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MAIN ARTICLE

Effect of chronic exposure to cellular telephone electromagnetic fields on hearing in rats

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Abstract

Objective: To study the effects of the electromagnetic field emitted by cellular telephones upon the inner ear of rats, using distortion product otoacoustic emissions.

Methods: Forty Wistar Albino rats were used. Twenty newborn and 20 adult rats were divided into two groups of 10, one to participate in the study and one as a control. The rats were exposed to the electromagnetic field for 6 hours per day, for 30 consecutive days. Before and after the 30 day exposure period, distortion product otoacoustic emissions were measured in each group and a signal-to-noise ratio calculated, which was later used in statistical analysis.

Results: For both the newborn and adult rat groups, there was no significant difference in distortion product otoacoustic emissions recorded before and after exposure to the cellular telephone electromagnetic field ($p > 0.05$).

Conclusion: Exposure to the electromagnetic field emitted by cellular telephones, for 6 hours a day for 30 consecutive days, had no effect on the hearing of newborn or adult rats, at the outer ear, middle ear or cochlear level.

Key words: Cellular Phone; Electromagnetic Fields; Adverse Effect; Otoacoustic Emissions

Introduction

The use of cellular telephones has increased tremendously over the past 15 years, and there are currently more than 1.6 billion users worldwide. The increased accessibility and ease of communication afforded by cellular telephones make them an integral part of many societies. However, there are also detrimental social, economic and health factors associated with their use. Further research is needed to delineate the exact mechanisms by which cellular telephones may be harmful to health.

Cellular telephones work similarly to walkie-talkies, but involve more complex electronic systems as they provide a two-way speaking capability. Cellular phones use frequencies which are close to each other but conducted on different radio waves.

Electromagnetic fields with frequencies of between 0 and 300 GHz are referred to as extremely low frequency and radiofrequency.[1] Such fields have long wavelengths. Microwaves fall within these categories of radio frequency.

Electromagnetic fields can be divided into two groups with respect to their known negative health effects on humans: ionising radiation and non-ionising radiation. The effects and applications of ultraviolet and radioactive radiation have been studied extensively, and the findings applied to the development of nuclear energy, medical imaging and medical radiotherapy.[2,3]

In the aftermath of World War Two, the science of radiation protection began to develop. Founded in 1965, the International Society for Radiological Protection began to play a role in the global development of ionising radiation safety standards.[3] In 1992, the International Commission for Non-Ionising Radiation Protection, an independent scientific body, was established.[2,3]

The radiofrequency waves emitted by cellular telephones fall within the limits imposed by the International Commission for Non-Ionising Radiation Protection. However, the proximity of these radiowaves to the brain via the ear has posed new questions and problems for scientists.

Cellular telephones are high frequency, low power devices which are kept in an active state continuously. Even when not in use, they are constantly updating their connection with the service provider. There are many sources of electromagnetic waves in our environment (like radio and television transmitters) other than the cellular telephones. Although these sources produce much more powerful and intense electromagnetic fields, they are located further away from humans and have less effect.[4] In contrast, a cellular

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telephone is held adjacent to the ear, and the radiowaves emitted are condensed. When the cellular telephone is in use, or when it communicates with the service provider, radiowaves are emitted as part of its receiving and transmitting capacity. Part of this electromagnetic energy impacts on the head, and specifically the ear region. Even though this energy is present at a low level, it still causes warming of the adjacent tissues. Unfortunately, the heating caused by newer, digital telephones is greater than that created by older, analogue models.[4]

The possible detrimental biological effects of the electromagnetic waves emitted by cellular telephones have not been proven, although they are certainly possible.[2,5] The present study studied the effect of cellular telephone electromagnetic fields on the hearing of rats.

Materials and methods

This study was conducted at the Marmara University Medical Research Institute between 30 March and 30 April 2009.

With regard to the use of experimental animals, the study followed the rules laid out in the Helsinki Final Act, and also the Turkish Ministry of Agriculture and Rural Affairs animal protection law number 5199. Prior to the experiment, the study was approved by the Marmara University Faculty of Medicine experimental animal ethics committee.

