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Mobile phones and hearing – A review

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Mobile phones are being widely used throughout the world. Although there is no clear evidence of harmful effects of radiofrequency (RF) radiation at the levels used by these devices, there is widespread public concern that there may be potential for harm. Of all anatomical structures, the ear is closest to the mobile phone, which may lead to relatively high energy deposition in the ear compared to other parts of the body. Till the year 2000 only a few studies had addressed potential adverse effects of EMFs on the hearing system. The potential adverse effects of mobile phone exposure on the hearing system should be investigated, because mobile phones are usually held close to the ear. Until now, most studies have assessed the influence of RF radiation on the central or peripheral auditory system. However, clear conclusions cannot be drawn from these studies regarding the presence or absence of effects because of the limitations in the audiological and/or dosimetric approaches and limited sample sizes. results. Although the presence of possible effects on hearing threshold levels cannot be dismissed entirely, the evidence available is not sufficiently strong to conclude that there are adverse effects. A replication study with a shift in hearing threshold levels at high frequencies as the a priori hypothesis is desirable to resolve this issue.

Key words: mobile phones, ear, energy deposition, potential adverse effects, hearing system, replication study.

Introduction

Mobile phones are being widely used throughout the world. Although there is no clear evidence of harmful effects of radiofrequency (RF) radiation at the levels used by these

devices, there is widespread public concern that there may be potential for harm. Of all anatomical structures, the ear is closest to the mobile phone [1-33], which may lead to relatively high energy deposition in the ear compared to other parts of the body. The fluid-filled inner ear possesses microhomeostatic mechanisms that are essential for the functioning of the mechanoelectrical transduction of the auditory hair cells in the cochlea. Thus, disturbances of the mechanoelectrical transduction and thermal effects may appear during cellular phone use, especially because there is a close proximity of the cellular phone to the cochlea resulting *a priori* in a fairly high absorption rate of the incident electromagnetic field (EMF). Although the hearing system is close to the exposure source and the hearing sensory cells are well known to be highly sensitive to exogenous and endogenous agents, till the year 2000 only a few studies had addressed potential adverse effects of EMFs on the hearing system [13]. The external ear may provide a natural route by which RF radiation emitted by mobile phones may reach the peripheral and central nervous system, leading to relatively high energy deposition in the ear. Moreover, the hearing sensory cells are highly sensitive to exogenous and endogenous agents, and hence they could constitute one specific target for possible threat to health.

In the recent past, the technological scenario has changed. After about one decade of mobile phones based on the GSM (Global System for Mobile Communications) standard, a new standard was introduced based on the UMTS (Universal Mobile Telecommunications System) standard. UMTS is expected to completely replace GSM in the near future. The two standards differ in terms of the frequency (900, 1800 and 1900 MHz for GSM, 2100 MHz for UMTS) and modulation of the signals. The potential adverse effects of mobile phone exposure on the hearing system should be investigated, because mobile phones are usually held close to the ear.

Auditory responses to pulsed radiofrequency energy

The human auditory response to pulses of radiofrequency (RF) energy, commonly called RF hearing, is a well established phenomenon. RF induced sounds can be characterized as low intensity sounds because, in general, a quiet environment is required for the auditory response. The sound is similar to other common sounds such as a click, buzz, hiss, knock, or chirp. Effective radiofrequencies range from 2.4 to 10 000 MHz, but an individual's ability to hear RF induced sounds is dependent upon high frequency

acoustic hearing in the kHz range above about 5 kHz. The site of conversion of RF energy to acoustic energy is within or peripheral to the cochlea, and once the cochlea is stimulated, the detection of RF induced sounds in humans and RF induced auditory responses in animals is similar to acoustic sound detection. The fundamental frequency of RF induced sounds is independent of the frequency of the radiowaves but dependent upon head dimensions. The auditory response has been shown to be dependent upon the energy in a single pulse and not on average power density. The weight of evidence of the results of human, animal, and modeling studies supports the thermoelastic expansion theory as the explanation for the RF hearing phenomenon. RF induced sounds involve the perception via bone conduction of thermally generated sound transients, that is, audible sounds are produced by rapid thermal expansion resulting from a calculated temperature rise of only $5 \cdot 10^{-6}$ °C in tissue at the threshold level due to absorption of the energy in the RF pulse. The hearing of RF induced sounds at exposure levels many orders of magnitude greater than the hearing threshold is considered to be a biological effect without an accompanying health effect. This conclusion is supported by a comparison of pressure induced in the body by RF pulses to pressure associated with hazardous acoustic energy and clinical ultrasound procedures.

