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Effects of chronic exposure of electromagnetic fields from mobile phones on hearing in rats

Ahmet Kizilay *, Orhan Ozturan, Tamer Erdem, M. Tayyar Kalcioglu, Murat Cem Miman

Department of Otolaryngology, Inonu University, School of Medicine, Malatya, Turkey

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Abstract

Objective: Little attention has been paid to the effects of electromagnetic field (EMF) of mobile phones on hearing. The aim of this study is to investigate the effects of chronic exposure to EMF emitting from mobile phones on the inner ear of adult and developing rats using distortion product otoacoustic emissions (DPOAEs). *Methods:* EMF of mobile phones exposure was scheduled according to a sham-exposure controlled experimental design. Every day seven of 14 adult and four newborn rats were exposed to 1-h mobile phone EMF for 30 days, while the other seven adult rats were assigned to control group. DPOAEs were measured in both groups before and after the chronic exposure to EMF. The newborn rats were tested following similar exposure beginning on the 2nd day after birth. *Results:* No measurable EMF associated changes in DPOAEs either in adult or developing rat inner ears were determined ($P > 0.05$). *Conclusion:* It was concluded that chronic exposure of EMF, as long as 30 days 1 h per day, emitting from a mobile phone did not cause any hearing deterioration in adult and developing rats, at least at outer and middle ear and cochlear levels.

Keywords: Cochlea; Rat; Adverse effect; Otoacoustic emissions; Mobile phones

1. Introduction

The wide spread use of the mobile phones rises a high concern regarding the problem of the health risk as a potential biological effects. Mobile telephones transmit and receive microwave radiation and health risk is connected with the high-frequency electromagnetic fields (EMFs) [1]. Mobile telephones operate with radiofrequencies mainly ranged 900 and 1800 MHz and these frequencies excite the rotations of the water and some organic molecules and have been attributed to thermal and non-thermal effects [1]. Thus, the effects of EMF on human being have been a subject of continuing investigation. It is clear that even a small elevated risk may have a large implication for public health as the use of mobile phones is rapidly increasing world-wide.

Guidelines for exposure limits of EMF are scientifically based, formulated, periodically revised and published following critical reviews of information covering biology, medicine, epidemiology and dosimetry [2]. The exposure of users of mobile phones can be quantified in terms of the amount of energy absorbed by a unit mass of the object. This is expressed as the specific absorption rate (SAR) with units of W/kg [1]. Basic limits for general public exposure are calculated as mean of total body SAR [2]. Radiowaves transmitted by mobile cellular phones are not above the SAR limits, because all modern GSM (Global System for Mobile Communications) mobile phones, irrelevant of make, emit a level of radiowaves that produce less than 1 W/kg in the head [3]. There is no worldwide common standard of SAR limits. Individual countries set SAR guidelines, which indicate to the public what level of electromagnetic waves emitted by electrical appliances is safe, as an example, the National Radiological Protection Board in the United Kingdom set the SAR guideline at 10 W/kg in the head [2].

* Corresponding address. Fax: +90-422-341-0728; http://www.medicine.inonu.edu.tr/ent.
E-mail address: akizilay@inonu.edu.tr (A. Kizilay).

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Some animal studies have shown that exposure to EMF may alter the endocrine or nervous systems [4,5]. Guidelines for risk limits are based on thermal effects of EMF [6]. The sensation of burning or warmth behind/around the ear, burning sensations in the facial skin [7], alteration of the blood-brain barrier [8] and headaches [9] have been reported as thermal effects from mobile telephone use. Non-thermal effects presented in the literature from mobile telephone use include modifications of the sleep (detected through electroencephalogram) [10], an increase in the blood pressure [11] and effects of cognitive tasks [12]. There are also a number of contradictory studies regarding potential carcinogenic effects of EMF in the literature [13,14].

The ear of the users is in the near field of the EMF source during call, because the distance from the antenna to the inner ear is only several centimeters. Even though, there is no published study for long airtime the effect of EMF created by mobile phones to the hearing of their users in the literature. The present study was designed to investigate possible effects of chronic and repeated exposures to EMF of mobile phones on the inner ears of adult and developing rats measured by changes in distortion product otoacoustic emission (DPOAE) amplitudes.