The study was completed with 20 healthy adult and 20 newborn Wistar Albino rats. Since otoacoustic emission measurements require a patent external ear and middle ear, these sites were evaluated by otomicroscopy. Otomicroscopic examinations were performed to all rats at the beginning of the study and after 30th day of study before distortion product OAE. Only those rats with clear external auditory canals and no evidence of acute or chronic otitis media were included in the study. Any rats which did not show Prayer's reflex were excluded. Seven rats from the experimental group did not meet the above criteria and were excluded from the study. New healty 7 rats were included to the study to provide the original numbers (the ratio of 20 adult and 20 newborn rats was preserved).

The rats' weights ranged from 200 to 240 g. During the study, the rats were kept under 12 hours of light and 12 hours of dark per day, at a temperature of 21°C, with a constant supply of food and water. The background noise was kept below 50 dB. During testing, the rats' oral temperature ranged from 37.5 to 39.0°C, and the background noise level was maintained at less than 50 dB.

The rats were divided into four groups for testing.

After anaesthetising the rats with an intramuscular injection of 45 mg/kg ketamine hydrochloride and 5 mg/kg Xylazine hydrochloride, distortion product otoacoustic emissions (distortion product OAEs) were measured.

Group one comprised 10 adult rats. The animals' distortion product OAEs were measured under general anaesthesia (see below). They were then exposed to electromagnetic waves for 30 days, as below. Following this, their distortion product OAEs were again measured under general anaesthesia. These animals' first and second distortion product OAE measurements were compared with each other and with the control group distortion product OAEs.

Group two also comprised 10 adult rats, and acted as a control for group one. These animals' distortion product OAEs were also measured under general anaesthesia. They were then kept in an environment without electromagnetic waves for 30 days, before undergoing repeated distortion product OAE measurement under general anaesthesia.

Group three comprised 10 newborn rats. The animals' distortion product OAEs were measured under general anaesthesia. They were then exposed to electromagnetic waves for 30 days, and subsequently underwent distortion product OAE measurement under general anaesthesia.

Group four comprised 10 newborn rats, and acted as a control for group three. These animals' distortion product OAEs were measured under general anaesthesia. They were then kept in an environment without electromagnetic waves for 30 days, before again undergoing distortion product OAE measurement under general anaesthesia.

Exposure to electromagnetic waves

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]. Two cellular telephones operating at frequencies of 900 to 1800 MHz were used: a Samsung model SGH-N170 (SAR value 0.934; Samsung, Suwon, South Korea) and an LG model KG275 (SAR value 0.851; LG, Seoul, South Korea). The animals were exposed to the electromagnetic field following the method of Burkhardt et al.[6]

Distortion product otoacoustic emissions measurement

Distortion product otoacoustic emissions were measured with a newborn probe using the Otodynamics ILOv6 system (Hatfield, UK.) The probe's narrow plastic adaptor was inserted into the ear canal while the animal's head was kept in a horizontal position. (This plastic adaptor has been shown not to cause any artefact during OAE measurement.)[7] The indicator and warning device probe waveform was calibrated with the appropriate configuration of the device.

Distortion production OAEs (i.e. 2f1−f2 cubic distortion product components) were measured using the general diagnostic mode of the Otodynamics ILOv6 device. The ratio between the f1 and f2 frequencies was kept at 1.22. The stimulus intensities for the f1 and f2 frequencies were 65 and 55 dB SPL, respectively, giving a 10 dB SPL difference between the two intensity levels. Results for the primary tones (f1 and f2)

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were shown as the geometric mean. When measuring distortion product OAEs in the external auditory canal, two different speakers were used for the two stimuli (f1 and f2). Distortion product otoacoustic emission measurements for the f1 and f2 frequencies were made using a microphone in the external auditory canal. Measurements were taken at the geometric mean of f1 and f2, and for the following frequencies: 1001, 1501, 2002, 3003, 4004, 6006 and 7996 Hz.

