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Effects of Intensive and Moderate Cellular Phone Use on Hearing Function

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The purpose of this study is to investigate 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.

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

Keywords BERA; Cellular phones; Hearing; Mobile phones; PTA.

Introduction

The rapid adoption of wireless communication, especially handheld cellular phones, has generated controversy over whether or not these systems pose a risk to human health. As do other devices that transmit radio signals, mobile phones

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emit microwave radio frequency (RF) energy. At high power levels, microwave RF exposure can rapidly heat tissue and cause visible damage, such as burns. Mobile phones operate at power levels well below the level at which such overt heating effects occur. Consequently, the mobile phone health issue has generally focused on whether there are any adverse biological nonthermal effects from long-term or frequent exposure to low-level RF emission (U.S. General Accounting Office, 2001).

Because the use of mobile phones operating in the 900 and 1800 MHz frequency bands is widespread and increasing rapidly, the question of whether microwave (MW) at these frequencies could cause some adverse biological effects is of public interest. Digital GSM telephones transmit in the 900 MHz band (890–915 MHz) with a maximum power level of 2 W (peak value). Multiplexing is used within each channel, and up to eight calls can be transmitted simultaneously. Thus, any one telephone transmits only one-eighth of the time. Information is sent in bursts of 577 μ s duration at a rate of 217 bursts per s (Linde and Mild, 1997).

As a way to determine internal exposure, the specific absorption rate (SAR) (in W/kg) is generally used as the dose metric in laboratory experiments. This becomes a problematic standard if nonthermal effects of MW radiation exist. For typical biological tissue, the SAR is given by $SAR = (E_{\text{local}})^2 \times \sigma_{\text{eff}} / \rho$, where E_{local} is the r.m.s. electric field (in V/m) generated in the organism at the point of interest, σ_{eff} is the effective conductivity in Siemens/meter, and ρ is the density in kg/m³ (Moulder et al., 1999). Due to the close proximity of a mobile telephone to the head during its use, the brain is exposed to a relatively high SAR, compared to the rest of the body. Exposure standards set by national and international institutions require limit values for SAR of 1.6 to 2 W/kg for local exposure to the general public (ANSI/IEEE, 1992; ICNIRP, 1996).

Scientists use two major methods to assess whether handheld cellular phones present a health risk: epidemiological and laboratory studies. In recent years, results of increasing numbers of studies of the effects of MW radiation from cellular phones and base stations appear to indicate that the MW emitted by cellular phones is not statistically dangerous. However, because some studies of MW emitted from mobile phones have reported positive findings, continuing research is advisable (Dasdag et al., 2003). Since RF exposure from mobile phones is concentrated to the head, research related to cell phone exposure is generally focused on brain tumors/cancer. However, some effort should also be focused on hearing function of cell phone users. For due to the close proximity of a mobile telephone device to the head, the auditory system is also exposed to relatively high specific absorption rates, compared to the rest of the body.

Some previous studies have investigated the effect of MWs on hearing. Wilen et al. (2003) found that SAR values >0.5 W/kg may be factor for the prevalence of some symptoms, especially in combination with long calling times per day. Kompis and Hausler (2002) confirmed that susceptibility to electromagnetic interference by compact bone-anchored hearing aid (BAHA) devices is low. Meric et al. (1998) indicated that the incidence of noise induced hearing loss (NIHL) at 4 kHz in people exposed to radio frequency is higher than in unexposed people. In contrast, Ozturan et al. (2002) showed that a 10 min repeated exposure to electromagnetic fields emitted from a mobile telephone had no effect on hearing, at least when applied at outer ear, middle ear, and cochlear levels.

Brainstem evoked response audiometry (BERA) provides an objective means of evaluating hearing by using a signal-averaging process to measure bioelectric

events in response to auditory stimulation. Responses can be recorded from the cochlea up into the midbrain. These potentials are valuable tools for measuring hearing sensitivity and neurologic disorders. BERA is the most popular audiological measure used for the identification of retro-cochlear disorders. Using both BERA and PTA makes it possible to differentiate cochlear from retro-cochlear pathologies.

To our knowledge, this is the first study investigating the effects of 900 MHz frequency cellular phones on hearing in users who talk for long periods and more frequently than in moderate/or control subjects using BERA and PTA measurements together.