2. Materials and methods

Fourteen adult Sprague–Dawley male rats, initial weighing between 105 and 140 g at age of 5 weeks were randomly divided into two groups of seven rats each (group A, exposure to EMF; group B, control) while four newborn rats were used in this study as a group C. The animals were fed with standard diet and water ad libitum besides keeping them in the room ambient temperature of 20–22 °C, with relative humidity of 50%. They were housed in plastic cages containing wood-chip bedding with three or four rats per cage. All adult rats examined initially by otomicroscopy. The presence of Preyer's reflex was used for initial acceptance of each adult animal subject to the study. Additionally, normal findings in DPOAEs confirmed the health of the hearing of the adult rats and made them eligible for the investigation.

The mobile phone utilized in this study was the Ericsson GH 688 (Ericsson, EU). The signals were radiated and received by a horn antenna. This mobile telephone transmits and receives radio signals in the 900 MHz range using the GSM system at a maximum SAR of 0.95 W/kg (obtained SAR limit on the internet; http://www.biztools.co.nz/sar.htm). We, therefore, developed a custom-made exposure system, similar to elsewhere [14] as an ideal simulation of exposure conditions for the human cellular phone user. Three exposure platforms were used to accommodate each group simultaneously. The mobile phone was positioned vertically in the center of the each exposure platform. The rats were oriented radially in the tube cells around a central antenna. The set-up consists of a carousel on which the rats were positioned near field with their snouts toward the antenna and the tubes restrain the movement of the animals. The distance from the antenna to the proximal edge of the tube was 4 cm. The animals were exposed to EMF of mobile phone 1-h daily for 30 days. Sham exposures were simulated in an identical platform. The newborns were exposed in a smaller platform 1-h daily for 30 days beginning on the second day of the birth.

The DPOAEs at $2f_1-f_2$ were elicited from the control and experimental animals utilizing ILO-96 cochlear emission analyzer (Otodynamics, London, United Kingdom). For DPgram, the intensities of primary stimuli were set as equilevel (L1 = L2) at 65 dB. The frequencies (f_1 and f_2) were adjusted as $f_2/f_1 = 1.21$. After an intramuscular injection of Ketamine (30 mg/kg) mixed with Xylocaine (6 mg/kg) anesthesia, the primary tones produced by two separate speakers were introduced into the animal's outer ear canal through an insert earphone probe. Detection thresholds and suprathreshold measures in the form of I/O functions were obtained by decreasing the primary tones from 75 to 36 dB SPL, in 3-dB steps. The level of the noise floor was measured at the frequency that was 50 Hz above the DPOAE frequency, using similar averaging techniques. An emitted response was accepted if the DPOAE at $2f_1-f_2 \geq 3$ dB above the noise-floor level at the $2f_1-f_2+50$ Hz frequency for DPgram and I/O functions. Both type of testing methods were recorded till the responses attain to its highest level, then the test was stopped when further measurement leading no increase in DPOAE amplitude levels.

We made two experiments of exposure, in which the adult and newborn rats were exposed to mobile phone's EMF. At first each animal in Group A and B was tested before the start of the exposure to EMF of mobile phone to determine the baseline hearing status. All animals of each groups were tested after completing the 30 days of exposures. Otomicroscopic examination of the rats was performed before DPOAE testings to exclude middle ear pathology that may impair DPOAE measurements. For each animal, I/O functions at 3, 4, 5 and 6 kHz were recorded and the detection threshold was noted. The f_2 frequencies examined for DPgram were ranged from 1 to 6.3 kHz. (1001, 1184, 1416, 1685, 2002, 2380, 2832, 3369, 4004, 4761, 5652, 6299 Hz.) Separate threshold and I/O functions were calculated for each group of subjects. Body weights, clinical signs and food and water consumption were recorded regularly. All animals were sacrificed upon completion of the study by giving overdoses of intraperitoneal pentobarbital sodium. At that time, disappearance of the DPOAE of the rats was

observed for the purpose of demonstrating the validity of measurements.

This research was performed under an animal use protocol approved by local Institutional Animal Care and Use Committee. Results were analyzed statistically by paired and unpaired t-test (SPSS® 5.0, SPSS) to determine differences in amplitudes of DPOAEs and corresponding noise floors differences and thresholds for each frequency. The effects of exposure was evaluated intrasubject and intersubject variation, looking at the baseline measurements and mean value.

3. Results

The experimental subjects tolerated the exposure of mobile phone's EMF well. In addition, no difference was observed in the body weighing, clinical signs and food and water consumption. In general, developmental progress of newborn rats were recorded as regular.