Animal studies

Galloni et al. [6] evaluated the cochlear functionality of Sprague-Dawley rats exposed to electromagnetic fields at the typical frequencies of GSM mobile phones (900 and 1800 MHz) by distortion product otoacoustic emissions, which are a well known indicator of the status of the cochlear's outer hair cells. A population of 48 rats was divided into exposed and sham-exposed groups. Three sets of four loop antennas were used for the local exposures. Rats were exposed 2h/day, 5d/week for 4 weeks at a local SAR of 2 W/Kg in the ear. Distortion product otoacoustic emissions tests were carried out before, during and after exposure. The analysis of the data showed no statistically significant differences between the audiological signals recorded for the different groups.

Galloni et al. [7] evaluated possible effects of cellular phone-like emissions on the functionality of rat's cochlea. Distortion Products OtoAcoustic Emission (DPOAE) amplitude was selected as cochlea's outer hair cells (OHC) status indicator. A number of protocols, including different frequencies (the lower ones in rat's cochlea sensitivity spectrum), intensities and periods of exposure, were used; tests were carried out before,

during and after the period of treatment. No significant variation due to exposure to microwaves had been evidenced.

Khavanin et al. [15] investigated the effect of mobile phone radiation on auditory system of rabbit. After measuring of click and tone burst at different frequencies (500, 1000, 2000, 4000 and 8000 Hz) with two intensities of 70 and 100 dB, the animals were exposed to electromagnetic waves from a simulator of mobile phone one week exposure and 16-19 h rest. The ABR tests showed that the latency time of wave V (ms) have some changes in the frequencies of the experiments. The latency time of wave V (ms) at the frequencies of 500 and 1000 Hz was ulmost unchanged, but at the frequencies of 2000, 4000 and 8000 Hz were decreased at the end of second week of exposure. Statistical analysis did not indicate any significant changes between time latency of wave in pre and post exposure.

Parazzini et al [26] evaluated the cochlear functionality of Sprague-Dawley rats exposed to electromagnetic fields at 900 MHz and to gentamicin by distortion product otoacoustic emissions, which are a well-known indicator of the status of the cochlea's outer hair cells. A population of 32 rats was divided into four groups: group 1 was treated with daily intramuscular injections of 150 mg/kg body weight gentamicin for 15 days; group 2 was treated with daily intramuscular injections of 150 mg/kg body weight gentamicin for 15 days and exposed to electromagnetic fields; group 3 was exposed to electromagnetic fields; group 4 was sham-exposed. Rats were exposed 2 h/day, 5 days/week for 4 weeks at a local SAR of 4 W/kg in the ear (continuous wave at 900 MHz). Distortion product otoacoustic emissions tests were carried out before, during and after the combined exposure. The analysis of the data showed no subchronic exposure to electromagnetic fields on the inner auditory system of rats in either normal ears or ears exposed to a well-recognized pathological agent.

Galloni et al. [8] evaluated possible influence of UMTS electromagnetic fields (EMF) exposure on cochlear outer hair cells' (OHCs) functionality in laboratory animals. Fortyeight male Sprague-Dawley rats were locally exposed (right ear) or sham-exposed to a controlled UMTSEMF, frequency of 1946 MHz, at SAR level of 10 W/kg, 2 h a day, 5 days a week, for 4 weeks. A group of 12 rats treated with kanamycin (KM) was also included as positive control. Rats were tested by recording Distortion Product Otaoacoustic Emissions (DPOAEs), a non-invasive test capable of assessing the status of the OHCs in the inner ear. DPOAEs were performed before, during (one or three times a week) and after (1-week) exposure to the EMF. The analysis of the data showed that no

statistically significant differences were found between the audiological signals recorded from the different experimental groups. The ototoxic effect of KM had been confirmed.

