

# BIOLOGICAL AND HEALTH EFFECTS OF EXPOSURE TO ELECTROMAGNETIC FIELD FROM MOBILE COMMUNICATIONS SYSTEMS

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Mobile communication devices are sources of radiofrequency (RF) electromagnetic field (EMF) that are common in daily life and can cause strong exposure to the head. Possible adverse health effects, especially on brain functions, have been of great concern among the general public since the explosive penetration of this technology began in the 1990's. The exposure complies with current safety guidelines. The established knowledge of biological effects of RF does not provide any evidence for anecdotally reported effects such as memory loss or causing brain tumors. However, there is no way to prove the absolute absence of such effects. The enormous efforts have been made to search for such unknown effects and ascertain the safety of this technology. Recent research on the possible effects of RF-EMF on the brain is briefly summarized here to show what is known and what remains unknown. The evidence reported so far indicates few effects that could possibly damage human health seriously. Only slight changes in physiological function in the brain may exist, but variation of the data is too great to believe that the exposure actually has the potential to affect function. The health risk, if any, at an individual level, would be very low in consideration of the available evidence. However, if mobile phone fields were actually hazardous, the very large number of mobile phone users could mean that, even if the individual risk were very low, the impact on public health could be considerable. This is the most important reason why so many efforts are being made in this issue.

Key Words: Health, Effect, Electromagnetic field, Mobile, Communications

## 1. INTRODUCTION

The explosive penetration of mobile communications into daily life in the 1990's has stimulated concerns of the general public on possible health effects of exposures to radiofrequency (RF) electromagnetic fields (EMF) from mobile telecommunications equipment (MTE) and their base stations. Although safety guidelines on exposure to RF-EMF have been issued in various countries based on experimental evidence since 1950's, the public fear of possible unrevealed effects of exposure below guideline levels is still increasing. The World Health Organization (WHO) initiated the International EMF Project in 1996 to promote investigations on this issue. A number of research projects focused on this issue have been done in various countries in the framework of this project.

Mobile communications are often used in transportation systems. An obvious risk accompanied with the use of MTE in transportation systems is electromagnetic interference with electronic circuits involved in the control systems. Banning the use of MTE in airplanes is commonly accepted to avoid such risks. It is also recognized that cellular telephones can interfere with implantable cardiac pacemakers if the immunity of the pacemaker is

poor and the distance is small (< 15cm). Guidelines to protect patients from this risk have been issued that cellular phone devices should not be used within certain distances (e.g., 22cm in Japan) from a pacemaker.

Another obvious risk associated with the use of MTE in transportation systems is reduced ability to drive a car resulting in an elevated risk of traffic accidents. A number of studies demonstrated the effect through volunteer studies<sup>1-3</sup> as well as epidemiological studies<sup>4,5</sup>. The reduction is attributed to the control of the MTE and conversation with one hand holding the MTE. Based on appropriate evidence, the use of MTE whilst driving is prohibited or discouraged in many countries. In relation to this issue, there is an anecdotal explanation that the EMF from MTE might directly interact with cognitive processes of the brain resulting in the reduction of driving ability. This explanation can be ruled out because the effect, if any, should be far less than overwhelming other obvious reasons.

In this paper we review the current state of knowledge on the biological and health effects of RF-EMF. First, we will review the established phenomena that form the basis of contemporary guidelines on the limit of exposure to RF-EMF. Then we will discuss the yet unestablished issues. We review recent results of studies with a special focus on the effects of exposure from MTE.

Especially the effects on brain functions are reviewed because it might have some association with the driving ability. We will also discuss health risk assessments that have been made by several expert groups to delineate the current view of experts on this issue.

## 2. ESTABLISHED PHENOMENA

### 2.1 Thermal effect<sup>6</sup>

Thermal effects of RF electromagnetic fields have been recognized since the 1930's, when RF diathermy was attempted in the treatment of various diseases. Tissue absorbs RF energy due to the dielectric loss of tissue resulting in elevation of tissue temperature. The "artificial fever" was believed to help the healing of patients from diseases. The temperature rise can affect physiological function of the body, which is sometimes beneficial to health, but can also result in adverse health effects. The adverse effect due to excess heating during diathermy was soon recognized.

