ORIGINAL ARTICLE

Effects of Electomagnetic Fields Formed by Bluetooth on Hearing

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Purpose: The aim of this study is to investigate the effects of long-term exposure to electromagnetic fields (EMF) generated by bluethooth systems operating at a frequency of 2400 MHz on the inner ear and hearing functions of neonatal and adult rats.

Materials and Methods: In this study 32 healthy Wistar-Albino rats (16 adults and 16 neonates) were used as test animals. After measurements of distortion product otoacoustic emissions (DPOAE), the adult and neonatal rats were divided into four groups: 8 for the experimental and 8 for the control group for each. The rats in the experimental groups were placed around activated headset bluetooth device attached to their cages with the audio. They were exposed to electromagnetic waves continuously 4 hours each day for 40 days. At the end of this period the experimental and control groups were reevaluated with DPAOE. The pre and post exposure results for the adult experimental and neonatal group were evaluated both within the group and in comparison to the control group.

Results: The pre and post-exposure results for adult and neonatal rats exposed to EMF were assessed both within the group and in comparison to those for the control group and no significant differences were observed in the inner ear and hearing functions (p>0,05).

Conclusion: In this study, it was concluded that 4 hours exposure for 40 days to EMF generated by bluethooth systems operating at a frequency of 2400 MHz did not have any determined effect on the inner ear and hearing functions of neonatal and adult rats.

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Introduction

"Bluetooth" is the name of the industry consortium which provides data transmission between electronic devices such as portable computers, modems, cameras, LAN access devices, telephones using short wavelength radio transmissions in the ISM (industrial scientific medical) band from 2400-2480 MHZ.[1] It is a technology that enables connectivity between devices in personal area network in short distances. In general it is known as a technology of low-cost, short-distance and limeted speed of 1 Mbps.

Electromagnetic radiation consists of discrete energy packets called as photons. Photon consists of vibrating electric field and magnetic field. The number of vibrations per second is called a frequency and measured in "Hertz".[1] In a radio transmiting system, transmiting signal is characterized by frequency as well as radio wave amplitude and phase.[1]

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It is possible to transfer information from point to point by the use of radio or electomagnetic waves without cable connection. Microwave radio transmitters can be used to tranfer data a few kilometers or more such as in bluetooth technology. Radio signals from antenna is inversely proportional to the distance and it weakens as the distance get longer. [2]

Electronic tools when they create a bluetooth connection, one of the tools takes up the role as administrator (master) while the other as participant (slave).

Bluetooth systems providing significant advantages such as ease of installation and freedom of movement can take place wired networks even more functions according to these networks. Bluetooth system is importantly prevalent in our everyday lives. The radiated output power of bluetooth devices varies between 1 and 100 mW and can operate continously or sporadically so total exposure to EMF radiation is quite variable. However, the effect on our health is not known. EMF's create heat and/or chemical damage leading to changes in the body's tissues. Some researches revealed that high electromagnetic waves can cause heat damage while long time exposure to low electromagnetic waves can cause chemical changes in the tissues. [3] Other studies have shown that the effect of electromagnetic waves emitted by EMA to the environment on biological systems in humans are physical and neural asthenia (weakness), sleep disturbances, headache, myalgia and dysesthesis in extremities. [4]

Clinical measurement of otoacoustic emissions (OAE) is the frequently preferred method to assess peripheral hearing function, as the method is noninvasive, painless, not requiring anesthesia, practicable independently of the patient's condition, in addition to being objective, fast and sensitive with definitive results and allowing the investigation of large patient groups.[5-7]

OAE's are vibratory energy generated in the cochlea and transmitted through the bone chain, the ear drum and the outer ear. In being powerful side-products of cochlear waves, OAE give an indication of the functional state of the middle ear bone chain, the oval window and the stapes together with the ear drum.[8,9] Therefore, the functional state of the middle ear must be assessed for making the OAE measurements.[10]

In this study, after otoscopic examination we investigate the effect of EMA derived from bluetooth device on the inner ear and hearing of rats by using the distortion product otoacoustic emission.

Materials and Methods

This study was carried out in Istanbul University Experimental Medical Research Institute (DETAM) animal laboratory on 16 healthy adult and 16 neonatal Wistar Albino rats. The rats were kept in an environment of 12 hours darkness and 12 hours of day light, 21^{o} centigrade temperature and a background noise below 50 dB, with free access to food and water.

After otoscopic examination, those free of any pathology were included in the study. After anesthesia with intramuscular ketamine hydrochloride 45 mg/kg and xylacine 5 mg/kg, DPOAE measurements were accomplished and rats with no measurable emissions were excluded.