The test duration was approximately 30 seconds. Any distortion product OAE values of less than 3 dB above the noise level were considered insignificant. Noise level measurements were performed in a room with less than 50 dB background noise. The distortion product OAE response was evaluated using the signal-to-noise ratio (i.e. 2f1−f2 cubic distortion products taken at the geometric mean of f1 and f2, for the frequencies 1001, 1501, 2002, 3003, 4004, 6006 and 7996 Hz); this is considered more reliable than the use of distortion product OAE amplitudes alone.[8]

Data were collected separately for each rat and the results statistically analysed.

Statistical methods

Statistical analysis used the paired *t*-test. Changes in the threshold frequency of each distortion product OAE amplitude and noise level were analysed. The analytical criteria were exposure effects within each group, intergroup variability measurements and mean baseline values.

Frequency curves were prepared for the results obtained for each rat in each group; each curve received an average of emission values and signal-to-noise ratio.

Results

For the duration of the study, the electromagnetic field was easily tolerated by the rats. There was no weight loss or excessive weight gain detected, and no difference in food and water consumption. The newborn rats exhibited normal growth patterns. Seven of the rats were excluded from the study due to otitis, but all other animals were included, and had distortion product OAE measurements taken from both ears.

The 10 adult rats in group one had mean signal-to-noise ratios before and after electromagnetic wave exposure of −4.1, 11.3, 23.6, 22.8, 29.4, 24.2 and 11.7, and −2.2, 9.7, 19.9, 21.4, 27.3, 20.1 and 13.4, respectively, for the frequencies 1001, 1501, 2002, 3003, 4004, 6006 and 7996 Hz, respectively.

In group one, the mean distortion product OAE values were 16.985 dB at day 0 and 15.657 dB at day 30. The difference between these two values, 1.33 dB, was not statistically significant (*t*-test: $t = 0.818957$, $p > 0.05$) (Figure 1).

The 10 adult rats in group two had mean signal-to-noise ratios at day 0 and day 30 of −3.7, 11.2, 20.6, 19.8, 26.4, 27.1 and 14.5, and −3.2, 9.7, 18.5, 15.4, 22.7, 24.6 and 12.9, respectively, for the frequencies

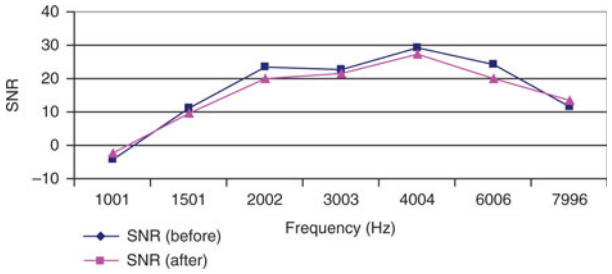

FIG. 1
Group one: SNR values before and after 30 days of exposure to electromagnetic waves.

1001, 1501, 2002, 3003, 4004, 6006 and 7996 Hz, respectively.

In group two, the mean distortion product OAE values were 16.55714 dB at day 0 and 14.37143 dB at day 30. The difference between these two values, 2.18 dB, was not statistically significant (*t*-test: $t = 0.690175$, $p > 0.05$) (Figure 2).

The 10 newborn rats in group three had mean signal-to-noise ratios before and after electromagnetic wave exposure of −1.1, 6.2, 12.3, 11.8, 16.3, 22.5 and 11.8, and −3.2, 10.7, 18.5, 19.4, 21.5, 23.1 and 10.3, respectively, for the frequencies 1001, 1501, 2002, 3003, 4004, 6006 and 7996 Hz, respectively.

In group three, the mean distortion product OAE values were 11.4125 dB at day 0 and 14.32857 dB at day 30. The difference between these two values, 2.89 dB, was not statistically significant (*t*-test: $t = 0.524864$, $p > 0.05$) (Figure 3).

The 10 newborn rats in group four had mean signal-to-noise ratios at day 0 and day 30 of −3.5, 4.7, 12.4, 10.5, 16.8, 21.5 and 18.6, and −4.9, 9.5, 17.8, 13.3, 21.3, 25.3 and 18.2, respectively, for the frequencies 1001, 1501, 2002, 3003, 4004, 6006 and 7996 Hz, respectively.