In the 1950's high-power microwaves had become commonly used in military services especially in the USA. In order to protect military personnel from excess exposure to microwaves, they needed to establish the safety limits to avoid adverse health effects due to microwave exposure. Tri-service organized a project to accomplish this task. They recognized that thermal effects were the prevailing effect over other effects and that adverse effects due to core temperature elevation were observed at about  $100\text{mW}/\text{cm}^2$  of incident power density in microwave frequencies. They decided that  $10\text{mW}/\text{cm}^2$  should be the maximum permissible exposure of microwaves on humans in consideration of a safety factor of 10 to the estimated threshold of  $100\text{mW}/\text{cm}^2$ . This was the most important outcome of this project.

### 2.2 Recognition of resonance and electromagnetic dosimetry

Electromagnetic fields in the high frequency region have a characteristic referred to as "electromagnetic waves". The wavelengths range from 3km at 100kHz to 1mm at 300GHz in the RF region. Current mobile phone systems mainly use frequencies between 800MHz and 2GHz, whose wavelengths are 37cm and 15cm respectively.

Waves are scattered by an object in a complex manner when the wavelength is comparable with the scale of the object. Thus it was recognized that a human body

could resonantly absorb EMF energy at frequencies with wavelengths around the height of the body. The whole-body absorption reaches a maximum at around 30MHz when the body is grounded and around 70MHz when it is isolated from the earth<sup>7</sup>. The shorter the object, the higher the resonant frequency becomes. Mice, for example, have a resonant frequency at around 2GHz. These facts were found in the 1970's and initiated a new research field called "electromagnetic dosimetry". Early studies were made using objects with a simple shape such as sphere or spheroid, and simple incident waves such as plane waves. Later on more complex exposure situations were considered such as near-field exposures from industrial heating machines.

With the rapid increase in the use of mobile phones it became necessary to assess the exposures to the head from hand-held telephone devices. Great efforts have been devoted to develop exposure assessment methods on MTE both in experimental and theoretical approaches.

Dosimetry is also important in the quality control of the experiments on the biological effects of electromagnetic fields. Accuracy of exposure assessment is one of the most important factors that determines the quality of the experiment. A number of early experiments were found to be incorrect in the exposure conditions when recent knowledge on dosimetry was applied in the evaluation of the exposure condition. For example, early studies on mice exposed to 2.45GHz should be carefully interpreted because incident power density of  $1\text{mW}/\text{cm}^2$  for mice at this frequency is equivalent to  $50\text{mW}/\text{cm}^2$  for humans in terms of the energy absorption due to the whole-body resonance. Recent experiments are of much higher quality than earlier studies owing to the progress in dosimetry. We should note that recent studies with well-conducted dosimetry often provide negative results or results explicable by thermal mechanisms in the experiments in which earlier studies suggested the presence of some "non-thermal effect".

### 2.3 Other established phenomena

There is an established effect of microwaves due to a non-thermal mechanism when the field has pulsed waveforms with a high peak power and a low average power. Abrupt absorption of power of pulsed microwaves causes a small but rapid temperature rise in tissue, resulting in thermal expansion to produce pressure waves which propagate in tissue as "thermoelastic waves"<sup>8</sup>. Auditory organs are very sensitive to vibrations. Thus the elastic waves can be perceived as a clicking or buzzing sound. This phenomenon is known as "microwave hearing". The

threshold is about 30 mJ/kg per a single pulse in specific energy absorption in the head when pulse duration is less than 50 microseconds. This corresponds to a peak incident power density of approximately 300mW/cm<sup>2</sup>.

Microwave hearing was first found in the 1950's in radar sites for military use in the US. The thermoelastic mechanism was established in the 1960-1970's. The amplitude of the stress waves is as small as 0.18Pa at the threshold of perception<sup>9</sup>. This value is much smaller than the amplitude of ultrasound used in medical imaging to visualize the fetus in a pregnant woman. It should be noted that it is the extremely high sensitivity that enables humans or animals to perceive a subtle vibration in the head. Microwave hearing is presently not considered as a health hazard but a problem of annoyance<sup>10</sup>.

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### 3. EXPOSURE GUIDELINES<sup>11-13</sup>

#### 3.1 Basic restrictions

Safety guidelines with regard to human exposure to electromagnetic fields have been developed by various organizations in the world. The recommended exposure limits are based on the scientific evidence of established phenomena. There is a consensus that thermal effects are the prevailing effect of exposure to RF-EMF. Thermal load to the body is evaluated in a quantity of absorbed power in the body per unit mass of tissue. This quantity is called "specific absorption rate" or SAR with the unit of watt per kilogram (W/kg). Whole-body average SAR of 0.4W/kg is widely adopted in most guidelines as the basic restriction based on the threshold of observed effects due to whole-body heating to cause significant elevation of core temperature (> 1°C). This restriction corresponds to absorbed energy of 28W in the body with a weight of 70kg. This thermal load is not significant compared with the metabolic heat production in the body of about 60W in the basal condition up to several hundred watts during hard exercise. This limit is considered appropriate to avoid deep-body temperature rise due to energy deposition of the absorbed RF energy.