The rats included in the study were evaluated in four groups:

The first group of 8 adult rats, after the initial DPOAE measurements, were exposed for 40 days to electromagnetic waves. At the end of the exposure, the DPOAE measurements were repeated. The two sets of measurements were compared within the group and with corresponding measurements made on the control group of rats.

The second group of 8 adult rats, after the initial DPOAE mesurements were kept for 40 days in the absence of internet sources and electromagnetic waves. At the end of this period the DPOAE measurements were repeated and the results were used as the control for the first group results.

The third group of 8 neonatal rats were exposed to electomagnetic waves for 40 days. At the end of this period DPOAE measurements were made and the results were compared with the results of the fourth group of rats.

The fourth group of 8 neonatal rats were kept for 40 days in the absence of any internet source and electromagnetic waves. DPOAE measurements made at the end of this period were used as the control for the third group of rats.

Standard headset bluetooth device which gave emissions at 2400 MHz frequency was used in the

experiment. It was connected to mobile phone and activated with audio for 4 hours each day. Experimental rats were placed around activated headset bluetooth device attached to their cages. The control group and the study group were isolated in seperate rooms which were not affected by electromagnetic waves used daily. The absence of any electromagnetic waves was confirmed by standard bluetooth device detectors. They were exposed to electromagnetic waves continuously 4 hours each day for 40 days with a total maximum output 100 mW bluetooth device.

In this study DPOAE was used to investigate the emissions. For this pupose the Otodynamics Ltd. ILOv6 instrument was employed with the smallest rubber tympanometry probe attached to the tip of the instrument probe. Measurements were begun after the probe indicator and the warning waveform were at the configuration appropriate for making measurements. DPOAEs (2f1-f2 cubic distortion product compounds) were made on General Diagnostic mode both as DPgram and input-output (I/O) measurements, using signals of different frequencies and intensities. In Dpgrams the primer signal intensities were equalled at 65dB (L1=L2). Two different frequencies (f1 ve f2) were organised as f2/f1= 1.22 to receive the strongest responses. Dpgram measurements were made at frequencies of 1001, 1184, 1416, 1685, 2002, 2380, 2832, 3369, 4004, 4761, 5652 ve 6726 Hz f2. Responses in I/O measurements were recorded during the f1=f2 =65 conditions and by reduction of the signal intensity. The threshold and supra-threshold measurements of I/O functions were made using primary sound tones decreasing in 5 dB steps from 65db to 40 dB, at frequencies of 3000, 4000, 5000, 6000 Hz.

The noise level for both Dpgram and I/O functions was measured at frequencies 50 Hz above the DPOAE frequencies. During measurements at 2f1-f2 frequency, the OAEs ≥3 dB above the noise intensity were accepted as positive. The test was finalised after recording up to the highest level the responses reached in both measurements.

The changes at each frequency in DPOAE amplitude and the noise threshold were analysed using "student t-test" (SPSS 13.0) in matched and unmatched samples.

Results

The experimental rats well tolerated the electomagnetic area (EMA). Weight loss or excessive weight gain was not observed; changes in food and water consumption were not recorded. The growth of the neonatal rats progressed normally. Since the rats became eligible for the experiments on the basis of successful otoscopic examination, Dpgram and I/O levels of all rats were recorded.

Adult rats: In the Dpgrams, the emission levels at frequencies of 1001, 1184, 1416, 1685 Hz were below the noise level but they were above the noise level at the higher frequencies. In the I/O measurements, when the primary stimulus was 40 or 45 dB at frequencies of 3000 and 4000 Hz, emissions were below the noie threshold; but they were above the noise threshold at primary stimuli of higher dB. The emissions in response to all primary stimuli at frequencies of 5000 and 6000 were above the noise threshold.

For the adult rats, the mean Dpgram values have been given in Figure 1 and the mean I/O emission values have been given in Figures 2-5. Statistically significant differences were not obtained (P>0,05), when the matched samples from the pre-exposure and post-exposure Dpgrams and the I/O emission values of the rats were analysed by the *t* –test. When the DPgram and I/O emission values were analysed by the *t*-test in unmatched samples, the differences were again not statistically significant (p>0,05)

Neonatal rats: DPOAEs were not recorded at the start of the experiment. In the Dpgrams recorded at the end of the experiment the mean emission levels at frequencies of 1001, 1184, 1416, 1685, 2002 Hz were below the noise threshold, but they were above this threshold at all other frequencies. In I/O measurements with primary stimuli of 40, 45, 50 and 55 dB at 3000 Hz frequency, and with primary stimuli of 40 and 45 dB at 4000 Hz frequency the emission levels were below the noise threshold, but at 5000 and 6000 Hz frequencies the emissions were above the noise level with all primary stimuli.