In group four, the mean distortion product OAE values were 11.57143 dB at day 0 and 14.35714 dB at day 30. The difference between these two values, 2.8 dB, was not statistically significant (*t*-test: $t = 0.586194$, $p > 0.05$) (Figure 4).

The difference between the mean distortion product OAE values of groups one and two was statistically insignificant (*t*-test: $t = 0.805068$, $p > 0.05$).

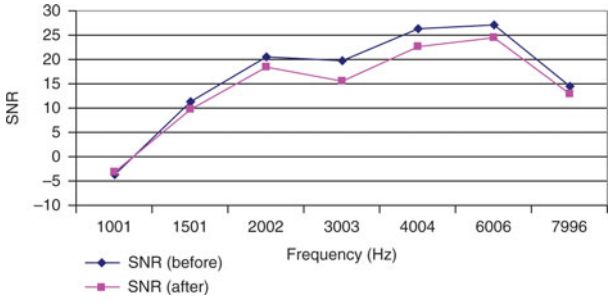

FIG. 2
Group two: SNR values before and after 30 days of exposure to electromagnetic waves.

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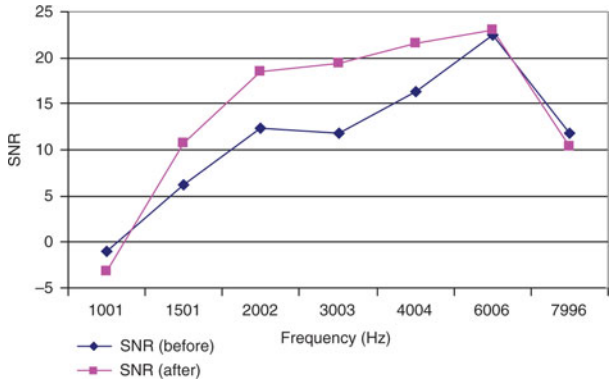

FIG. 3
Group three: SNR values before and after 30 days of exposure to electromagnetic waves.

Likewise, the difference between the mean distortion product OAE values of groups three and four was statistically insignificant (*t*-test: $t = 0.995634$, $p > 0.05$).

Discussion

Electrical and electromagnetic fields contribute tremendously to our everyday lives, and have made possible technological advancements which have facilitated communication around the world. However, there is a lack of information about the risks and dangers of electromagnetic fields for humans. Further research is needed to improve our understanding of these risks, and to enable the implementation of appropriate security and protective measures. The interaction between electromagnetic fields and biological organisms depends on the energy delivered and its frequency. At some frequencies, the human body is permeable to electromagnetic fields, while at other frequencies it is not. For example, while sunlight can only permeate the skin, magnetic fields can pass through the whole human body.[9]

Electromagnetic fields can cause damage to humans by heating and by causing chemical changes within the body's tissues, with high wattage electromagnetic fields causing more heat damage and low wattage fields causing long-term chemical change. The electromagnetic fields emitted by cellular telephones cannot permeate the whole body but can affect the subcutaneous tissue, and this direct transmission causes a high level of electrical conductivity in the skin.[10] The effects of warming around the ear are currently being investigated, and it is thought that this may damage the brain as well. Some theories propose that radiowaves which come into contact with the head are absorbed but scatter before reaching the brain, causing no damage. The ideal upper limit for a cellular telephone call is 3–5 minutes;[11] beyond this time, the accumulated radiowave energy warms the tissues around the face and causes possible harm.[11]

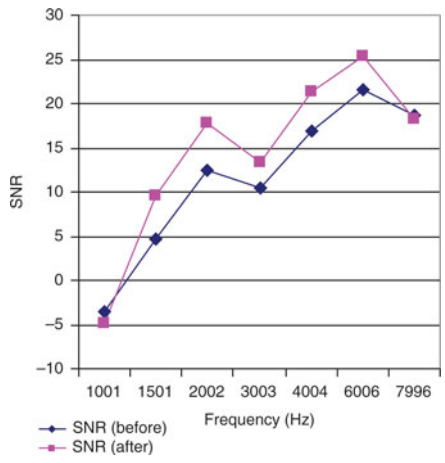

FIG. 4
Group four: SNR values before and after 30 days of exposure to electromagnetic waves.