Materials and Methods

The study was carried out on three voluntary groups of 20 male subjects. The first group of subjects (mean age: 34.7; SD: 7.1; range 25–47) used cellular phones very frequently and spoke approximately 2 h per day for four years due to their business activities (intensive users). The second group of subjects (moderate use) used their phones for 10–20 minutes per day for four years (mean age: 32.1; SD: 6.6; range 22–48). The third group consisted of subjects (mean age: 37.6; SD: 7.1; range 26–53) who never used a cellular phone. All subjects were healthy, right-handed native speakers. None of the subjects used hand-free sets. The users in this study used various models of cellular phones produced by different manufacturers. However, the highest SAR values for the cellular phones used in this study when tested by manufacturers for use at the ear lay between 0.60 W/kg–0.82 W/kg.

The subjects in this study were informed about the aim of the study before giving their consent. An otolaryngologist (first author) examined the subjects' ears and excluded those with ear pathologies such as otitis media, otosclerosis, acoustic trauma, and any history of ear and/or neurologic diseases, which could affect the neurologic auditory pathway. To avoid experimental errors, men who had a history of exposure to RF because of their job or living in close proximity to an antenna were excluded from the study. Men exposed to loud noise from acoustic devices such as CD players were also excluded.

A pure tone audiometer (Madsen electronics, OB-822, Copenhagen, Denmark) was used to test the hearing acuity of the subjects. Next, BERA was performed using Sapphire 2A EP System (Medelec, Old Woking, UK) device on supine subjects lying on a bed in an acoustically and electrically shielded room.

Recording of BERA

Three silver–silver chloride disk electrodes were placed: a) at the forehead in the midline (ground), b) at the mastoid ipsilateral to the acoustic stimuli (negative), and c) at the vertex of the skull (positive). Inter-electrode resistance was maintained at 4 k Ω or less. Rarefaction clicks of 100 μ s duration were used as acoustic stimuli. Brainstem responses to 2048 clicks were recorded for each run. The recorded signals were bandpass-filtered to lie between 100 and 2000 Hz, and were processed by a signal-averaging computer. Automatic artifact rejection was used to reduce the inclusion of any high-amplitude muscular activity in the averaged responses. Sampling was discontinued whenever there were excessive (if any muscle artifacts distort normal BERA waveforms) muscle artifacts on the monitoring oscilloscope. In repeating records, waves with stable duration and shape were recorded at 90 dB

sound pressure level (SPL) delivered monaurally through TDH 39 earphones and used for comparisons. Both of the ears of every subject were tested, during testing an ear. The contralateral ear was always masked with white noise 40 dB below the ipsilateral click stimuli in order to get a correct response. All subjects were tested at a click rate of 10 per s.

In addition to the evaluation of hearing, we asked some questions to all subjects about habitual laterality of phone use and whether they have any other symptoms such as warm sensation behind/around the ear, headache, difficulty of concentration, and discomfort, and also calling time per day, plus number of calls per day.

Statistical Analysis

Nonparametric Mann Whitney *U* test was used in audiometry results to obtain intergroup comparisons. One-way analysis of variance (ANOVA) was performed for BERA values of 90 dB SPL. The distribution of the symptoms among groups was compared using the Fisher's exact χ^2 test.

Results

Statistical analysis of patients' BERA findings demonstrated no statistically significant differences in the I–III, III–V, and I–V interpeak intervals among the three groups ($p > 0.05$), and no neurological disorders were found among the subject groups. The test results of the findings on interpeak intervals are given in Table 1.

Statistical analysis of the pure tone audiometry results revealed a significant difference indicating sensorineural hearing loss at 4000 Hz in right ears, and at 500, and 4000 Hz in the left ears of intensive users as compared to moderate and nonusers. No difference was observed between moderate users and nonusers. The mean values at each frequency in each group are shown in Tables 2 and 3.

In the intensive use group (Group I), 13 subjects said they used both ears equally without paying attention to which side they usually use, 5 used mostly their left ears, and 2 used mostly their right ears when they answered calls. Thus, statistical analysis for comparison of lateralization of phone use and hearing threshold levels for each group was not possible, since most of the subjects used both ears when answering the calls without being aware of which side they usually used.

Table 1
The results of BERA interpeak intervals in three groups

Interpeak intervals	I–III*(ms.) $X \pm SD$	III–V*(ms.) $X \pm SD$	I–V*(ms.) $X \pm SD$	<i>F</i>	<i>p</i>
Intensive users	2.143 $\pm$ 0.235	1.755 $\pm$ 0.287	3.898 $\pm$ 0.299	2.141	0.123
Moderate users	2.162 $\pm$ 0.152	1.684 $\pm$ 0.260	3.846 $\pm$ 0.253	0.325	0.723
Control subjects	2.182 $\pm$ 0.229	1.782 $\pm$ 0.256	3.989 $\pm$ 0.319	1.168	0.315

*There is no difference among three groups ($p > 0.05$).