The mean DPgram values of the neotal rats have been shown in Figure 6 and the mean I/O emission values have been given in Figures 7-10. When the DPgram and I/O emission values of the neonates exposed to EMA waves were compared to those of the control group of neonates not exposed to EMA, the *t*-test analyses of unmatched samples did not yield statistically significant differences (p>0,05).

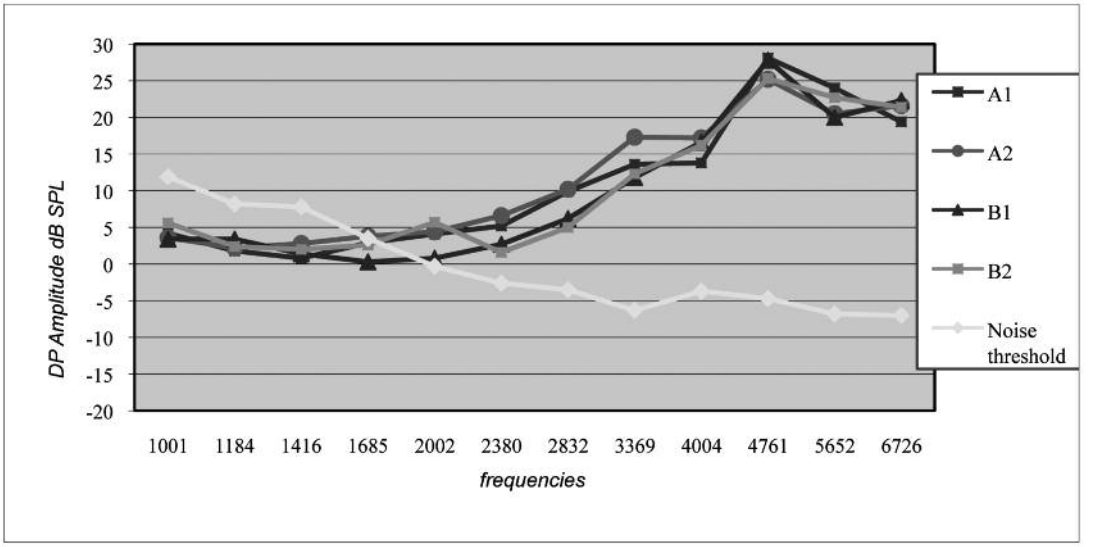

Figure 1. The mean DPgram curves of adult rats in 65/55 dB; A1:Experimental group before exposure to EMA; A2:Experimental group after exposure to EMA ; B1: Control group at the start of the experiment; B2: Control group at the end of the experiment

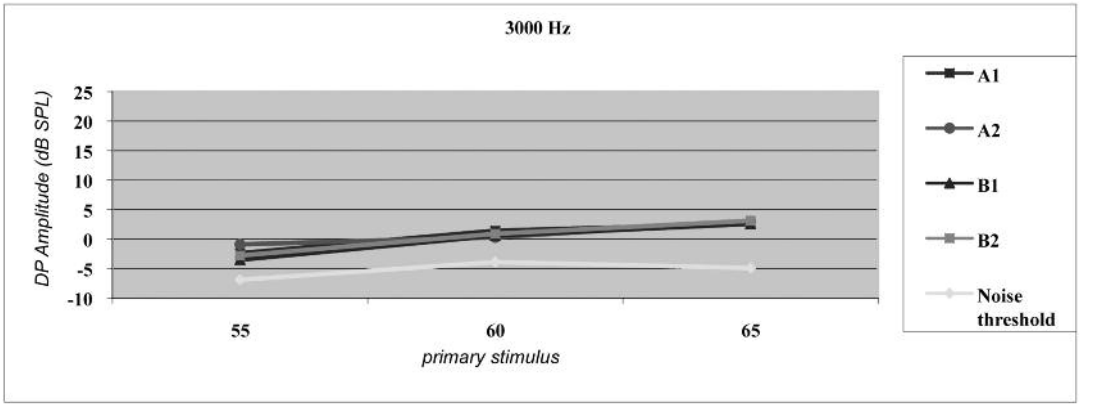

Figure 2. 3000 Hz mean I/O values of adult rats; A1:Experimental group before exposur to EMAe; A2:Experimental group after exposure to EMA; B1: Control group at the start of the experiment; B2: Control group at the end of the experiment