Some studies have found electromagnetic fields to be harmless, while others have found just the opposite. Electromagnetic waves, and their emitting devices, have been reported to cause the following: physical weakness and neural asthenia, sleep disorders, headache, myalgia, and dysaesthesia of the extremities (involving a decrease in the signalling ability of the skin and mucous membranes).[12]

Sandstrom *et al.*[13] reported short- and long-term effects arising from electromagnetic waves. The short-term effects were: heart disease, narrowing of the field of vision, temporary and permanent hearing disorders, tinnitus, dizziness, headaches, increased risk of brain tumour, memory loss, intense stress and fatigue, impairment of attention and concentration, weakening of the immune system, and increased risk to the unborn fetus. The long-term effects (defined as occurring within 10 years) were: high blood pressure, genetic degradation, reduced sperm count, lymphoma and skin cancer formation, and injury to the blood–brain barrier.[13]

McKinlay studied the effects on mouse brain cells of an electromagnetic wave frequency slightly lower than that used by cellular telephones.[14] This study investigated the area of the brain which controls memory and learning, and found that the radiowaves evaluated may interfere with this area. Under the influence of radiowaves, brain activity either stopped or slowed significantly; when the radiowaves were stopped, normal activity resumed.

Ozturan *et al.* studied the effect of electromagnetic waves on the hearing of 30 volunteers.[7] Subjects were exposed to 10 minutes of cellular telephone use, and OAEs were compared before and after. The electromagnetic field thus received appeared to have no effect on the subjects' hearing.

Uloziene *et al.* conducted a double-blind study to assess the acute effects of cellular telephone electromagnetic fields.[4] The experimental and control groups underwent pure tone average and transient OAE testing before and 10 minutes after cellular telephone use. No significant difference was observed between the control and experimental groups.

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Another study found no increased incidence of tinnitus, hearing impairment or balance impairment in students who use cellular telephones, compared with students who did not use cellular telephones.[15]

Galloni *et al.* conducted a study in which rats were exposed to cellular telephone electromagnetic waves two hours a day, five days a week, for four weeks. They found no significant difference between distortion product OAE measurements taken before and after exposure.[16]

Kızılay *et al.* exposed adult and newborn rats to cellular telephone electromagnetic waves for 1 hour a day for 30 days, and also found no significant differences in pre- versus post-exposure distortion product OAEs.[11]

Other researchers have investigated the long-term use of cellular telephones and their impact on different systems, and especially on the risk of cancer. Animal studies have shown that electromagnetic waves cause damage to DNA, but have not shown direct causation of cancer.[17] In this context, Toyran was one of the first to examine electromagnetic damage with respect to cancer type, drawing much attention to this subject.[18] Toyran's review concluded that the use of analogue devices caused an increased risk of acoustic neuroma and glioma.[18]

The effects of cellular telephones on various physiological systems have also been investigated. Animal and human studies have shown that exposure to electromagnetic waves can cause changes in the endocrine system.[4]

Our study evaluated the effects of cellular telephone electromagnetic waves, at the frequencies most commonly used (900–1800 MHz), on the hearing of adult and newborn rats, using distortion product OAE measurement. This study can be considered to involve long-term exposure (i.e. 30 days) of both adult and newborn rats, using continuous exposure of at least 6 hours per day.

The developing ear is sensitive to changes in its environment, such as noise exposure and the presence of certain ototoxic drugs.[19] In rats, cochlear development is normally present by 25 days postpartum, the most sensitive time for development being between 11 and 20 days; this is why newborn rats were included in the current study.[20]

In clinical practice, OAE measurement is non-invasive, painless and requires no anaesthesia.[21] In children (especially infants), cochlear function testing is useful in the assessment of developmental impairment; the test is quick and accurate, and is useful in a broad range of conditions.

