Taylor & Francis healthsciences

Effects of the Electromagnetic Field of Mobile Telephones on Hearing

ORHAN OZTURAN, TAMER ERDEM, MURAT CEM MIMAN, MAHMUT TAYYAR KALCIOGLU and SEMIH ONCEL

From the Department of Otorhinolaryngology, School of Medicine, Inonu University, Malatya, Turkey

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.

The widespread use of mobile telephones has given rise to concern about the potential influences of electromagnetic fields (EMFs) on human health. Anatomically, the ear is in close proximity to the mobile telephone during use. Hearing loss due to mobile telephone use has not been described in the medical literature; however, if there is a subtle cochlear involvement, it might be detected by means of changes in evoked otoacoustic emissions (OAEs). 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. To the best of our knowledge, this is 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. *Key words*: *adverse effect, cochlea, mobile telephone, otoacoustic emissions*.

INTRODUCTION

The use of mobile telephones is increasing rapidly worldwide. They transmit and receive microwave radiation at frequencies of ≈ 900 MHz and 1,800 MHz, respectively and these frequencies excite rotations of water molecules and some organic molecules and have been associated with thermal and non-thermal effects (1). Headaches (2), the sensation of burning or warmth on the ear or behind/around the ear, burning sensations in the facial skin (3) and alteration of the blood–brain barrier (4) have been reported as thermal effects resulting from mobile telephone use. Non-thermal effects of mobile telephone use described in the literature include modifications of sleep patterns (detected by means of electroencephalography) (5), an increase in blood pressure (6) and effects on cognitive function (7). The potential carcinogenic effect of electromagnetic fields (EMFs) is a subject of controversy (8, 9).

Guidelines for exposure limits to EMFs have been published and are periodically revised (10). EMF power intensity is measured in units of mW/cm^2 but this provides little information about the biological consequences unless the amount of energy absorbed is known. Exposure limits relevant to mobile telephones are expressed 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. Individual countries set SAR guidelines to indicate to the public what level of electromagnetic waves emitted by electrical appliances is safe; for example, the National Radiological Protection Board in the UK set the SAR guideline for the head at 10 W/kg (10). The responsibility for complying with the recommended exposure limits lies with the manufacturers. Radio waves transmitted by mobile telephones do not exceed the SAR limits because all modern Global System for Mobile Communications (GSM) mobile telephones, irrespective of the manufacturer, emit a level of radio waves that produces a SAR for the head of <1 W/kg. Calculations using an anatomical mathematical model of the human head have indicated that current mobile telephones comply with the exposure limit (11). However, the widespread use of mobile telephones has given rise to concerns over whether the EMFs emitted are detrimental to the hearing of their users. Mobile telephone use necessitates holding the unit in close proximity to the ear but to date it has not been reported as a cause of hearing loss in the literature. If it causes subtle deleterious effects to the cochlea these may be observable by means of changes in evoked otoacoustic emissions (OAEs). The present study was designed to investigate the acute after-effects of the EMFs emitted by mobile telephones on human hearing as determined by changes in evoked OAEs.

MATERIALS AND METHODS

Thirty adults with normal hearing (17 males, 13 females; age range 19–36 years; mean age 25 years) volunteered to participate in this study. All subjects were right-handed medical students or nurses. Only the right ears of subjects were exposed to EMFs and evaluated. Subjects with tinnitus, middle ear pathology or a history of noise exposure were not enrolled in this study. Otoscopic examinations were performed by an otolaryngologist before testing in order to rule out any external or middle ear pathology that could affect audiometric measurements. After confirming

 ISSN 0001-6489

the subject's health status by means of a complete medical and otologic history and otoscopic examination, tympanometry (Zodiac 901 Middle Ear Analyzer; Madsen, Denmark) was performed to eliminate the possibility of middle ear problems. The hearing levels of subjects with a type A tympanogram were tested using pure-tone audiometry (PTA; AC 5 Clinical Audiometer; Interacoustics, Denmark). The criteria for normal hearing were as follows: pure-tone thresholds 20 dB hearing limit or better for the octave (250–8,000 Hz) and interoctave frequencies (1,500, 3,000 and 6,000 Hz); and normal middle ear function as determined by tympanometry. Volunteers meeting these criteria were enrolled in the study and underwent evoked OAE testing sessions. The study was conducted on three different dates and calibration was performed prior to each test session. All tests were performed in a sound-treated room. This project and the related consent form were approved by the Ethical Committee of the Medical Faculty of Inonu University, and the consent form was signed by each subject after the nature of the experimental procedure had been fully explained.

