wireless Phones: A Literature Review

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In this article, several issues related to the safety of electromagnetic field exposure of children when using wireless devices such as mobile phones are described. The information available in the literature is reviewed and open areas that need to be subject of future research are identified. A lack of proof that dielectric properties change with age and an inconsistency in absorption studies in children is reported. The number of biological studies relevant to children is limited. Only some of the cognitive studies specifically target children and these show no significant effect of exposure. There is also a need to investigate the impact of electromagnetic fields on the developmental process of children. All this makes a definitive answer to the question if children are more sensitive to electromagnetic fields than adults impossible. More consistent research will be needed. This study is part of the European COST281 project "Potential Health Implications from Mobile Communication Systems." Bioelectromagnetics Supplement 7:S133–S137, 2005. © 2005 Wiley-Liss, Inc.

Key words: GSM; mobile phone; electromagnetic exposure; children; COST281

INTRODUCTION

There is a wealth of research on potential health hazards of radio-frequency (RF) radiation, but very little is targeted specifically at children. The possible higher sensitivity of children was raised by the UK Independent Expert Group on Mobile Phones (IEGMP) in the "Stewart report" [Stewart, 2000].

This was the background for launching a subproject "Mobile Communications and Children" within the framework of the European COST281 project "Potential Health Implications from Mobile Communication Systems" [COST281 project, 2001] during the COST281 meeting in Rome on May 5, 2002. The goal of the study was to collect and review information related to the following six areas [Martens, 2003]:

1. Anatomical properties and biophysical and biochemical mechanisms,
2. Dielectric properties,
3. Absorption of electromagnetic waves,
4. Biological effects,
5. Patterns of usage of mobile phones,
6. Communication on electromagnetic fields (EMF).

The focus of the project was on the electromagnetic exposure to wireless devices and more particularly to mobile phones. RF radiation from fixed antennas, used in GSM/UMTS or TV/radio stations, is not included.

Differences in usage pattern, dosimetry, and biological effects between children and adults using mobile phones are especially investigated. If children were more sensitive to electromagnetic radiation than adults, it could be due to the anatomical differences, biophysical and biochemical changes during growth, higher absorption of electromagnetic fields. In the following, we analyze this potential higher sensitivity based on published research and identify open questions that must be answered to make scientifically based conclusions.

The importance of this topic is emphasized by the increasing number of young children that are nowadays using mobile phones. For example, in an Australian survey of 333 children of age 6–13 in February 2003, 93% of the children aged 6–9 reported sometimes using their parents' mobile phones. In the group of children aged 10–13, 36% own their own mobile phone [McNair Ingenuity Research, 2003].

Finally, the topic has been further reviewed by the Health Council of The Netherlands that came to the

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Received for review 4 November 2004; Final revision received 15 March 2005

DOI 10.1002/bem.20150
Published online 29 July 2005 in Wiley InterScience (www.interscience.wiley.com).

conclusion that there was no scientific evidence to restrict the use of wireless phones by children [Van Rongen et al., 2004].

In reply to the publication of Van Rongen et al., Grigoriev stated that the conclusion of the Dutch Health Council was ill-founded. He claimed that the unique vulnerability of children as they grow and develop should be taken into account and that there is not enough scientific information for the evaluation of consequences of the use of wireless phones by children [Grigoriev, 2004].

LITERATURE REVIEW

The following review summarizes the literature related to children and electromagnetic radiation safety collected so far in the aforementioned project. It should be mentioned that this review paper only covers the main lines of the research and illustrates these with examples of publications, but does not give an in depth detailed analysis of all the published literature.

Anatomical Properties and Biophysical and Biochemical Mechanisms

There is a wealth of scientific information available on the development mechanisms and the anatomical properties of children available in the literature. A Swiss study [Prader et al., 1989], for example, performed antromorphic measurements, such as weight, height and head circumference, on 137 individuals of each sex from birth to adulthood between 1954 and 1976. A considerable literature describes the anthropometry of the head and the face [e.g., Farkas, 1984] as well as the auxology of the body [e.g., Sempé et al., 1979].

Growth of the head and brain primarily happens during the first decade of life. For example, the circumference of the 1 year old child's head is 84% and that of a 7 year old child head is already 93%–95% of the circumference of an adult's head [Prader et al., 1989]. The growth is mainly in the skull and in the brain. The thickness of the cranial bones increases up to the age of about 18 but the increase is fastest in the first decade, from an average of 1.4 mm at birth to 6.8 mm at 12 years of age [Koenig et al., 1995].

From 5 to 20 years of age, the brain volume increases by about 10% while the skull thickness increases by more than 70%. Furthermore, the red and yellow marrow in the cranial bones change considerably with age. A newborn's marrow is almost all red, while this red marrow reduces to 50% at the age of 20 [Simonson and Kao, 1992].