Computation of specific absorption ratio of the hearing system

Parazzini et al [28] investigated the internal electric and magnetic field distribution and the specific absorption rate (SAR) values in a magnetic resonance imaging-based model of the inner hearing system exposed to 900 and 1800 MHz. The internal fields distributions were calculated using the Finite Integration Technique. The estimation of the field values was evaluated along lines passing through that target organ, specifically from the vestibular to the cochlear region and from the apex to the base of the cochlea. The specific findings were: 1) higher internal fields strength and SAR value in the vestibular region rather than in the auditory region, especially for the inner ear closer to the external source; 2) higher internal fields strength in the basal and apical region of the cochlea than in the middle one; 3) local differences in the internal fields distribution and SAR value, comparing the head models including or not the inner auditory system model; 4) results variability evaluated by changing the head-source mutual position and the dielectric properties of the inner hearing system.

Human studies

Ozturan et al. [30] studied the effects of the electromagnetic field of mobile phone on hearing. Thirty volunteers with normal hearing were exposed to mobile telephone EMFs for 10 min and evoked OAEs were measured before and after exposure. No measurable change in evoked OAEs was detected and none of the subjects reported a deterioration in hearing level. Their was the first study on the effects of EMFs emitted by mobile telephones on hearing. It was concluded that a 10-min exposure to the EMF emitted from a mobile telephone had no effect on hearing, at least at outer ear, middle ear and cochlear levels.

Arai et al. [2] investigated whether pulsed high-frequency electromagnetic field (pulsed EM field) emitted by a mobile phone for 30 min has short-term adverse effects on the human central auditory system. They studied the auditory brainstem response (ABR), the ABR recovery function and middle latency response (MLR) before and after

using a mobile phone for 30 min in 15 normal hearing volunteers. None of the 3 measures were affected by exposure to pulsed EM field emitted by a mobile phone for 30 min. Based on the ABR and MLR methods utilized in the study, they concluded that 30 min mobile phone use has no short-term adverse effects on the human auditory system.

Sievert et al. [31] examined the question whether mobile phone emissions could affect cochlear or auditory brain stem functions. In 12 healthy test persons with normal hearing, auditory brain stem reflexes recordings were performed before, during, and after exposure to electromagnetic emissions by standardized mobile phone devices. Two modes of electromagnetic emissions fields were administered: pulsed and continuous. For acoustic stimulation simultaneous to field exposure, special 'plugin' earphones had to be used. No impact on auditory brain stem reflexes recordings in terms of absolute and interpeak latencies could be found. They stateed that there are no adverse effects of mobile phone emissions on the ear function, at least on a short-term range. Of course, any long-term effects could not be excluded by their study.

Pau et al [30] applied a simulated GSM signal (889.6 MHz/2.2 W) to one ear at a time, while video nystagmography was performed. The experimental setup was similar to that used for caloric (hot and cold water) testing of the peripheral vestibular organ. Data were evaluated by a computer system. There were 13 volunteers (26 ears) included in their study. In an additional experiment, temperatures of human temporal bones were measured by thermography, while a continuous or pulsating EM field was applied. In no volunteer could EM radiation-induced nystagmus be recorded. This corresponded well to findings that in the human temporal bone very weak caloric effects could only be found in the tissue layers next to the radiation source (antenna of the mobile phone), whereas deeper regions (horizontal semicircular canal) seemed unaffected (at least less than 0.1°C). Their results do not support the theory that mobile phone-induced EM radiation may cause caloric negative effects in the human ear.

Monnery et al. [19] investigated whether there is a measurable effect on Otoacoustic emissions from PEMF radiation. A total of 12 volunteers were recruited who had normal hearing; confirmed by pure tone audiometry. An Otoacoustic emission trace was obtained. The test subjects were exposed to a mobile telephone that was placed over the test ears mastoid process. The subjects had Otoacoustic emissions measured without the telephone and again on receive and transmit. There was no change in the trace signature during the test. There was no statistically significant change in the trace figures. Their results indicated that PEMF from commonly available hand held mobile

telephones have no measurable effect on the outer hair cell function during the time of use.

Janssen et al. [12] investigated potential effects of electromagnetic fields (EMF) of GSM (Global System for Mobile Communication) cellular phones on OHCs by means of DPOAEs. DPOAE measurements were performed during exposure, i.e., between consecutive GSM signal pulses, and during sham exposure (no EMF) in 28 normally hearing subjects at tone frequencies around 4 kHz. For a reliable DPOAE measurement, a 900-MHz GSM-like signal was used where transmission pause was increased from 4.034 ms (GSM standard) to 24.204 ms. Peak transmitter power was set to 20 W, corresponding to a specific absorption rate (SAR) of 0.1 W/kg. No significant change in the DPOAE level in response to the EMF exposure was found. However, when undesired side effects on DPOAEs were compensated, in some subjects an extremely small EMF-exposure-correlated change in the DPOAE level (< 1 dB) was observed. In view of the very large dynamic range of hearing in humans (120 dB), it was suggested that their observation is physiologically irrelevant.