The mobile telephone utilized in this study was the Panasonic GD 600 (Panasonic, UK), which transmits and receives radio signals in the region of 900 MHz using the GSM system. Despite repeated inquires to Panasonic concerning its SAR level, they did not respond. In general, all modern mobile telephones utilize intensity levels between 0.02 and 2.0 W during use (10).

For the purposes of monitoring the potential negative effects of EMFs emitted by a mobile telephone on hearing, transiently evoked (TE) and distortion-product (DP) OAEs were recorded consecutively and analyzed utilizing an ILO-96 cochlear emission analyzer (Otodynamics, London, UK). Four evoked OAE test sessions were separately conducted for each subject. The baseline measurement was repeated 10 min after completion of the test to confirm test–retest reliability. After the second measurement, the subjects held the activated mobile telephone to their right ear for 10 min without interruption in the room next to the sound-treated testing room. The subjects did not converse with anyone during this time to avoid the possibility of a negative acoustic effect on the outer hair cells and to ensure exposure to EMFs only. The third measurement was performed immediately after the 10-min period of telephone use. Finally, a fourth measurement was carried out 10 min after the last test to assess the recovery of hearing, in case there was any alteration due to EMF exposure. Each evoked OAE measurement session lasted $\approx$2–2.5 min.

TEOAEs were obtained with stimuli consisting of clicks of 80 μs duration. The stimulus level in the outer ear was set at 80 ± 3 dB peak equivalent sound pressure level. The click rate was 50/s and post-stimulus analysis was performed in the range 2–20 ms. A total of 260 sweeps was averaged above the noise rejection level of 47 dB. Stimuli were presented in the non-linear mode, in which every fourth click stimulus is inverted and three times greater in amplitude than the three preceding clicks. A TEOAE was defined as a response if its amplitude was ≥ 3 dB above the level of the noise floor. Reproducibility $\geq 60\%$ was considered acceptable for the analysis at 5 successive frequency bands ranging from 1 to 5 kHz.

DPOAEs were determined as DPgrams, where the intensity levels of the primary tones are held constant and DPOAE data are recorded for different frequency regions, ranging from 1 to 6.3 kHz, and plotted as a function of f2. The resolution of the DPgram was obtained at four points per octave. The frequency ratio of the two primary tones (f2/f1) was fixed at 1.22. Stimulus levels were kept at 65 dB for f1 and 55 dB for f2. DPOAE measurement at 2f1–f2 was considered significantly different from the background noise if it exceeded it by ≥ 3 dB.

Statistical methods

In order to provide a statistical analysis power of 80% (beta: 0.2; alpha: 0.05) the study group comprised 30 volunteers. TEOAE amplitudes and reproducibility and DPOAE amplitudes found in four separate test sessions for the related frequencies showed normal distributions as calculated by the Kolmogorov–Smirnov test. Each session was compared with another session using a paired Student's *t*-test. Comparisons were made statistically between any two paired sessions (e.g., between first and second, second and third, etc.).

RESULTS

As all our subjects had normal hearing, TEOAEs were recorded above the noise floor between 1 and 4 kHz, but below the noise floor at 5 kHz. Similarly, reproducibility was $> 60\%$ for 1–4 kHz and $< 60\%$ for 5 kHz. In the DPgram, the emission amplitude levels were greater than the noise floor throughout the 1–6.3 kHz test frequency range for all sessions. The first and second measurements were not significantly different, demonstrating the high repeatability of the evoked OAEs. There was no statistically significant difference in the mean amplitudes of the evoked OAEs between the second (before the EMF exposure) and third (after the EMF exposure) measurements, in addition to the four separate test measures ($p > 0.05$). The results of this study suggest that 10-min exposure to EMFs emitted by a mobile telephone did not cause any detectable alteration in evoked OAE measurements. As there was no significant difference between the test sessions, the last test, conducted for the purpose of assessing recovery from a potential hearing effect, was of no use. Figures 1 and 2 illustrate the average amplitude levels of the TEOAEs and DPOAEs, respectively.