Myelinization is the formation of a layer of proteins and lipids, i.e., fatty substances, that forms a sheath around nerves and speeds the transmission along nerve cells. Without myelin the brain cannot transmit/receive messages to/from other parts of the body. Myelinization starts during gestation and is in an advanced state in all subcortical areas at the end of the second year of age [Holland et al., 1986; Van der Knaap and Valk, 1995], but in a few regions it continues during teenage and young adult life [Yakovlev and Lecour, 1967]. As myelinization increases, the water content and therefore also the conductivity decreases.

As a mobile phone is held close to the ear, it plays an important role in the absorption. For example the pinna undergoes changes as a function of age. This influences the absorption of electromagnetic radiation from the mobile phone directly but also indirectly because the changes will influence the positioning of the mobile phone.

Finally, the skin thickness also varies with age. It may increase by 70% from a 2 year old child to an adult. This increase must be taken into account when evaluating the absorption.

While the vulnerability and resilence of developing organs to the exposure to environmental toxicants have been investigated for a long time [e.g., Andersen, 2003], the impact of electromagnetic fields on the development from child to adult has not yet been studied.

Dielectric Properties

Important parameters for the absorption of RF are the dielectric properties of human tissue. In electromagnetic simulations, these parameters have been until now assumed to be constant; however, measurements on animals show that the dielectric constant and conductivity decrease with age.

Some studies [Thurai et al., 1984] and [Thurai et al., 1985] reported systematic changes in the dielectric properties of mouse and rabbit brain tissue as a function of the age of the animal. In another study [Lu et al., 1994], measurements of dielectric properties of human red blood cells in suspension revealed statistically significant age dependence with a critical age of about 49 years, above which both permittivity and conductivity decreased significantly. This is because the dielectric properties of blood in the radio frequency range depend on the value of haematocrit [Jaspard et al., 2003]. As the haematocrit increases, as happens in the transition from childhood to adolescence [Bao et al., 1993], the conductivity decreases.

Recently, two studies of dielectric properties of tissues from newborn to fully-grown rats were carried out over a wide frequency range [Peyman et al., 2001; Peyman and Gabriel, 2002]. In the first study [Peyman et al., 2001] dielectric measurements were performed in the high-frequency region of the spectrum (130 MHz–10 GHz). The second study [Peyman and Gabriel, 2002] extends the characterization of dielectric properties of rat tissues as a function of age to the lower frequency range of 300 kHz to 300 MHz. Many tissues and animal age groups were considered. The outcome confirmed previous findings in Thurai et al. [1984, 1985] and proposed that the variation of dielectric properties of tissues with age may prove a relevant factor in the assessment of the exposure of children.

Although measurements of dielectric properties of animal tissues are available in which changes with ages are clearly noted, the extrapolation of results to humans is questionable, especially when rats or rabbits are used that are not really representative for humans.

Specific Absorption Rate (SAR) Determination

Reasons for different RF absorption or SAR in children's and adults' heads could stem from differences in head sizes, tissue sizes, and dielectric properties of the tissues. A thinner skull could for example be a reason for deeper field penetration in the head. However, contradictory results have been found in simulation studies [Lin, 2003]. Some research groups found an important SAR increase in children's head with respect to adults' [Ghandi et al., 1996] while other groups do not find any relevant differences [Shönborn et al., 1998]. There may be various reasons for these contradictions. Some groups have used layered spherical models with different dimensions for adults and children [e.g., Anderson, 2003], others used simple scaling to obtain a child's head model starting from an adult model. However, this does not deliver realistic SAR results. A better approach which has recently been applied [e.g., Wiart et al., 2004] is nonuniform scaling where the different tissues are differently scaled in order to obtain realistic distribution of the tissues in the head. Not many real models based on magnetic resonance imaging (MRI) data are available for children due to the duration of a detailed MRI scan during which the child may not move. Christ et al. [2005], for example, used a high-resolution head model of a 3 year old child.

Even these models will however not lead to an accurate comparison of the SAR in children and adults because these models do not include the elasticity of the ear. Since the child's ear is less elastic and thinner [Ito et al., 2001], the mobile phone pressed against it could come closer to the brain and an increased absorption in the brain could result.

The position of the mobile phone with respect to the head and the antenna model are critical parameters in simulation programs and may account for the differences in SAR results. Further, some simulation results are based on constant input power while others are assuming the input current to be constant. In the first case, the current and thus the magnetic field and absorption in the head of the child increase, while in the second case, the field and thus the SAR are maintained at a rather constant level [Wang and Fujiwara, 2003]. Which case is relevant will depend on the actual engineering design of the mobile phone. As with all simulations, it is important to ascertain that the differences in SAR are not due to numerical uncertainty.