Uloziene et al. [33] ssessed potential changes in hearing function as a consequence of exposure to low-intensity EMF's produced by mobile phones at frequencies of 900 and 1800 MHz. The within-subject study was performed on thirty volunteers (age 18-30 years) with normal hearing to assess possible acute effect of EMF. Participants attended two sessions: genuine and sham exposure of EMF. Hearing threshold levels (HTL) on pure tone audiometry (PTA) and transient evoked otoacoustic emissions (TEOAE's) were recorded before and immediately after 10 min of genuine and/or sham exposure of mobile phone EMF. The administration of genuine or sham exposure was double blind and counterbalanced in order. Statistical analysis revealed no significant differences in the mean HTLs of PTA and mean shifts of TEOAE's before and after genuine and/or sham mobile phone EMF 10 min exposure. The data collected showed that average TEOAE levels (averaged across a frequency range) changed less than 2.5 dB between pre- and post-, genuine and sham exposure. The greatest individual change was 10 dB, with a decrease in level from pre- to post- real exposure. It could be concluded that a 10-min close exposure of EMFs emitted from a mobile phone had no immediate after-effect on measurements of HTL of PTA and TEOAEs in young human subjects and no measurable hearing deterioration was detected in their study.

Meo and Al-Dreess [18] investigated a link between the use of mobile phones and hearing and vision symptoms in the Saudi population and also to contribute to the

increase in social awareness of health problems associated with the use of these devices. A total of 873 (57.04% of males and 39.86% of females) subjects using mobile phones were invited to participate in the presented study. A structured questionnaire was distributed among them to collect a detailed medical history. The Chi-square test was employed to observe the relationship between duration of calls and hearing and vision complaints. Their present study showed an association between the use of mobile phones and hearing and vision complaints. About 34.59% of problems were related with impaired hearing, ear ache and/or warmth on the ear, and 5.04% of complaints with the decreased and/or blurred vision. It was concluded that the use of mobile phone is a health risk factor, and thus was is suggested that excessive use of mobile phones should be avoided and social awareness increased through health promotion activities, such as group discussions or public presentations, and via electronic and printed media sources.

Al-Abduljawad [1] studied the effects of the mobile phone on the hearing function of the users. Forty-eight Students aged 18-23 years old were divided into three groups. They were investigated from September 2005 till October 2007. Group one 16 girls who have used mobile phones frequently and spoken approximately 3-4 hours per day for two years. Group two 16 girls who have used mobile phones for 1-2 hours per day for two years. Group three 16 girls who have never used mobile phones (control group). Medical history was obtained and pure tone was performed. Examination showed that four students from group one had reported ear pain, headache, tinnitus, weddings noise, and party noise in the used ear and only one from group two suffered from tinnitus and headache. While two from group three suffered from tinnitus. Their findings, conducted on small number of individuals for limited period, showed that high degree of limited hearing loss might be associated with long-term use of the mobile phones. However, the possibility remains that there could be other health effects and that we need to conduct further study on larger number of individuals and for a longer period.

Oysu et al [22] evaluated the short-term effects of the electromagnetic fields (EMF) of mobile phones on human auditory brainstem responses. Their prospective study of healthy adults evaluated the influence of EMF. Eighteen healthy adult volunteers participated in their study. Mobile telephones emitting signals in the region of 900 MHz and with the highest SAR value of 0.82 W/kg were positioned in direct contact to the right ear, which was exposed to the phone signal for 15 min before and after ABR testing with click stimuli of 60 and 80 dB nHL intensities. The latencies of the waves and interwave latencies were measured on screen by an experienced audiologist. The

differences of the mean latencies of waves I, III and IV were not significant in initial and post-exposure ABR measurements at both 60 and 80 dB nHL stimulus levels ($p > 0.05$). Similarly, differences of the mean interwave intervals I-III, I-V and III-V remained insignificant at the initial and postexposure ABR measurements at stimulus levels of both 60 and 80 dB nHL ($p > 0.05$). Acute exposure to the EMF of mobile phones does not cause perturbations in ABR latencies. However, their negative results should not encourage excessive mobile communication, because minor biological and neurophysiological influences may not be detectable.