Effects of localized heating should also be considered in addition to the whole-body effect, especially when a part of the body is exposed to a small radiation source such as an MTE. The temperature rise in local tissue, however, is not simply related to the local SAR but it depends on the circulation around the tissue and also on the environmental conditions such as temperature and relative humidity. The exposure limit in terms of local SAR

has not been unified yet but most guidelines adopt the limit of local SAR of 10W/kg averaged over any 10 grams of tissue or 8W/kg averaged over any 1 gram of tissue. The former is adopted in Japanese guidelines as well as in the European Council recommendation. The latter is adopted in the United States and some other countries.

Those values are applied when the exposure condition is well controlled. An additional safety factor of 5 has been introduced in the exposure of general public, or uncontrolled environment, in consideration of higher uncertainty of the sensitivity to the fields as well as exposure conditions. Thus 0.08W/kg for whole-body average SAR and 2W/kg for maximum local SAR are applied as the maximum permissible exposure for general public.

#### 3.2 Reference levels

The restrictions in SAR are closely related to physiological phenomena but we have no instruments available to measure SAR directly in the body. We need reference levels expressed in measurable quantities such as environmental electric and magnetic field strengths to determine whether the environment may cause exposure exceeding the SAR specified in the basic restrictions. So we convert the limits in SAR to the strengths of environmental electric and magnetic fields. The derived values are called "reference levels", which are expressed in electric (E) and magnetic (H) field strengths.

We should note that the reference levels are derived on the assumption that the worst-case coupling occurs between EMF and the body. This condition is typically a whole-body exposure to homogeneous plane waves with the polarization (orientation of E-field) parallel to the body axis. In the case of exposure by MTE, the radiation source is usually located near the head and the exposure is localized. This exposure condition is far from the maximum coupling assumed in the derivation of the reference levels. We cannot apply the reference levels in the assessment of exposure by MTE but we must apply the basic restrictions.

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### 4. EXPOSURE ASSESSMENT ON MTE

The majority of MTE are hand-held devices operating at 800MHz-2GHz. The antennas are usually located on the top of the chassis. So the brain near the ear of the user is strongly exposed to the EMF from the device. This fact raised public concern on possible adverse health ef-

fects on the brain, such as causing brain tumors, due to the exposure from such devices.

The exposure assessment must be done based on the basic restrictions specified in SAR values, as mentioned in the previous section. According to the results of exposure assessment the exposure by currently used MTE actually complies with the exposure guidelines for the general public, or the local SAR is less than the limit of the basic restrictions (2W/kg averaged over 10g tissue)<sup>14</sup>. However, the margin to the guideline is not large enough to consider the compliance. Authorities in many countries, including Japan, have decided to set out mandatory regulation on the compliance of these devices with the guidelines. Nevertheless the public is still concerned about possible unknown effects of exposure at lower levels than the basic restrictions in some non-thermal mechanisms.

Some people use a hands-free headset in order to reduce the exposure from MTE. It is obviously the simplest and most effective way of reducing exposure to keep the radiating structure away from the body. However, a report claimed that the hands-free headset could enhance the exposure. This report is now considered wrong after more careful measurements were reported.

Base stations of cellular telephone systems are another source of exposure related to mobile communications. The public concern is greater towards the base stations than on the telephone devices as people tend to perceive more risks in what they cannot avoid by themselves. However, the levels of exposure from base stations are far smaller than the reference levels of the guidelines<sup>15</sup>.

There is a concern about the non-thermal effects caused by the specific waveforms of EMF from mobile communications systems. There have been suggestions that RF-EMF with amplitude modulation at extremely low frequencies (ELF) could affect biological functions in a different way from continuous-wave exposures (see Section 6.1). Many of the mobile communication systems employ digital modulation signals that have pulsed waveforms with a repetition rate in the ELF region. Time division multiple access (TDMA) systems are typically the case. For example, PDC (Personal Digital Cellular) systems used in Japanese digital cellular telephones and NADC (North American Digital Cellular) used in the US have a pulsed waveform with repetition rate of 50Hz. The GSM system, which is a digital cellular system widely used in European countries and other countries in the world, has a repetition rate of 217Hz.