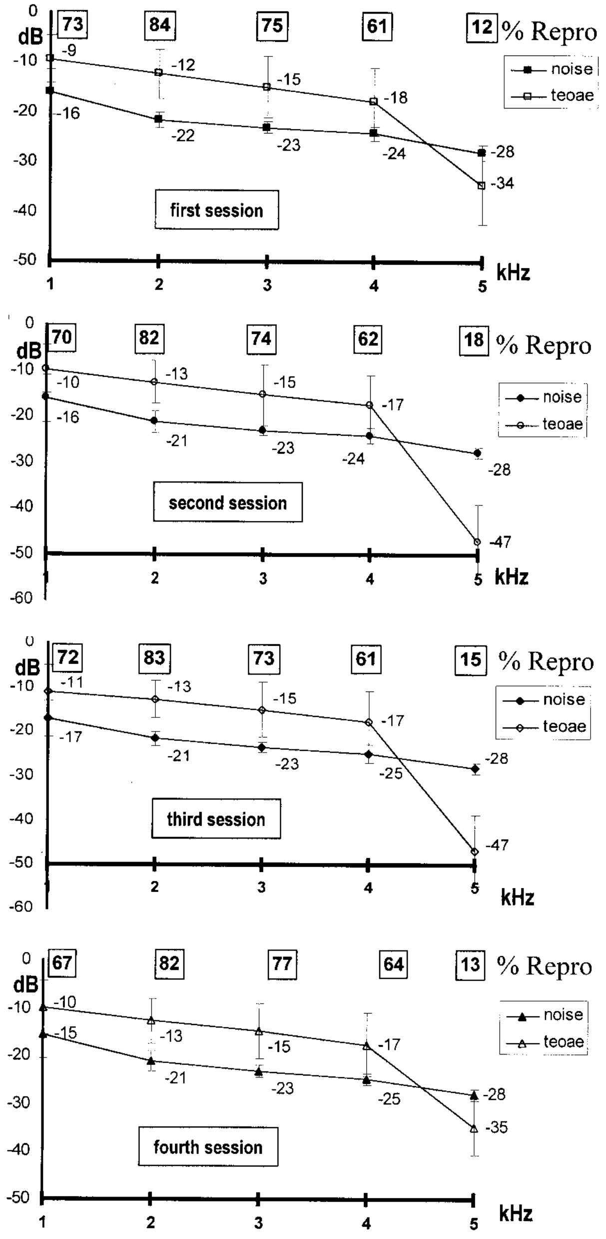

Fig. 1. Mean amplitudes and reproducibility percentages of the TEOAEs ($\pm$ SDs) and mean noise floor levels ($\pm$ SDs) from four measurement sessions.

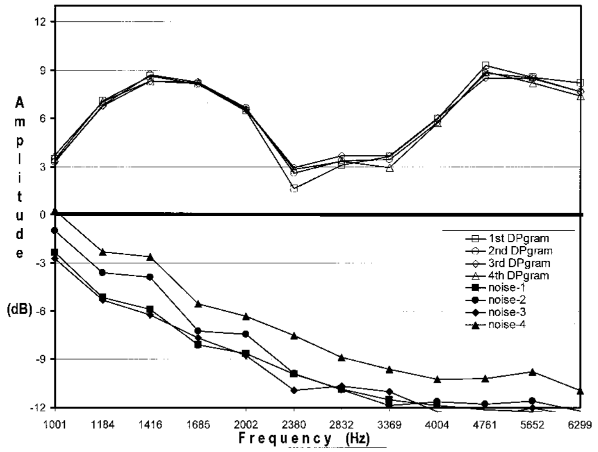

Fig. 2. Mean amplitudes of the DPOAEs and mean noise floor levels from four measurement sessions.

DISCUSSION

The rapid worldwide increase in the use of mobile telephones raises questions regarding possible effects of the emitted radio frequencies on the health of consumers. Of all the anatomical structures, the ear is in closest proximity to the mobile telephone. This may lead to relatively high SAR deposition in the ear compared to other parts of the body. Although the effect of mobile telephones on hearing aids has been studied (12), there has been no investigation on hearing itself. After confirming the test–retest reliability, the outcomes of this study were based on the comparison of evoked OAE parameters prior to and following exposure to the EMFs emitted by the mobile telephone. This exposure was achieved by subjects holding the activated mobile telephone for 10 min without conversation or interruption for the purpose of exposure to EMF per se.

Under certain stimulus conditions, the healthy cochlea emits acoustic energy that 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. Mild cochlear functional changes, that are not revealed by PTA, cause obvious changes in DPOAEs (13). Evoked OAEs are also a well-described method for detecting the effects of ototoxic drugs on the cochlea (14). The high test–retest reliability of OAE measurements permits the utilization of these emissions for monitoring dynamic changes in cochlear responsiveness (15). The measurement of evoked OAEs is non-invasive, painless and quick and does not require the active participation of the subject (15). For these reasons, OAE measurements appear to be well suited for the investigation of potential cochlear involvement as a result of exposure to EMFs emitted by mobile telephones.