3.1. Experiment 1

Since all adult rats had otomicroscopic examination and DPOAEs testing in advance, DPgrams and I/O functions were recorded. In the DPgrams, the emission amplitude levels were greater than the noise floor throughout the testing frequencies for all sessions. Mean amplitudes of DPOAEs prior to and following 1-h exposure of EMF for 30 days in adult rats, including noise floor levels and the measurements of the DPOAE I/O results of all groups in 3–6 KHz were shown in Figs. 1 and 2. Intrasubject measurement parameters of DPgrams and I/O functions of group A in paired t-test were not found significantly changed between the first and second measurements ($P > 0.05$). The analysis of the results in the mean amplitudes of DPgrams and I/O functions with the unpaired t-test with equal variation did not reveal any statistically significant differences between exposure (group A) and non-exposure (group B) conditions ($P > 0.05$), suggesting that chronic exposure to EMF of mobile phone did not have any detrimental effects on the hearing of adult rats.

3.2. Experiment 2

In newborn rats, the initial baseline DPOAE measurements were not performed. Mean amplitudes of DPOAEs and noise floor levels in newborn and corresponding adult rats measurements were shown in Fig. 3. The measurements of developing rats following exposure for 30 days (group C) were compared with the results of the first measurement of group B revealed no significant differences between their DPgrams and I/O functions in all frequencies ($P > 0.05$). The result of the second experiment showed that chronic exposure of the newborn rats to EMF of mobile phones did not cause any detectable alteration during cochlear development of rats.

4. Discussion

The use of mobile phone is becoming increasingly popular and indispensable in modern daily life. This is one of the fastest growing technological developments of today. However, there is increasing amount of public concerns in health risk of EMF created by mobile

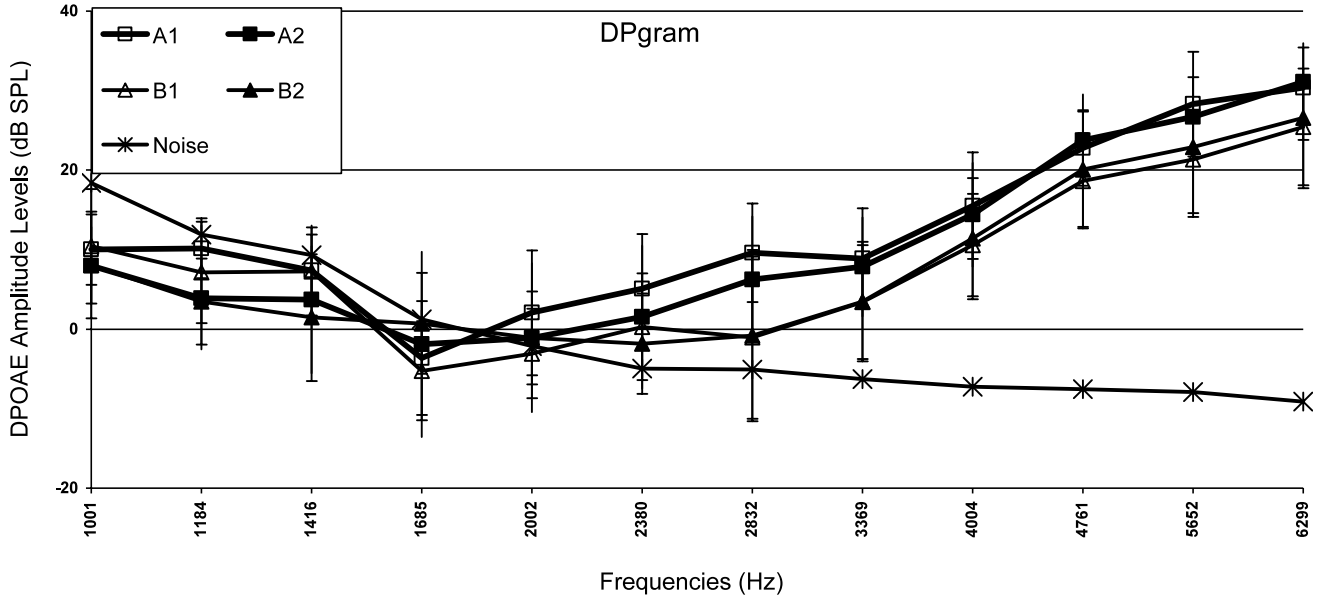

Fig. 1. Mean amplitudes of DPOAEs and variations of each data (S.D.) prior to and following exposure of EMF for 30 days in adult rats, including noise floor levels (Group A: A1; prior to, A2; following exposure, Group B: B1; prior to, B2; following exposure).