## 5. CONCERNS ON NON-THERMAL EFFECTS<sup>6</sup>

There have been concerns on possible “non-thermal effects”. The initiation of the concern was an incident that occurred at the US Embassy in Moscow in the former Soviet Union, which was moved from near Kremlin to a new site several miles away in 1952. The routine check of nonionizing radiation in 1953 revealed the presence of a microwave signal apparently beamed at the embassy from a nearby building. The intensity was far weaker than the US standards but later they found that it was 100 times larger than the exposure limit of the Soviets in those days. They also found a number of bioeffect research suggesting the presence of “non-thermal effects” in Soviet literature translated in the 1960’s. These findings stirred up the concerns about unknown effects of weak microwaves. Numerous research projects have been done in the US to investigate the unknown effects of RF exposure at non-thermal levels. However, no firm evidence has been found. It was concluded that such unknown effects did not exist. The traumatic memory of the “Moscow Embassy Crisis”, however, may be one reason for the fear from weak long-term exposure to microwaves that remains in people’s minds ever since.

In the 1970’s several reports suggested an unusual effect of low-level RF-EMF with amplitude modulation at extremely low frequencies on the efflux of calcium ions in brain tissue (see next section). Because calcium ions play an important role in the regulation of cell functions, these reports attracted the attention of investigators. It should be noted that some digital cellular communication systems have waveforms similar to the waveforms used in these reports. There are people who still believe the existence of adverse effects of low-level RF fields especially when it has some specific waveforms.

With the increasing use of MTE, concerns on the non-thermal effects have revived. A matter of great concern is the effect on brain functions as the brain is the organ most strongly exposed to EMF from MTE. They question whether RF-EMF disturbs normal regulatory functions of the brain. Neurological and behavioral effects of RF-EMF at non-thermal levels have been major endpoints of investigations on non-thermal effects. There have also been concerns on carcinogenicity of weak RF-EMF that may be eventually caused by the possible disturbance of cellular regulation.

In the following sections we summarize the current state of knowledge on the possible effects of RF-EMF which are not explained by thermal mechanisms. More

comprehensive reviews are found in other reports that have been issued by several expert groups<sup>16,17</sup>.

## 6. EFFECTS ON BRAIN FUNCTION

### 6.1 In vitro studies

The effect of weak RF-EMF on the function of the central nervous system was suggested as early as the 1970's. Bawin et al.<sup>18</sup> reported that exposure to 147MHz fields at very low intensities increased efflux of calcium ions from isolated chick brain only when the field was amplitude modulated at 16Hz. The continuous wave at RF carrier frequency alone had no obvious effect.

Blackman et al.<sup>19,20</sup> confirmed the same phenomenon. They found that the effect was maximal at 16Hz, and higher and lower modulation frequencies were less effective. This nature was called the "window effect". Since calcium ions in cells play an important role in signal transduction related to regulation of various cell functions, including cell proliferation, this phenomenon was of great interest. Adey<sup>21</sup> suggested that changes in calcium efflux may be due to an amplification process in which weak electric fields might be set up in the tissue, and they might "trigger" a sequence of events of biological significance. He suggested very weak fields could interact with this pathway, resulting in significant biological events. However, there is no obvious theoretical basis and firm experimental evidence supporting such effects.

A number of subsequent studies in other laboratories, however, have failed to detect an increase in calcium efflux from isolated brain tissue *in vitro* although they did not follow precisely the same conditions<sup>22</sup>. The existence of this phenomenon is disputed because these replication studies in the 1980's had generally better experimental designs than earlier studies.

### 6.2 Animal studies

#### (1) Electroencephalogram (EEG)

In parallel with the calcium efflux studies, the same group also reported changes in EEG activity in animals caused by exposure to weak RF with amplitude modulation at a dominant EEG frequency<sup>23</sup>. They exposed cats to a modulated 147MHz field. The animals had been previously conditioned to produce selected EEG rhythms in response to a flash light. Changes were reported in the performance of the conditioned EEG response task. It was argued that the fields affected brain tissue to cause re-

lease of calcium ions, resulting in some change in membrane excitability, which could possibly affect EEG rhythms.