Table 2
Hearing threshold of the right ears.

Frequencies (Hz)	Groups and type of conduction					
	Group I (intensive)		Group II (moderate)		Group III (nonusers)	
	Air cond.	Bone cond.	Air cond.	Bone cond.	Air cond.	Bone cond.
250	10	10	10	15	15	15
500	10	10	10	10	10	5
1000	10	10	10	5	10	5
2000	10	5	10	5	10	5
4000	22.5*	20**	15	15	12.5	10
8000	17.5	17.5	17.5	17.5	20	20

*Difference between Group I and Group III only, **difference between Group I and Group II and between Group I and Group III.

P values in statistical analysis of comparison PTA hearing threshold in both air and bone conduction of right ear among three groups.

Frequencies (Hz)	Groups comparison					
	Air conduction			Bone conduction		
	I-II	I-III	II-III	I-II	I-III	II-III
250	$p > 0.05$	$p > 0.05$	$p > 0.05$	$p > 0.05$	$p > 0.05$	$p > 0.05$
500	$p > 0.05$	$p > 0.05$	$p > 0.05$	$p > 0.05$	$p > 0.05$	$p > 0.05$
1000	$p > 0.05$	$p > 0.05$	$p > 0.05$	$p > 0.05$	$p > 0.05$	$p > 0.05$
2000	$p > 0.05$	$p > 0.05$	$p > 0.05$	$p > 0.05$	$p > 0.05$	$p > 0.05$
4000	$p > 0.05$	$p < 0.05^*$	$p > 0.05$	$p < 0.05^*$	$p < 0.05^*$	$p > 0.05$
8000	$p > 0.05$	$p > 0.05$	$p > 0.05$	$p > 0.05$	$p > 0.05$	$p > 0.05$

Group I: intensive users, Group II: moderate users, Group III: unexposed controls, * $p < 0.05$.

In response to the questions about symptoms, users in Group I reported more symptoms than the other two groups. In this group, sensation of burning or warmth behind/around/on the ear during or after the call were observed in 11 subjects (55%), which was significantly higher than the other two groups ($p < 0.05$). Difficulty in concentration and/or discomfort were observed in 8 (40%) subjects, and headaches were observed in 7 (35%) subjects, in Group I. Although these latter symptoms were more prevalent in Group I, the differences were not significant.

Discussion

The use of mobile phones is becoming increasingly popular and almost indispensable in modern daily life. This is one of the fastest-growing technological developments of our times. However, there is an increasing amount of public concern over possible health risks of electromagnetic field (EMF) exposure from cellular phones.

Guidelines for risk limits are based on thermal effects of EMFs INIRC (1998). A sensation of burning or warmth behind/around the ear, or a burning sensation

Table 3
Hearing threshold of the left ears.

Frequencies (Hz)	Groups and type of conduction					
	Group I (intensive)		Group II (moderate)		Group III (nonusers)	
	Air cond.	Bone cond.	Air cond.	Bone cond.	Air cond.	Bone cond.
250	15	15	15	15	15	15
500	15*	15**	15	10	10	7.5
1000	10	10	15	10	10	5
2000	10	10	10	7.5	10	10
4000	20*	20*	20	15	15	10
8000	27.5	27.5	20	17.5	20	20

*Difference between Group I and Group III only, **difference between Group I and Group II and between Group I and Group III.

P values in statistical analysis of comparison PTA hearing threshold in both air and bone conduction of right ear among three groups.

Frequencies (Hz)	Groups comparison					
	Air conduction			Bone conduction		
	I-II	I-III	II-III	I-II	I-III	II-III
250	$p > 0.05$	$p > 0.05$	$p > 0.05$	$p > 0.05$	$p > 0.05$	$p > 0.05$
500	$p > 0.05$	$p < 0.05^*$	$p > 0.05$	$p < 0.05^*$	$p < 0.05^*$	$p > 0.05$
1000	$p > 0.05$	$p > 0.05$	$p > 0.05$	$p > 0.05$	$p > 0.05$	$p > 0.05$
2000	$p > 0.05$	$p > 0.05$	$p > 0.05$	$p > 0.05$	$p > 0.05$	$p > 0.05$
4000	$p > 0.05$	$p < 0.05^*$	$p > 0.05$	$p > 0.05$	$p < 0.05^*$	$p > 0.05$
8000	$p > 0.05$	$p > 0.05$	$p > 0.05$	$p > 0.05$	$p > 0.05$	$p > 0.05$

Group I: intensive users, Group II: moderate users, Group III: unexposed controls, * $p < 0.05$.