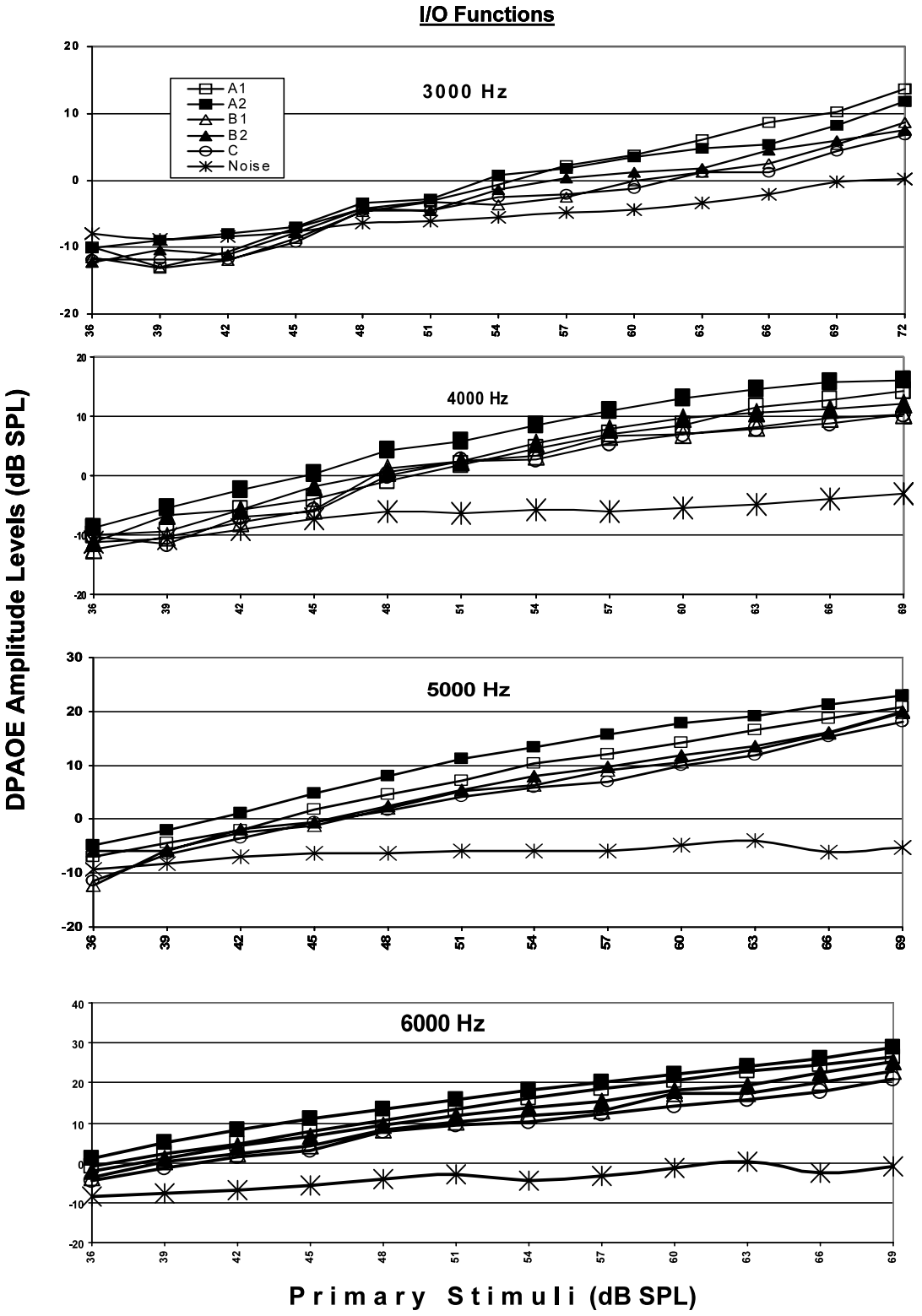

Fig. 2. No significant differences were found among the measurements of the DPOAE I/O results of all groups in 3000–6000 Hz frequencies (Group A: A1; prior to, A2; following exposure, Group B: B1; prior to, B2; following exposure, C; newborn).