Takashima et al.<sup>24</sup> reported changes in the EEG of rabbits following exposure to a modulated 5MHz field with amplitude modulation at 14–16Hz. Enhancement of EEG activity at 10–15Hz was observed. The SAR could be estimated to be about 1mW/kg and no rise in body temperature was detected during exposure. There have been other studies reporting the effects on EEG activities<sup>25,26</sup>.

In summary, for all reports suggesting some changes, no consistent and firm evidence of the effects on EEG activities has been presented.

#### (2) Blood-brain barrier

Blood-brain barrier (BBB) is a function of brain capillaries vessel to prevent unwanted molecules from permeating into the cerebrospinal fluid. Increase in the permeability of the BBB could result in increasing the risk of brain diseases such as brain tumor as well as neurological symptoms such as headaches<sup>27</sup>. It has been known that a significant temperature rise in brain tissue can cause an increase in the BBB permeability. On the other hand, some work has also suggested that the BBB might be susceptible to low level RF fields<sup>28,29</sup>. Some early studies were later criticized that they might have been confounded by various factors including alteration in cerebral blood flow and the effect of anesthesia<sup>30</sup>. More recently, two studies<sup>31,32</sup> have reported increased BBB permeability to protein (albumin) following RF exposure at SARs as low as 0.016W/kg. Subsequent studies, however, failed to replicate these results<sup>33,34</sup>. Although the effect of RF-EMF on BBB is controversial, it should be noted that recent well-conducted studies reported no effect.

#### (3) Learning and memory

Lai et al.<sup>35</sup> reported a detrimental effect on spatial learning of rats. The animals learned to obtain food pellets at one arm of a radial-arm maze. They were acutely exposed for 45 minutes each day to pulsed 2.45GHz fields with a whole-body average SAR of 0.6W/kg immediately before training sessions. The duty factor of the pulse was 1,000 and the repetition rate was 500 pulses per second (pps). The exposed animals consistently made more errors than the control animals. Wang and Lai<sup>36</sup> also reported RF-induced changes in spatial memory. They employed a circular water maze in this experiment. Rats were to learn to escape from the water by using a submerged platform to survive. Acute exposure was made

for 60 minutes to pulsed 2.45GHz fields at 1.2W/kg whole-body average SAR and in a temporally averaged value. The exposed animals took more time to find the platform than control animals. It was concluded that exposure had disrupted functions of spatial reference memory.

It should be noted that the waveform had a very high peak power as much as 1,000 times of the average power in these positive studies (temporally peak SAR reached 1,200W/kg). Watanabe et al.<sup>37</sup> showed by numerical simulation that the exposure condition was enough to elicit microwave auditory perception in exposed rats. It was strongly suggested that auditory annoyance might be the reason for the deficit in the learning task.

The pulsed waveforms of digital cellular phones have a duty ratio of three in the PDC system and eight in the GSM system. The peak powers of those waveforms are much smaller than that used by Lai's group when the average power is the same. These waveforms cannot cause microwave auditory effects.

Sienkiewicz et al.<sup>38</sup>, using an experimental design similar to that of Lai et al., exposing mice to 900MHz RF radiation with a simulated waveform of the GSM system at a whole-body SAR of 0.05W/kg. The behavior of the animals was tested each day for 10 days in an eight-arm radial maze, either immediately after exposure for 45 minutes, or after delays of 15 and 30 minutes. There were no significant differences in either the original performance of the exposed animals, the rate at which their learning increased or the final levels of performance.

Yamaguchi et al.<sup>39</sup> reported the absence of effect on spatial memory learning using a T-maze test. Rats were exposed to simulated signal of a PDC waveform of 1,439MHz. They found no difference in learning ability at a brain average SAR of up to 7.4W/kg. When the brain average SAR was 25W/kg, the learning ability was obviously reduced due to the significant thermal stress.

These results show that exposures to RF-EMF with similar waveforms to cellular phones at non-thermal levels do not cause any disturbance in spatial memory learning, while exposure to a pulsed field with very high peak power could cause some disturbance due to the microwave auditory effect.

### 6.3 Human volunteer studies

Volunteer studies have limitations in the permissible exposure level and in the available number of subjects due to ethical reasons. Thus the results are often regarded as skeptical in terms of reproducibility. On the

other hand, they can reflect effects on humans which might be different from those on animals. With all these limitations, a number of volunteer studies have been conducted, some of which suggested effects on the neurological function of humans.