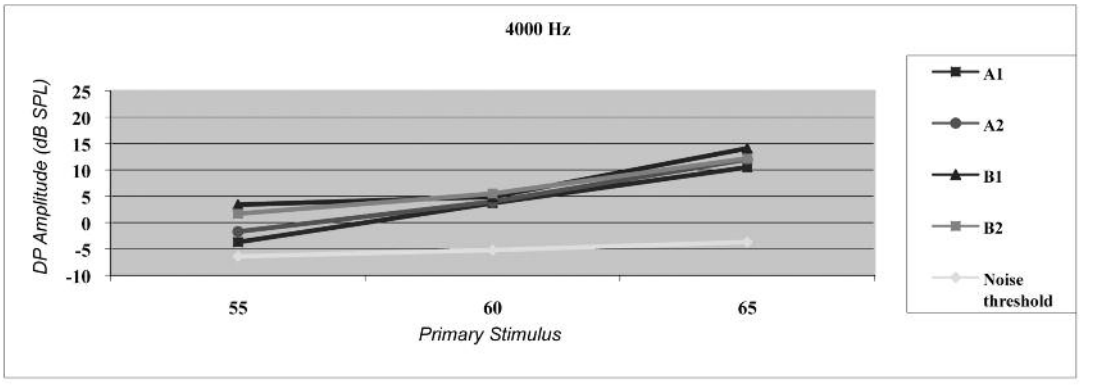

Figure 3. 4000 Hz mean I/O values of adult rats; A1:Experimental rats before exposure to EMA; A2:Experimental rats after exposure to EMA; B1: Control group at the start of the experiment; B2: Control group at the end of the experiment

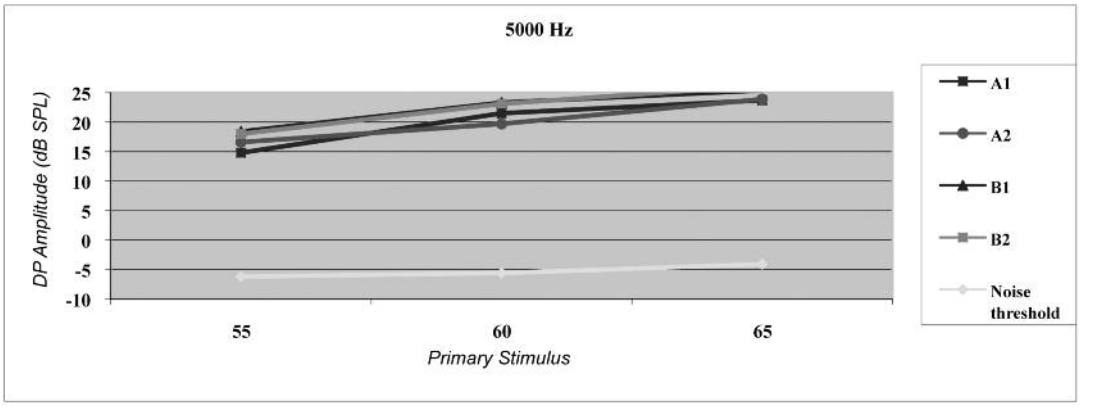

Figure 4. 5000 Hz mean I/O values of adult rats; A1:Experimental rats before exposure; A2:Experimental rats after exposure; B1: Control group at the start of the experiment; B2: Control group at the end of the experiment

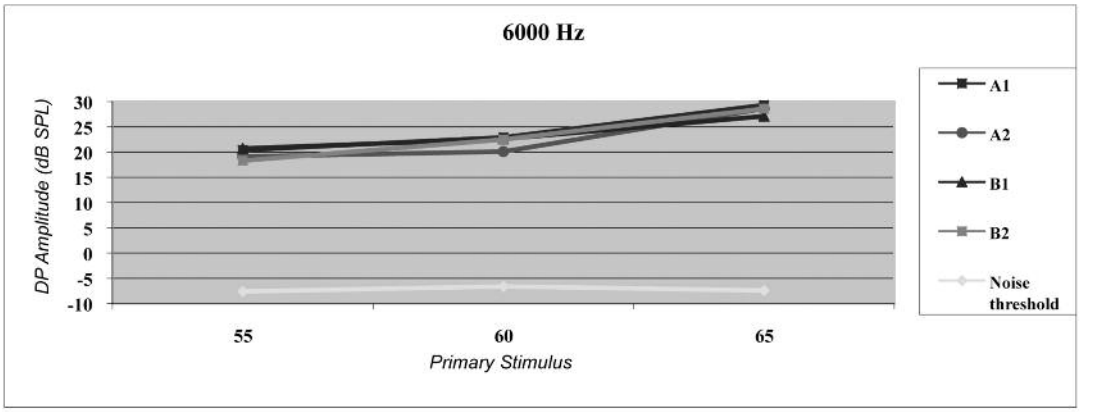

Figure 5. 6000 Hz mean I/O values of adult rats; A1:Exprimental group of adult rats before exposure to EMA; A2:Experimental group pf adult rats after exposure to EMA; B1: Control group at the start of the experiment; B2: Control goup at the end of the experiment.