Mora et al. [20] conducted a study of the effects of mobile cellular telephone microwave radiation on the auditory system in 20 healthy men. After the subjects underwent baseline measurements of transient evoked otoacoustic emission (TEOAE) and auditory brainstem response (ABR), they participated in three sessions of exposure to an electromagnetic field of 900 to 1800 MHz produced by a cellular phone. Sessions ranged from 15 to 30 minutes in length. TEOAE and ABR were again measured after or during each exposure. Throughout the study, no significant changes in either measurement were noted. They concluded that the use of cellular phones does not alter the auditory system in the short term.

Oktay and Dasdag [21] investigated the effects of radiation emitted by mobile phones on the hearing of users. The study was carried out on three groups: 1) 20 men who have used a cellular phone frequently and spoken approximately 2 h per day for four years; 2) 20 men who have used a cellular phone for 10-20 min per day for four years; and 3) 20 healthy men who have never used a cellular phone (the control group). Brainstem evoked response audiometric (BERA) and pure tone audiometric (PTA) methods were used to measure the effects of exposure on hearing function of the subjects. In BERA measurements, I-III, III-V, and I-V interpeak latencies were evaluated. Interpeak latency of subjects in two experimental groups was compared to that of subjects in the control group. The BERA results showed no differences among the groups ($p > 0.05$). In PTA measurements, detection thresholds at 250 Hz, 500 Hz, 1000 Hz, 2000 Hz, 4000 Hz, and 8000 Hz frequencies were measured in all three groups. No differences were observed between moderate mobile phone users (10-20 min per day) and control subjects. However, detection thresholds in those who talked approximately 2 h per day were found to be higher than those in either moderate users or control subjects. Differences at 4000 Hz for both bone and air conduction for right ears, and 500 Hz, and 4000 Hz bone and air conduction for left ears were significant for mean hearing threshold. Their study showed

that a higher degree of hearing loss is associated with long-term exposure to electromagnetic (EM) field generated by cellular phones.

Davidson and Lutman [4] investigated the prevalence of student mobile phone ownership and any possible chronic effects of usage on hearing, tinnitus and balance. Questionnaires for electronic self-completion were distributed to University of Southampton postgraduates, and 117 out of 160 returned met the criteria for analysis. A total of 94% were current mobile phone users, and only 2% had never used a mobile phone. Duration of ownership and daily usage ranged from 0-7 years and 0-45 minutes respectively. Text-messaging was more popular than talking. High or long-term users reported no worse hearing, tinnitus, or balance than low or short-term users. The results of their study confirmed that the prevalence of mobile phone ownership amongst students is extremely high. However there appear to be no harmful effects of mobile phone usage on their audiovestibular systems within the range of exposure of the study, in so far as can be detected by the self-report method employed.

Stefanics et al. [32] conducted a study to advance understanding of potential adverse effects of the GSM mobile phones on the human hearing system. Auditory Brainstem Response (ABR) was recorded with three non-polarizing Ag-AgCl scalp electrodes in thirty young and healthy volunteers (age 18-26 years) with normal hearing. ABR data were collected before, and immediately after a 10 minute exposure to 900 MHz pulsed electromagnetic field (EMF) emitted by a commercial Nokia 6310 mobile phone. Fifteen subjects were exposed to genuine EMF and fifteen to sham EMF in a double blind and counterbalanced order. Possible effects of irradiation was analyzed by comparing the latency of ABR waves I, III and V before and after genuine/sham EMF exposure. Paired sample *t*-test was conducted for statistical analysis. Results revealed no significant differences in the latency of ABR waves I, III and V before and after 10 minutes of genuine/sham EMF exposure. Their results suggested that, in their experimental conditions, a single 10 minute exposure of 900 MHz EMF emitted by a commercial mobile phone does not produce measurable immediate effects in the latency of auditory brainstem waves I, III and V.

Parazzini et al [27] assessed the outer hair cell function of 15 subjects was by DPOAE recording before and after a controlled EMF exposure. To increase the sensitivity of DPOAE recording to identify even small changes in hearing function, an inverse fast Fourier transform (IFFT) analysis and time-domain windowing was applied to separate the two generation mechanisms of DPOAE, the so-called place-fixed and wave-fixed

mechanisms, in order to verify if EMF can affects the two DPOAE emission mechanisms. Statistical analysis of the data showed that 10 min of EMF exposure at the maximum power (2 W at 900 MHz or 1 W at 1800 MHz) does not induce any changes in either DPOAE generation mechanism.