#### (1) Cognitive function

Preece et al.<sup>40</sup> reported the effects of a simulated mobile phone signal on cognitive functions. They employed 36 volunteer subjects and examined 15 measures of human cognitive functions including simple and choice reaction time, and short-term and long-term memory tests. Among these measures they found a slight but statistically significant decrease in the choice reaction time in discrimination of the words "yes" and "no" when the subjects were exposed to a simulated RF signal of analog phones. No change was observed when exposed to RF of a digital phone signal. They observed no change in any other measurements.

Subsequently Koivisto et al.<sup>41,42</sup> reported similar results of shortened reaction times after the exposure to RF signal of GSM digital modulation. These results were reasonably consistent with the results from Preece et al. and suggested that exposure to RF-EMF from cellular phones could affect human cognitive functions. The authors concluded in their paper<sup>42</sup> that "With respect to behavioral consequences of the RF fields in humans, all available evidence points to the same direction: RF fields facilitate rather than disrupt performance. The physiological mechanisms underlying such influences are poorly understood, and it is too early to conclude what the significance of the observed effects is on human health".

However, we should be careful to evaluate these results although they are somewhat consistent and statistically significant. The difference was marginal and these differences were found only in a part of the experimental data. In addition, the suggested effect did not indicate any adverse nature to health. More studies are necessary before these results are considered to be established.

#### (2) Effect on EEG and sleep

EEG reflects the electrical activity of neurons in the brain. It can be measured objectively so that we can exclude subjective fluctuations which are often the problem of human studies. There are two different approaches to the EEG measurement. One is spontaneous EEG, which is observed in a spontaneous condition. Characteristics of the waveforms of EEG, especially in the spectral region, reflect to some extent the state of brain function. However, spontaneous EEG is vulnerable to any kind of stimu-

lation to the subject. It is not easy to extract information of slight difference caused by the exposure. The spontaneous EEG is fairly stable when the subject is sleeping.

Another approach is event-related potential (ERP) or evoked potential, which is the potential evoked by an intentional stimulation to the subject. As the evoked signal is very small, measurement is made with phase-locked summation of the waveforms for repetitive sequence of stimulation to improve the signal to noise ratio.

Reiser et al.<sup>43</sup> reported an increase in the power of spontaneous EEG of waking subjects in frequencies above 10Hz, while Roschke and Mann<sup>44</sup> were unable to detect any differences in EEG. Hietanen et al. also reported a statistically significant increase in waking EEG power in a certain band only for one phone out of five phones. It is not prudent to make any conclusion from the results on spontaneous EEG of waking subjects as it is not stable enough.

Sleep EEG is a little more stable than waking EEG but the situation is not so different. Mann and Roschke<sup>45</sup> reported that exposure to GSM-like signals reduced latency to sleep onset, and altered the abundance and spectral characteristics of REM sleep. Subsequent studies by the same group<sup>46,47</sup>, however, failed to replicate these findings. More recently Borbely et al.<sup>48</sup> reported exposure to a "GSM-like signal" (900MHz, duty cycle of 87.5% while 12.5% in GSM) during sleep caused an increase in EEG power in a certain frequency range (around 10Hz) and reduced waking after sleep onset. The same group reported in the subsequent study that exposure *before* sleep also enhanced the sleep EEG power in the same frequency range<sup>49</sup>.

Studies on ERPs have also been done. Urban et al.<sup>50</sup> investigated visual sensory responses to checkerboard reversal during exposure to GSM-like signals, but found no effect. Other studies reported some changes by the exposure. Eulitz et al.<sup>51</sup> reported changes in the brain's electrical response to acoustic stimuli. Freude et al.<sup>52</sup> reported a small reduction in the amplitude of response-related potentials in a visual monitoring task while no such effect was found in the potentials evoked by a simple finger movement task. They did not find any exposure effects on task performance. The same result was replicated in the subsequent study<sup>53</sup>.

The findings from EEG studies suggest that exposure to mobile phone signals might influence brain function slightly. The evidence warrants further investigation but we should note that it would be very difficult to obtain firm evidence of effects on brain from EEG studies because of the large variation of the results.

### (3) Subjective symptoms

Subjective symptoms caused by the use of mobile phones have often been reported anecdotally. Hocking<sup>54</sup> investigated 40 people with complaints of subjective symptoms which they related to the use of mobile phones. The symptoms were located mainly to the head, including headache, sensation of heat on the skin, and dizziness. However, it remained unclear whether there was any causal relationship to mobile phone use.