in the facial skin (Oftedal et al., 2000), alteration of the brain-blood barrier (Fritze et al., 1997) and headaches (Frey, 1998), modification of sleep (detected through electroencephalogram) (Borbely et al., 1999), and effect on cognitive tasks (Preece et al., 1999) all have been reported as thermal and nonthermal effects from cellular telephone use. The signal-transducing apparatus of the ears of phone users is in the closest proximity to the EMF of the cellular phone during a call, because the distance from the phone's antenna to the inner ear is only a few centimeters. Radio frequency signals are radiated from and received by the antenna during a call. This may lead to relatively high SAR deposition in the region of the ear as compared to other parts of the body. It can penetrate the tissue and be absorbed and converted into heat (Ozturan et al., 2002).

The SAR level for each model of cellular telephone is not currently available in many attributable or consistent forms, and there is not yet a consensus concerning an appropriate test method by which to assess SAR. The exposure rate usually is not actually determined on the basis of individual exposure, but is experimentally determined in the laboratory using phantom models with shape and dielectric properties as close as possible to a human head, or is computed using spherical

mathematical models. Estimates for SAR to the head from a 900 MHz mobile telephone vary from 0.16 to 0.69 W/kg (Gandhi, 1995).

Although the acute effect of cellular phones on hearing has been studied, there are no published data regarding chronic effects of EMFs created by cellular phones. The present study was designed to investigate possible effects of frequent and long-term repeated exposure to EMF of cellular phones on the hearing of adult users, as measured by changes in BERA interpeak intervals and pure tone audiometry.

Cochlear nerves and temporal lobes are the neural structures most exposed to the pulsed EMF emitted by cellular phones. Therefore, cellular phones are ideally positioned to affect the auditory system. Such fields have been shown to have some adverse effects on the brain (Lonn et al., 2004). Several studies have investigated the interaction between cellular phones and brain function in humans (Eulitz et al., 1998; Freude et al., 1998; Kellenyi et al., 1999; Ozturan et al., 2002; Reiser et al., 1995). Other studies have revealed nonthermal adverse effects of cellular phones (Huber et al., 2002; Kellenyi et al., 1999; Reiser et al., 1995). On the other hand, Kizilay et al. (2003) found that 1 hr of daily exposure for 30 days to EMFs generated by a cellular phone did not have any detrimental effects on the hearing of adult and developing rats as measured by otoacoustic emissions (OAEs). Ozturan et al. (2002) showed that a 10-min exposure to EMFs emitted from a mobile telephone had no effect on hearing, at least at the cochlear level by using OAEs. However, those studies were designed to investigate short-term acute exposure, and the results obtained did not provide any information regarding the potential effects of longer or chronic cumulative exposure. In this study, we did not find any difference in the I–III, III–V, or I–V interpeak intervals among the three groups. Although BERA provides valuable information regarding auditory function and hearing sensitivity, it is also an effective tool in the evaluation of retro-cochlear pathologies from cochlear nerve to midbrain. The I–III, III–V, and I–V latencies provide information regarding the integrity of cochlear nerve to the auditory brainstem and midbrain. The lack of effect on BERA in this study suggests that the fundamental pathways mediating an auditory stimulus, from cochlear nerve to midbrain, are not affected by cellular phones.

PTA is a rapid and standard behavioral measure used to quantify degree of hearing loss. In statistical analysis of the pure tone audiometry results, there was a significant difference indicating sensorineural hearing loss at 4000 Hz in the right ears, and at 500, and 4000 Hz in the left ears of intensive users when compared to moderate and nonusers. This may be related to right-handed subjects using mostly their left ears when they answered the calls. No difference was observed between moderate users and nonusers. Another feature of GSM telephones is that they emit maximum power, which might have some detrimental effect on hearing, for a few seconds during the initiation of a call. The telephone rings only after it has received this powerful transmission, and the power then decreases to a level that is just sufficient to sustain the connection. These features of GSM cellular telephones may explain the hearing loss obtained in this study.

In this study, sensation of burning or warmth behind/around/on the ear was observed only in extensive users. Although not significant, the incidences of headaches, difficulty of concentration, and discomfort were more in the same group. The results related to symptoms and calling time obtained in this study are in agreement with the results of Wilen et al. (2003). However, Hietanen et al. (2002) did not find adverse subjective symptoms or sensations which were provoked by phone exposure.

Although little is known about the details of the biological effects of cellular telephone use, this study shows that a higher degree of hearing loss is associated with long-term exposure to EM fields generated by cellular phones. Therefore, we propose the prudent use of mobile telephones. Cellular telephones should be used only for short periods, and only for essential purposes.

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