In the current study, we studied the effects of cellular telephones on rat hearing, using distortion product OAE measurements. Distortion product OAE testing is quick, reliable and does not require active participation.[22] Monitoring of the outer hair cells, the most sensitive part of the cochlea, has been shown to accurately assess cochlear damage. In animal models, distortion product OAE changes have been shown to precede morphological damage to the outer hair cells.[23] Furthermore, minor changes in cochlear function which are undetectable by pure tone audiometry produce obvious distortion product OAE changes.[22] There are well described methods for using evoked OAEs to monitor the cochlear effects of potentially ototoxic medication.[24] When a specific region of the cochlea is affected, a decrease in distortion product OAEs in the relevant frequency region can be observed, due to the frequency specificity of this test.[25] The high level of test–retest reliability of OAE testing enables the monitoring of dynamic cochlear responses.[26] For these reasons, OAE testing appears to be well suited to the investigation of cochlear damage following exposure to mobile telephone electromagnetic fields.

On the other hand, evoked OAE testing may be useless in assessing hearing loss of more than a mild degree, and in the presence of any problem compromising the acoustic transfer function of the middle ear (required for the double pass of the stimulus and subsequent eliciting of cochlear emissions).[27] Therefore, in the present study otomicroscopic examination was performed before baseline and end-point distortion product OAE testing.

No significant differences were observed between distortion product OAE measurements taken before and after electromagnetic wave exposure, in either adult or newborn rats. These findings are similar to others reported in the literature; however, our study was more specific and prolonged with respect to the number of study animals, the study length and the electromagnetic wave exposure period. The current investigation is the second published study of its type to use newborn rats; however, the current study exposed newborn rats to cellular telephones for periods six times as long.[11]

- **Cellular telephones emit electromagnetic waves; their negative biological effects are unproven but certainly plausible**
- **This study investigated the effects of cellular telephone electromagnetic waves on rat hearing, using distortion product otoacoustic emission testing**
- **Exposure to electromagnetic waves for 6 hours per day for 30 consecutive days had no significant effect on the hearing of newborn or adult rats**
- **However, this experimental exposure was limited, compared with mobile phone use in humans**

In the current study, electromagnetic field exposure was for a period of 6 hours, the limiting factor being the battery life of the cellular telephones.

For financial reasons, it was not possible to use separate cellular telephones for each rat.

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The improved hearing observed in groups three and four was attributed to the natural development of the newborn rats.

The current study showed that exposure to cellular telephone electromagnetic waves for 6 hours a day for a period of 30 days had no significant effect on hearing (at least at the outer-ear, middle-ear and cochlear levels) in adult and newborn rats.

Despite the results of this study, it is still possible, and indeed probable, that using cellular telephones for a longer period of time may cause harm to humans, especially the newer, high level radiofrequency emitting models currently being produced. The current third generation of cellular telephones uses a wider range of frequencies, and this trend is expected to continue in the forthcoming fourth generation; thus, new research is needed.

In this context, the use of higher frequency distortion product OAE measurement may be useful, to generate more detailed and reliable data.

Cellular telephones are becoming more and more common, and it should not be forgotten than even a small problem caused by them could quickly become a public health issue. Therefore, until the possible harmful effects of cellular telephones are proven or disproven, they should be used as little as possible, to limit users' exposure to electromagnetic fields.

Conclusion

This study aimed to examine the effects of electromagnetic fields emitted by cellular telephones upon the hearing of adult and newborn rats, using distortion product OAE testing. Adult and newborn rats were exposed to cellular telephone electromagnetic fields for 6 hours per day for a period of 30 days; these animals' results were compared with control groups. There were no statistically significant differences in distortion product OAE measurements, both within and between the experimental and control groups. Compared with human exposure, our study animals had more limited exposure over a reduced time span. Therefore, until a study is undertaken which simulates real-life conditions more accurately, users should be cautious about the harmful effects of the electromagnetic fields emitted by cellular telephones.

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