A larger-scale study on self-reported, subjective symptoms was also made. Data were collected from about 11,000 mobile phone users in Sweden and Norway<sup>55</sup>. The data were taken via a postal questionnaire on various symptoms. The result showed that 13% of participants in Sweden and 30% in Norway reported the occurrence of at least one symptom, which they themselves related to mobile phone use.

However, we should carefully interpret these reports that with respect to there being a causal relationship between these symptoms and mobile phone use. The data were collected from self reports, which can be influenced by various factors such as anecdotal fear from possible health effects of EMF from mobile phones.

To explore the causal relationship Koivisto et al. conducted a volunteer study with 24 males and 24 females<sup>56</sup>. The subjects rated subjective symptoms including headache, dizziness, fatigue, itching and tingling of the skin, redness of the skin, and the sensation of warmth on the skin. The subjects reported their rating at the beginning, middle (30 minutes after the beginning) and the end of a 60 minute exposure/non-exposure period. They found no difference in the rating of subjective symptoms between exposed and non-exposed subjects. This result is not conclusive but suggested the absence of subjective symptoms if the data were collected carefully.

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## 7. CANCER RELATED STUDIES

The cancer-related effect is of the greatest concern to the public when possible risks of some agent are discussed. This is the case in the safety issue of mobile communications. The process of development of cancer is considered to follow several stages. Initiation is the first stage in which the gene or DNA is injured by the agent. Promotion is the next stage where the injured gene makes cancer cells. Progression is the stage where the cancer cells proliferate to form a malignant tumor and possibly metastasize to other organs. Numerous studies have been

done to explore the possible association of exposure from mobile phones and carcinogenesis. The following review is a brief overview of this research.

### (1) Genotoxicity

The photon energy of RF-EMF is far smaller than the minimum ionization energy of a molecule, which corresponds to photon energy in the ultraviolet region. Hence it is not probable for RF-EMF to damage DNA in a similar manner to ionizing radiation such as X-rays or gamma rays. However, genotoxicity has been a matter of great concern for years. Some early studies suggested genotoxicity of RF-EMF at rather high intensities both *in vivo* and *in vitro* experiments. The exposure conditions in these studies were, however, poorly controlled, and temperature elevation in the specimen was suspected to exist. It should be noted that heating alone can be genotoxic and can enhance the action of known genotoxic agents<sup>57</sup>.

Recently, three studies in rodents have suggested that RF fields at lower intensities may affect DNA directly. Sarker et al.<sup>58</sup> reported that large scale structural rearrangement occurred in cells in the brains of mice exposed to 2.45GHz microwaves. However, some artifact was suspected to confound the result<sup>59</sup>. Lai and Singh<sup>60,61</sup> suggested an increase in the breaks of DNA strands of cells in brains of rats after exposure to 2.45GHz microwaves. Other researchers tried to replicate this phenomenon in various experimental conditions including exactly the same condition as Lai's experiment. No studies, however, succeeded in replicating the same phenomenon<sup>62-64</sup>.

### (2) Cancer promotion

There is one positive report suggesting carcinogenic potential of exposure by digital mobile phones<sup>65</sup>. *Eμ-Pim1* mice, which are genetically engineered to be susceptible to the development of lymphoblastic lymphomas, were exposed or sham-exposed for one hour per day for eighteen months to pulse-modulated 900MHz RF radiation simulating the GSM signal. The authors reported an increase in the incidence of lymphomas in the exposed mice (43% in the exposed animals, vs 22% in the controls). This report brought up a serious issue of the possible carcinogenic potential of low level exposure to mobile phone signals. However, there have been a number of criticisms of this study. Firstly, the dosimetry of this study was so poor that the SAR of the animals were reported just between 0.08–4.2W/kg. It was also pointed out that standing waves might have existed in the room where the exposure was performed. The relevance of the use of the transgenic mice in such a long term study has also been

discussed. The lack of histopathological examination of apparently healthy mice was also criticized. In view of both the significance of the result and several defects, this study must be confirmed by replication studies. Two such studies are ongoing in Australia and the EU with an improved exposure setup and procedures. It should also be noted that the principal author of the study commented himself that it will be necessary to do further assessment of the relevance of these findings for human health even if the same result is replicated in these studies<sup>66</sup>.