phone. It is well established that EMF exposure in entire body SAR of 1–4 W/kg produces pathological reactions in mammals [15]. Occasional electromagnetic interference with medical electronic devices by mobile phones has been known by several years [16]. The SAR level for each model of mobile telephone is not currently available in any attributable form and there is not yet a consensus concerning an appropriate test method by

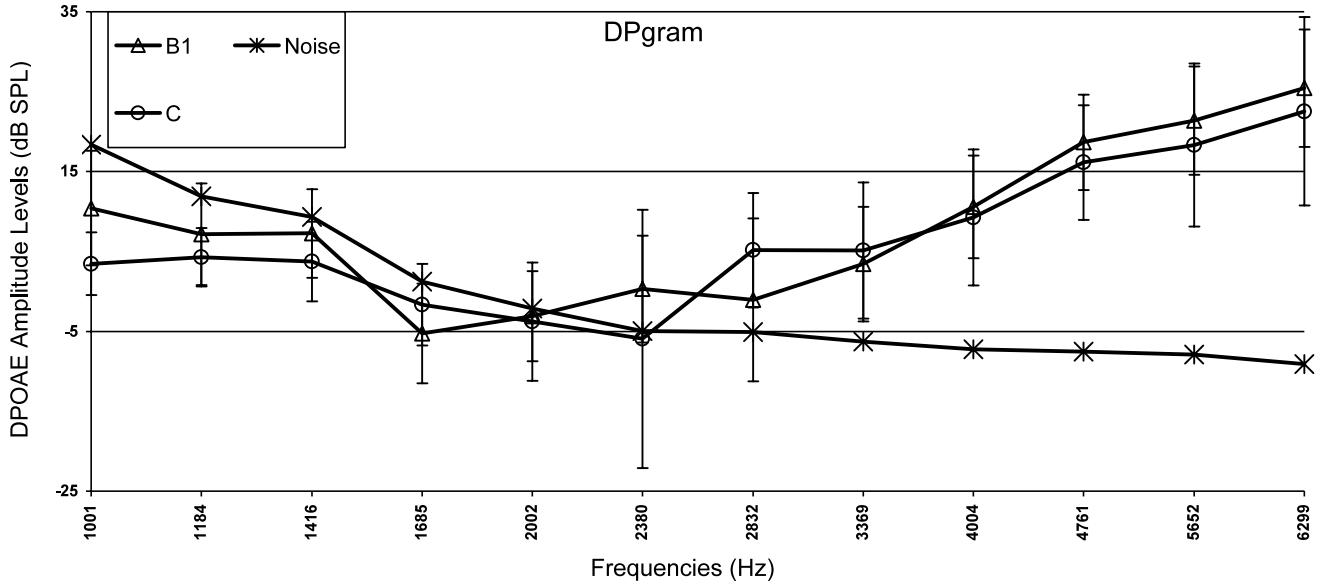

Fig. 3. Mean amplitudes of DPOAEs and variations of each data (S.D.) and noise floor levels in newborn and corresponding adult rats measurements (B1; prior to, C; newborn).

which to assess SAR [1]. This exposure rate is not actually determined on the basis of individual exposure, but is experimentally determined in the laboratory using phantom models having the shape and dielectric properties as close as possible to the human [1] or computed through mathematical models. Estimates for SAR to the head from a 900 MHz mobile telephone vary from 0.16 to 0.69 W/kg [17].

The ear of the phone users is in the close proximity to the EMF of the mobile phone, because the distance from the antenna to the inner ear is only a few centimeter. Radiofrequency signals are radiated and received by an antenna in the vicinity during a call. This may lead to relatively high SAR deposition in the ear compared to other parts of the body. It can penetrate into organic tissue and be absorbed and converted into heat. Although the effect of mobile phones on hearing aids was studied [18], there is no published investigation on hearing itself. Experiments presented in the current report were designed as a relatively long-term (30 day) repeated exposure (1 h per day) to mobile phones' EMF of rats either adult or developing. We have utilized DPOAEs measurements as the test of hearing for monitoring the effects of mobile phone. This measurement is non-invasive, painless and quick and does not require active participation and reliable as well [19,21].