Parazzini et al [25] studied the effects of GSM cellular phones on human hearing. The European multicenter project named GUARD involved nine centers and aimed to assess potential changes in auditory function as a consequence of exposure to low-intensity electromagnetic fields (EMFs) produced by GSM cellular phones. Participants were healthy young adults without any evidence of hearing or ear disorders. Auditory function was assessed immediately before and after exposure to EMFs, and only the exposed ear was tested. The procedure was conducted twice in a double blinded design, once with a genuine EMF exposure and once with a sham exposure (at least 24 h apart). Tests for assessment of auditory function were hearing threshold level (HTL), transient otoacoustic emissions (TEOAE), distortion

product otoacoustic emissions (DPOAE), and auditory brainstem response (ABR). The exposure consisted of speech at a typical conversational level delivered via an earphone to one ear, plus genuine or sham EMF exposure. The EMF exposure used the output of a software-controlled consumer cellular phone at full power for 10 min. A system of phone positioning that allowed participants to freely move their heads without affecting exposure was used. Analysis of the data showed there were no effects of exposure to GSM mobile phone signals on the main measures of the status of the auditory system.

Pagliolanga et al [24] assessed potential subtle changes in cochlear function by measuring the temporal and spectral fine structure of transiently evoked otoacoustic emissions (TEOAE) in normal hearing subjects after exposure to EMFs emitted by Global System for Mobile Communication (GSM) mobile phones. TEOAEs were recorded in 27 healthy young adults before and after 10 min of real or sham exposure in a double-blind design. TEOAE data were analyzed both globally (broadband analysis) and using the Wavelet Transform (analysis of the time-frequency fine structure). The broadband analysis revealed no significant effect on TEOAEs related to exposure, confirming results of previous studies; in addition, no significant change was detected in the analysis of the elementary wavelet components, suggesting that the temporal and spectral fine structure of TEOAEs is not affected by 10 min exposure to low-intensity EMFs emitted by GSM mobile phones.

Parazzini et al [29] studied the effects of UMTS cellular phones on human hearing. The European project EMFnEAR was undertaken to assess potential changes in human auditory function after a short term exposure to radiofrequency (RF) radiation produced by UMTS (Universal Mobile Telecommunication System) mobile phones. Participants were healthy young adults with no hearing or ear disorders. Auditory function was assessed immediately before and after exposure to radiofrequency radiation, and only the exposed ear was tested. Tests for the assessment of auditory function were hearing threshold level (HTL), distortion product otoacoustic emissions (DPOAE), contralateral suppression of transiently evoked otoacoustic emission (CAS effect on TEOAE), and auditory evoked potentials (AEP). The exposure consisted of speech at a typical conversational level delivered via an earphone to one ear, plus genuine or sham RF-radiation exposure produced by a commercial phone controlled by a personal computer. Results from 134 participants did not show any consistent pattern of effects on the auditory system after a 20-min UMTS exposure at the maximum output of the phone with 69 mW/kg SAR in the cochlea region in a double blind comparison of genuine and sham exposure. An isolated effect on the hearing threshold at high frequencies was identified, but this was statistically nonsignificant after correction for multiple comparisons. It was concluded that UMTS short-term exposure at the maximum output of consumer mobile phones does not cause measurable immediate effects on the human auditory system.

Conclusion

Until now, most studies have assessed the influence of RF radiation on the central or peripheral auditory system. Some investigators [2, 3, 10, 11, 13, 17, 20-22, 25, 29, 31, 32] between mobile phones and the central auditory system using auditory brainstem responses or the auditory event-related potential and most found no effect. However, two studies [10, 13] found an effect on neural activity. Some investigators [1, 4, 12, 18-20, 23-25, 29, 30, 33] studied the interaction between mobile phone exposure and the inner ear, in particular the cochlear OHC using otoacoustic emissions, and concluded in general terms that no effects occur. However, clear conclusions cannot be drawn from these studies regarding the presence or absence of effects because of the limitations in the audiological and/or dosimetric approaches and limited sample sizes.