Other recent studies investigating a possible promoting effect on chemically induced cancers have generally found negative results. Imaida et al.<sup>67,68</sup> found no effect of exposure to 929.2MHz and 1.439GHz PDC signals for six weeks using the medium-term rat liver cancer promotion model. Adey et al.<sup>69</sup> found no increase in brain tumors in rats exposed to 836.55MHz radiation with the NADC waveform and the frequency modulation waveform used in analog systems<sup>70</sup> over a 24-month period. These negative studies were made with well controlled exposure conditions and suggested that exposure to mobile phone radiation is not likely to be carcinogenic.

### (3) Epidemiological studies on cancer

Epidemiology is regarded to provide the most direct evidence of environmental hazards to human health as it observes the relationship between human disease and exposure to the agent of concern. It is known that the carcinogenic potential of some agents for rodents is sometimes different from that to humans. That is why the International Agency of Research on Cancer (IARC) gives epidemiological data the highest priority in its overall evaluation of carcinogenicity of agents to humans.

We should note that there are a number of limitations in the epidemiological approach for all its merits. In the case of mobile phone studies, one of these limitations is accuracy of exposure assessment. Self-reporting to a questionnaire is often used to collect data, but the accuracy is limited. In addition, the actual radiation power from the MTE varies greatly depending on the distance to the base station, as well as the condition of speech. Uncertainty cannot be excluded in the estimation of the actual "dose" from collected data.

A limited period of exposure is the most serious limitation when we deal with delayed effects such as cancer. It was only several years since the use of mobile phones became common. This period may not be enough to detect association, if any, between mobile phone use and the incidence of cancer. Confounding factors should also be excluded. Mobile phone users since early days

might be rather healthy workers with a higher socio-economic status, compared with non-users, for example.

A number of epidemiological studies have been done so far to explore the possible association between mobile phone use and cancer, especially brain tumors. Only a few studies suggested possible links between brain tumors and mobile phone use<sup>71</sup> while other studies found no association<sup>72,73</sup>. However, these studies are not conclusive yet in consideration of the limitations above. It is recognized that further studies are necessary. The IARC has organized an international epidemiological study on the association of mobile phone use with cancers in the head and neck region. Fourteen countries, including Japan, are participating in this project. The results in each participating country will be pooled together and analyzed. Some conclusions will be addressed by 2005, based on the results of this project.

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## 8. HEALTH RISK ASSESSMENT

It has been recognized that there is an urgent need for health authorities to address guidance on possible health risks, if any, of mobile communications systems. The World Health Organization (WHO) has set about this task in 1996, and are scheduled to be completed in 2005. Along with this project, national research programs have been organized in various countries. A number of review documents have been issued by expert groups to clarify the *status quo*, gaps of knowledge and research needs. The conclusions were reasonably consistent among these reviews. In brief, the conclusion was as follows. There exists no firm scientific evidence to support the hypothesis that exposures to RF-EMF below current safety guidelines should cause adverse health effects to the general population. It is, however, impossible to prove that there is no possibility that exposure to low level RF-EMF might cause any detrimental effect on health. The brief review presented in this paper is also in line with these reviews.

In consideration of the uncertainty in the sense that no one can prove absolute absence of adverse effects, some precautionary approach is sometimes recommended. For example, the UK Expert Group<sup>16</sup> recommended that "the widespread use of mobile phones by children for non-essential calls should be discouraged". The main reason for this would be the indications of effects on physiological changes in EEG and cognitive functions and the possible vulnerability of young brains.

In view of the uncertainty of the evidence on which these recommendations are based, it is important to compare risks of using mobile phones with that of not using them to avoid possible health risks. It is well recognized that mobile communications provide a means of communication in the case of an emergency. This should reduce any existing risk. The choice should be made by individuals in a voluntary manner with all the available information presented.

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## 9. CONCLUSION

Mobile communication devices are sources that may cause strongest exposure to RF-EMF to the human head in daily lives. Possible health hazards of the electromagnetic fields from mobile communication devices have become of concern and enormous efforts have been made to clarify the possible hazards and risks of exposure associated with this technology. The research is still continuing but the evidence reported so far indicates few effects that could possibly damage human health seriously. Only slight changes in physiological function in the brain may exist but the variation of the data is too large to believe that the exposure actually has the potential to affect function.

Overall, the health risk, if any, at an individual level, would be very low in consideration of the available evidence. However, if mobile phone fields were actually hazardous, the very large number of mobile phone users could mean that, even if the individual risk were very low, the impact on public health could be considerable. This is the most important point that warrants the large studies promoted by those international and national organizations involved in this issue.

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