The healthy cochlea emits acoustic energy under certain stimulus conditions. This acoustic energy is objectively measurable in the ear canal. Monitoring the status of the outer hair cell, the most vulnerable structure of the cochlea, has been shown to provide a very sensitive index of cochlear damage. DPOAE changes were detected in experimental animals before morphological damage occurred in the outer hair cells [20]. Mild cochlear functional changes, not revealed in pure-tone audiometry, cause obvious changes in DPOAEs [21]. Evoked OAEs are well-described detection method of imminent cochlear involvement by ototoxic drugs [22,23]. When the cochlea is affected in a specific region, a decrease in DPOAE level in the relevant frequency region of the DPgram can be recorded due to its frequency-specificity [24]. The high test–retest reliability of OAE measures permits the utilization of these emissions to monitor dynamic changes in cochlear responsiveness [25]. For these reasons, OAE measurements appeared to be well suited for the investigation of potential cochlear involvement from the exposure of the mobile telephone EMF. On the other hand, hearing loss of greater than mild degree and any problem compromising the acoustic transfer function of the middle ear, due to the double pass of the stimulus and the subsequently elicited emission from the cochlea, may render evoked OAE testing useless [26]. Therefore, otomicroscopic examinations were performed before baseline and endpoint testings.

The developing ear is sensitive to changes in its environments such as noise exposure, ototoxic effects of certain drugs [27]. In rats, the development of cochlea appears fully developed by 25th days after birth [28]. The most sensitive period for production of ototoxicity in rats is postnatal days 11–20 [19]. Since the cochlea in the first 25 days of newborn rats are vulnerable, in the present study, 2 days old newborn rats were started to be

exposed to EMF of mobile phones for 30 days. Following exposure, the measurements of DPOAEs has not found to be affected by EMF.

The present experiments investigated whether the chronic exposure to 900 MHz EMF emitting from mobile phones produces any adverse effects on the inner ears of adult and developing rats. To our knowledge, this was the first experimental study searching for the effects of chronic mobile phone EMF exposure on hearing. The increasing use of mobile telephones and the close proximity of EMF source of such a device to the ear have concerns about the biological interactions between EMF and inner ear. We have demonstrated that 1-h daily exposure for 30 days to EMF generated by a commercially available mobile phone did not have any detrimental effect on hearing of the adult and developing rats. The results from these experiments suggest that the use of mobile phones is not associated with a higher risk of hearing loss on rats, in addition, these devices is not affecting cochlear development of rat. The senior authors found that a 10-min close exposure of mobile phone had no after-effect on hearing in 30 young adult humans with normal hearing [30].

Findings on the thermal effect of acute exposure to the EMF were consistent, resulting in an increase of cellular, tissue or body temperature by 1 °C or more. Guidelines for risk limits are based on this thermal effect [6]. In deep tissues, like the brain, maximum temperature rise due to mobile telephone EMF exposure was calculated to be no more than about 0.1 °C [29]. This is similar to the normal daily fluctuations in body temperature and is considered to be too low to cause adverse effects. It is speculated that since the cochlea is enclosed by very dense compact bone and located relatively deep, this helps to shield it from the mobile telephone EMF. In addition, the cochlea is positioned as immersed with endolymph and perilymph [30]. These two reasons may save the cochlea from heat fluctuations. The technical feature of the GSM telephones may also have a role for not causing any detrimental effect on hearing. Specifically, GSM telephones can emit a few watt power besides always the maximum power for a few seconds during initiation of the connection with the mobile telephone. Following rings of the telephone, the powerful transmission has been received and the power decreases to the level which is just enough for the connection [1]. In view of the above, it is also concluded that mobile phones may appear safe on hearing. One hour close exposure to mobile phone's EMF for 30 days had no effect on hearing, at least at the outer and middle ear and cochlear level. But it is not sufficient to conclude that long-term exposure (5 year) to EMF do not lead to any hazardous health effects.

The measurements of this study had been restricted by the frequency spectrum of the commercially available DPOAE instrument designed for human use. Higher frequency measurements could be able to reveal more comprehensive information about the effects of EMF exposure. Therefore, the following prudent use of mobile telephones is recommended: use mobile telephones for as short of periods as possible, only for essential purposes, with low SAR values and with hands-free devices provided that they have been proved to reduce SAR exposure [2]. Even a small elevated risk may have a large implication for public health because mobile phones are commonly used worldwide.

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