Parazzini and colleagues [25] summarized the outcome of the EC Project GUARD on possible effects of GSM phones on the auditory function. The study design and protocols applied were suitable for drawing conclusions, and the results showed no effects on the main audiological measures related to exposure from the GSM RFR source. The study by Parazzini and colleagues [29] the first to address the possible interactions of UMTS phones on the hearing system of humans. They found no general effects on the main audiological measures for short-term (20 min) exposure to a commercial UMTS phone. Only pure tone hearing threshold level measurements showed two values that were significantly different when sham and UMTS exposure were compared. However, no other audiological measures tested showed any sign of effect; hence no corroboration was found for the audiometric results.

Although the presence of possible effects on hearing threshold levels cannot be dismissed entirely, the evidence available is not sufficiently strong to conclude that there are adverse effects. A replication study with a shift in hearing threshold levels at high frequencies as the a priori hypothesis is desirable to resolve this issue.

References

[1] Al-Abduljawad KA. Effects of the mobile phones on hearing function of the users. Bah Med Bull. 2005.

[2] Arai N, Enomoto H, Okabe S, Yuasa K, Kamimura Y, Ugawa Y. Thirty minutes mobile phone use has no short-term adverse effects on central auditory pathways. Clin Neurophysiol. 2003; 114: 1390-1394.

[3] Bak M, Sliwinska-Kowalska M, Zmyslony M, Dudarewicz A. No effects of acute exposure to the electromagnetic field emitted by mobile phones on brainstem audipotentials in young volunteers. Int J Occup Med Environ Health. 2003; 16: 201-208.

[4] Davidson HC, Lutman ME. Survey of mobile phone use and their chronic effects on the hearing of a student population. Int J Audiol. 2007; 46: 113-118.

[5] Elder JA, Chou CK. Auditory responses to pulsed radiofrequency energy. Bioelectromagnetics. 2003; Suppl 6: 162-173.

[6] Galloni P, Lovisolo GA, Mancini S, Parazzini M, Pinto R, Piscitelli M, Ravazzani P, Marino C. Effects of 900 MHz electromagnetic fields exposure on cochlear cells' functionality in rats: evaluation of distortion product otoacoustic emissions. Bioelectromagnetics. 2005; 26: 536-547.

[7] Galloni P, Parazzini M, Piscitelli M, Pinto R, Lovisolo GA, Tognola G, Marino C, Ravazzani P. Electromagnetic fields from mobile phones do not affect the inner auditory system of Sprague-Dawley rats. Radiat Res. 2005; 164: 798-804.
[8] Galloni P, Lopresto V, Parazzini M, Pinto R, Piscitelli M, Ravazzani P, Marino C. No effects of UMTs exposure on the function of rat outer hait cells. Bioelectromagn. 2005; 30: 1-8.
[9] Guard report: Potential adverse effects of GSM cellular phones on hearing. Final report. p.1-45, 2005.
[10] Hamblin DL, Croft RJ, Wood AW, Stough C, Spong J. The sensitivity of human event-related potentials and reaction time to mobile phone emitted electromagnetic fields. Bioelectromagn. 2006; 27: 265-273.
[11] Hamblin DL, Wood AW, Croft RJ, Stough C. Examining the effects of electromagnetic fields emitted by GSM mobile phones on human event-related potentials and performance during an auditory task. Clin Neurophysiol. 2004; 115: 171-178.
[12] Janssen T, Boege P, Von Mikusch-Buchberg J, Raczek J. Investigation of potential effects of cellular phones on human auditory function by means of distortion product otoacoustic emissions. J Acoust Soc Am. 2005; 117: 1241-1247.
[13] Kellenyi L, Thuroczy G, Faludy B, Lenard L. Effects of mobile GSM radiotelephone exposure on the auditory brainstem response (ABR). Neurobiol. 1999; 7: 79-81.
[14] Khalil S, Nunez DA. Do mobile phones have a detrimental impact on auditory function? J Laryngol Otol. 2006; 120: 822-826.
[15] Khavanin A, Najfi P, Rezaee A, Bakhtou H, Akbari M. Effects of mobile system (GSM-900) on the rabbit hearing with aauditory brainstem response. J Biol Sci. 2007; 7: 200-204.
[16] Kleinlogel H, Dierks T, Koenig T, Lehmann H, Minder A, Berz A. Effects of weak mobile phone-electromagnetic fields (GSM, UMTS) on event related potentials and cognitive functions. Bioelectromagn. 2008; 29: 488-497.
[17] Maby E, Le Bouquin Jeannes R, Liegeois-Chauvel C, Gourevitch B, Faucon G. Analysis of auditory evoked potential parameters in the presence of radiofrequency fields using a support vector machines method. Med Biol Eng Comput. 2004; 42: 562-568.
[18] Meo SA, Al-Dreess AM. Mobile phone related hazards and subjective hearing and vision symptoms in the saudi population. Int J Occup Med Env Health. 2005; 18: 45-49.
[19] Monnery PM, Srouji E, Bartlett J. Is cochlear outer hair cell function affected by mobile telephone radiation? Clin Otolaryngol Allied Sci. 2004; 29: 747-749.
[20] Mora R, Crippa B, Mora F, Delle Piane M. A study of the effects of cellular telephone microwave radiation on the auditory system in healthy men. Ear Nose Throat J. 2006; 85: 162-163.