No input/output functions were recorded because of the necessity of minimizing the test duration following the EMF exposure so as not to miss temporary threshold changes. Alternative methods, such as PTA and Bekesy audiometry, were not utilized for the evaluation of the possible effects of mobile telephone EMFs on hearing (13) because they are subjective, protracted and less sensitive methods for measuring subtle cochlear involvements (13, 16). Both TEOAEs and DPOAEs have great potential for the detection of temporary threshold shifts after cochlear insults (17). TEOAEs provide a more sensitive and more objective method of detecting a subtle noise-induced disturbance of cochlear function than PTA or DPOAEs (16), and can be determined in a shorter time than the DPgram. For this reason we determined TEOAEs first, followed by DPgrams.

The only potential insult to which subjects were exposed during this investigation was 10-min use of the mobile telephone. TEOAEs were analyzed in terms of emission level and reproducibility as a function of frequency (1–4 kHz). These parameters were not valid for evaluation when recorded at 5 kHz. DPOAEs were obtained as DPgrams between 1 and 6.3 kHz. The DPgram amplitudes were determined for each subject. As TEOAEs are most reliable in practice between 1,000 and 4,000 Hz and DPOAEs between 2,000 and 6,000 Hz (18), both types of evoked OAE were recorded, in order to take advantage of their differing frequency sensitivities. Four consecutive measurement sessions did not demonstrate any significant changes in emission amplitudes. Statistical analyses of the evoked OAE levels between test sessions corroborated that mobile telephone use does not cause either positive or negative after-effects on hearing. Evoked OAE measurements are very sensitive for the detection of any subtle cochlear involvement (13–17) and should therefore have revealed any significant impact of the mobile telephone on the cochlea. Furthermore, low primary levels (65 and 55 dB) were used for the enhanced sensitivity of the DPOAEs, so as to reveal even minor influences on active cochlear properties (19).

Radio frequency electromagnetic radiation is emitted from mobile telephone antennae. This can penetrate organic tissue and be absorbed and converted into heat. The close proximity of a mobile telephone antenna to the user's ear may lead to the deposition of a large amount of EMF energy in the ear. The energy radiated by a mobile telephone is low. GSM telephones always emit maximum power 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 which is just sufficient to sustain the connection (1). This safety feature of GSM mobile telephones may be one reason for the negative results obtained in this study.

The rate of absorption and the distribution of EMF energy in an organism depend on many factors, including the dielectric composition of the irradiated tissue, e.g. bone (with a lower water content) absorbs less energy than muscle; the frequency of the EMF; the shape, geometry and orientation of the object; and the proximity of the source (11). Heating of biological tissue can occur as a consequence of EMF energy absorption by the water in the tissue. The rise in temperature depends primarily on the intensity of the radiation and the efficiency of the thermoregulation mechanism of the body (11). In deep tissues, such as the brain, maximum temperature rise due to mobile telephone EMF exposure was calculated to be no more than $\approx 0.1°C$ (20). 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 as the cochlea is enclosed by very dense compact bone, located relatively deeply and filled with perilymph and endolymph, these factors all help to shield it from mobile telephone EMFs.

The results of the present study may appear comforting in terms of the effects of mobile telephones on hearing. However, it is not reasonable to conclude that exposure to EMFs during mobile telephone use does not lead to any hazardous health effects. As the electromagnetic emissions from the mobile telephone would have interfered with the detection and recording of the emission apparatus, hearing could not be evaluated simultaneously with mobile telephone use, but only immediately following EMF exposure. Therefore, the status of the cochlea during mobile telephone use remains unclear. Unfortunately, the cost of mobile telephone use for periods > 10 min for each volunteer in this study was financially prohibitive. However, the average duration of a mobile telephone call does not exceed 10 min.

To the best of our knowledge this is the first study to evaluate the effects on hearing of mobile telephone use. A 10-min exposure to EMFs emitted by a mobile telephone had no after-effect on hearing, in that the non-linearity of the outer hair cell functions was not altered. This study was designed to investigate short-term acute exposure and the results obtained did not reveal any information regarding the potential effects of longer exposure or chronic cumulative exposure. Thus, it is recommended that further studies should examine whether hearing is affected by longer or repeated EMF exposure. As little is known about the biological effects of mobile telephone use, there are gaps in our knowledge and suspicions that the EMFs radiating from mobile telephones can have detrimental effects on health. Therefore, the following guidelines for the prudent use of mobile telephones are proposed: use mobile telephones only for short periods; use them only for essential purposes; use telephones with low SAR values; and use hands-free devices, provided that they have been proven to reduce SAR exposure (10).