Biological Effects

Many studies have been published relative to animals (birds, mice, rats, and monkeys) exposed to RF prenatally and/or during early development. Some of these use powers comparable to those of mobile phones and make use of high-quality dosimetry, guaranteeing an appropriate control of the SAR values.

The development of the central nervous system (CNS) is similar for humans and animals, albeit on a different time scale. Thus animal studies might provide important information regarding human CNS development.

Adey et al. [1999] examined the effects of chronic exposure of modulated 836 MHz microwave radiation on the incidence of spontaneous and ENU-induced (ENU [ethylnitrosourea] is a chemical mutagen that alters a base pair in a gene) primary CNS tumors in Fisher 344 rats during their 2 year lifetime, starting at an age of 33 days. The authors concluded that the results do not point to an increase in tumorgenesis in the mammalian CNS resulting from exposure to TDMA signals used by some mobile phones, e.g., GSM. However, they reported a trend towards reduced tumor incidence among the exposed versus the unexposed animals that was not significant for the overall population, but was reported to be significant among the 32 ENU-treated animals that died before the end of the study.

In Gatta et al. [2003] it is shown that immunological parameters were not altered in mice exposed to radio-frequency, whole body SAR of 1 and 2 W/kg. A very recent study by Anderson et al. [2004] revealed that a 1.6 GHz RF field exposure of Fisher 344 rats from 36 days until 2 years old did not affect the incidence of cancer.

There are several on-going studies that investigate effects of GSM- or UMTS-like signals as a function of age, e.g., Bornhausen et al. [2003]. The European PERFORM-A project, funded by the European Commission under the 5th framework program, includes several 2 year animal studies at mobile phone frequencies. The objective of the project is to provide data on possible carcinogenic effects of radio waves in animals.

Cognitive Functions and Reaction Time

Other studies investigate the impact of electromagnetic waves on cognitive and other biological functions. An interesting discussion is published by Lin [2004]. Many cognitive studies regarding electromagnetic radiation are reported, but only a limited number relate to children. These studies investigate the impact of RF radiation on EEG, behavior, reaction time, and subjective symptoms. The influence on EEG during different memory tasks (either auditory or visual) has been for example studied in [Krause et al., 2000, 2004]. EMF seem to affect human brain electric oscillatory responses around 8 Hz during cognitive processing. This might be due to the pulse modulated character of the mobile phone signal containing low frequency components.

Haarala and Preece [2003] compare two studies of the reaction time of children with and without exposure from GSM phones. The first study performed by Preece's team measured reaction times of eighteen 10–12 year old children using a standard GSM telephone mounted in a headset to compare sham, 10% of maximum power (0.025 W average), and full power (0.25 W), while the second study by Haarala's team tested thirty-two 10–14 year old children (16 boys and 16 girls). Under double-blind conditions the subjects performed the tests twice: once during an exposure to an active standard 902 MHz GSM mobile phone, and once when the phone was inactive. No differences in the reaction times between exposure conditions were obtained in both studies. The same results were found in comparable studies on adults [e.g., Haarala et al., 2003].

There is certainly a need for more studies with children because intensive usage of mobile phones starts with children between the ages of 6 and 12. However, ethical aspects concerning these studies are under discussion.

Patterns of Usage of Mobile Phones

Children use mobile phones in a different way than adults do. Duration and frequency of calls and the usage of SMS are examples in which children may differ from adults. This may have a large influence on the duration and exposure to EMF. As the patterns of use of mobile phones change rapidly, especially by children, a continuous monitoring is needed.

EMF Communication to Children

Not a lot of information is available with regard to specific electromagnetic field (EMF) communication to adolescents and children. Two websites have been identified that are more or less oriented to inform adolescents, one Belgian [Belgian government, 2005] and one Swiss [Research foundation mobile communication, 2005]. Information on EMF needs to be converted in material suitable for different age groups. An EMF communication strategy and material for children and adolescents are scarce and need to be further developed.

CONCLUSIONS

In this study, an overview of different safety aspects of electromagnetic exposure of children when using wireless devices is given. In general, the following can be mentioned based on the literature reviewed. Upto now it cannot be concluded that children are more or less sensitive than adults to RF electromagnetic radiation, in particular from wireless devices. There is still an inconsistency in the literature data regarding absorption in the head of children and adults. Although most biological studies do not indicate an impact of electromagnetic radiation from wireless devices on the development of animals and on cognitive functions in children, results of important on-going studies could provide more definitive conclusions. Finally, research focused on children using consistent protocols is recommended.

ACKNOWLEDGMENTS

The author wants to thank all the contributing scientists and the COST281 management team for the support of this study project. Leen Verloock and Christof Olivier are acknowledged for their assistance in organizing the study project. The author also thanks the reviewers for very useful comments and contributions with publications.

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