[21] Oktay MF, Dasdag S. Effects of Intensive and Moderate Cellular Phone Use on Hearing Function. Electromagn Biol Med. 1006; 25(1): 13-21.
[22] Oysu C, Topak M, Celik O, Yilmaz HB, Sahin AA. Effects of the acute exposure to the electromagnetic field of mobile phones on human auditory brainstem responses. Eur Arch Otorhinolarynogol. 2005; 262: 839-843.
[23] Ozturan O, Erdem T, Miman MC, Kalcioglu MT, Oncel S. Effects of the electromagnetic field of mobile telephones on hearing. Acta Otolaryngol. 2002; 122: 289-293.
[24] Paglialonga A, Tognola G, Parazzini M, Lutman ME, Bell SL, Thuroczy G, Ravazzani P. Effects of mobile phone exposure on time frequency fine structure of transiently evoked otoacoustic emissions. J Acoust Soc Am. 2007; 122: 2174-2182.
[25] Parazzini M, Brazzale AR, Paglialonga A, Tognola G, Collet L, Moulin A, Lutman ME, Bell SL, Thomas NA, Ravazzani P. Effects of GSM cellular phones on human hearing: the European project 'GUARD'. Radiat Res. 2007; 168: 608-613.
[26] Parazzini M, Galloni P, Piscitelli P, Pinto R, Lovisolo A, Tognola G, Ravazzani P, Marino C. Possible combined effects of 900 MHz CW electromagnetic fields and gentamicin on the auditory system of rats. Radiat Res. 2007; 167: 600-605.
[27] Parazzini M, Bell S, Thuroczy G, Molnar F, Tognola G, Lutman M, Ravazzani P. Influence on the mechanisms of generation of distortion product otoacoustic emissions of mobile phone exposure. Hear Res. 2005; 208: 68-78.
[28] Parazzini M, Tognola G, Franzoni C, Grandori F. Ravazzani P. Modelling of the internal fields distribution in human inner hearing system exposed to 900 and 1800 MHz. IEEE Trans Biomed Eng. 2007; 54: 39-48.
[29] Parazzini M, Siebella F, Lutman ME, Mishra S, Moulin A, Sliwinska-Kowalska M, Woznicka E, Politanski P, Zmyslony M, Thuroczy G, Molnar F, Kubinyi G, Tavartkilaadze G, Bronyaakin S, Uloziene I, Uloza V, Gradauskiene E, Ravazanni P. Effects of UMTS cellular phones on human hearing: Results of the European project 'EMFnEAR'. Radiat Res. 2009; 172: 244-251.
[30] Pau HW, Sievert U, Eggert S, Wild W. Can electromagnetic fields emitted by mobile phones stimulate the vestibular organ. Otolaryngol Head Neck Surg. 2004.
[31] Sievert U, Eggert S, Pau HW. Can mobile phone emissions affect auditory functions of cochlea or brain stem? Otolaryngol Head Neck Surg. 2005; 132: 451-455.
[32] Stefanics G, Kellenyi L, Molnar F, Kubinyi G, Thuroczy G, Hernadi I. Short GSM mobile phone exposure does not alter human auditory brainstem response. BMC Public Health. 2007; 12: 325-342.
[33] Uloziene I, Uloza V, Gradauskiene E, Saferis V. Assessment of potential effects of the electromagnetic fields of mobile phones on hearing. BMC Public Health. 2005; 5: 1-9.