REFERENCES

1. Szentpali B. Human exposure to electromagnetic fields from mobile phones. In: Proceedings of the 4th conference on telecommunications in modern satellite, cable and broadcasting services 'Telsiks '99'; 1999 Oct. 13–15, at the Faculty of Electronic Engineering, University of NIŠ, Yugoslavia; 1999; 222–31.
2. Frey AH. Headaches from cellular telephones: are they real and what are the implications? Environ Health Perspect 1998; 106: 101–3.
3. Oftedal G, Wilen J, Sandstrom M, Mild KH. Symptoms experienced in connection with mobile phone use. Occup Med 2000; 50: 237–45.
4. Fritze K, Sommer C, Schmitz B, et al. Effect of global system for mobile communication (GSM) microwave exposure on blood-brain barrier permeability in rat. Acta Neuropathol (Berl) 1997; 94: 465–70.
5. Borbely AA, Huber R, Graf T, Fuchs B, Gallmann E, Achermann P. Pulsed high-frequency electromagnetic field affects human sleep and sleep electroencephalogram. Neurosci Lett 1999; 275: 207–10.
6. Braune S, Wrocklage C, Raczek J, Gailus T, Lucking CH. Resting blood pressure increase during exposure to a radio-frequency electromagnetic field. Lancet 1998; 351: 1857–8.
7. Preece AW, Iwi G, Davies-Smith A, et al. Effect of a 915-MHz simulated mobile phone signal on cognitive function in man. Int J Radiat Biol 1999; 75: 447–56.
8. Repacholi MH, Basten A, Gebski V, Noonan D, Finnie J, Harris AW. Lymphomas in E mu-Piml transgenic mice exposed to pulsed 900 MHz electromagnetic fields. Radiat Res 1997; 147: 631–40.
9. Moulder JE, Erdreich LS, Malyapa RS, Merritt J, Pickard WF, Vijayalaxmi. Cell phones and cancer: what is the evidence for a connection?. Radiat Res 1999; 151: 513–531.
10. International Non-Ionizing Radiation Committee of the International Radiation Protection Association. Guidelines for limiting exposure to time-varying electric, magnetic, and electromagnetic fields (up to 300 GHz). Health Phys 1998; 74: 404–522.
11. Hyland GJ. Physics and biology of mobile telephony. Lancet 2000; 356: 1833–6.
12. Byrne D, Burwood E. The Australian experience: global system for mobile communications, wireless telephones and hearing aids. J Am Acad Audiol 2001; 12: 315–21.
13. Kemp DT. Development in cochlear mechanics and techniques for noninvasive evaluation. Adv Audiol 1988; 5: 27–45.
14. Ozturan O, Jerger J, Lew H, Lynch GR. Monitoring of cisplatin ototoxicity by distortion-product otoacoustic emissions. Auris Nasus Larynx (Tokyo) 1996; 23: 147–51.
15. Lonsbury-Martin BL, McCoy MJ, Whitehead ML, Martin GK. Clinical testing of distortion-product otoacoustic emissions. Ear Hear 1993; 14: 11–22.
16. Plinkert PK, Hemmert W, Wagner W, Just K, Zenner HP. Monitoring noise susceptibility: sensitivity of otoacoustic emissions and subjective audiometry. Br J Audiol 1999; 33: 367–82.
17. Vinck BM, Van Cauwenberge PB, Leroy L, Corthals P. Sensitivity of transient evoked and distortion product otoacoustic emissions to the direct effects of noise on the human cochlea. Audiology 1999; 38: 44–52.
18. Hall JW. Handbook of otoacoustic emissions. San Diego, CA: Singular Publishing Group, 2000.
19. Engdahl B, Kemp D. The effect of noise exposure on the details of distortion-product otoacoustic emissions in humans. J Acoust Soc Am 1996; 99: 1573–87.
20. Van Leeuwen GM, Lagendijk JJ, Van Leersum BJ, Zwamborn AP, Hornsleth SN, Kotte AN. Calculation of change in brain temperatures due to exposure to a mobile phone. Phys Med Biol 1999; 44: 2367–79.

Submitted July 24, 2001; accepted November 29, 2001

Address for correspondence:
Orhan Ozturan, MD
Department of Otorhinolaryngology
School of Medicine
Inonu University
TR-44300 Malatya
Turkey
Tel.: +90 532 5486236
Fax: +90 422 3410728
E-mail: orhanent@yahoo.com