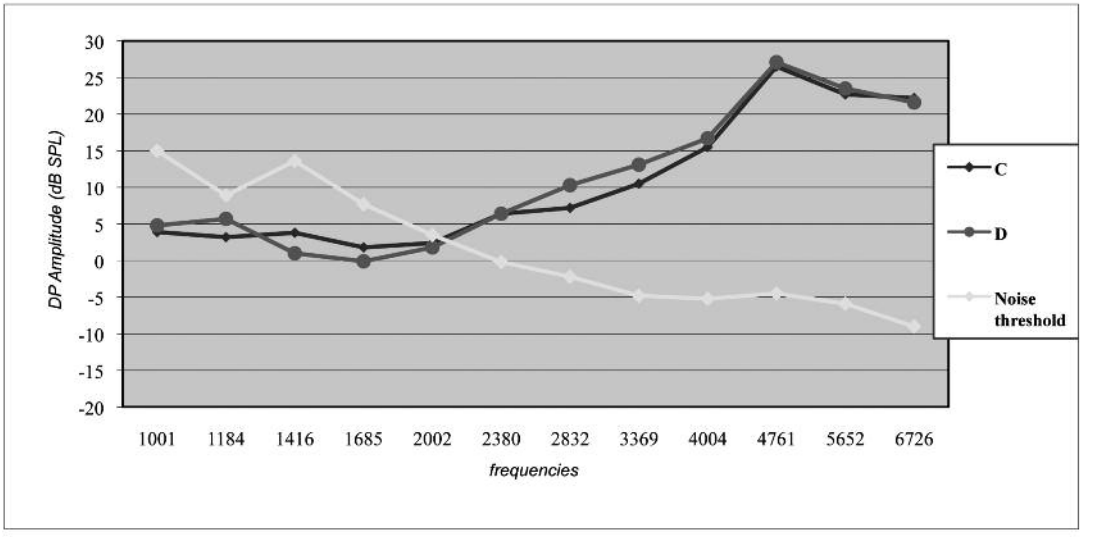

Figure 6. Mean DPgram curves for neonatal rats in 65/55 dB; C: Experimental group of neonates exposed to EMA; D: Control group of neonates

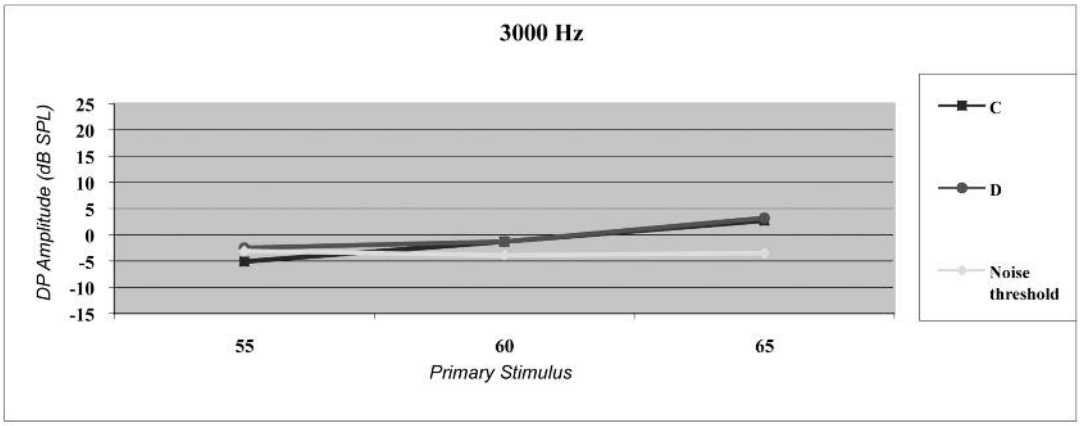

Figure 7. 3000 Hz mean I/Ovalues of neonatal rats; C: Experimenatl group of neonates exposed toEMA; D:Control group of neonates.

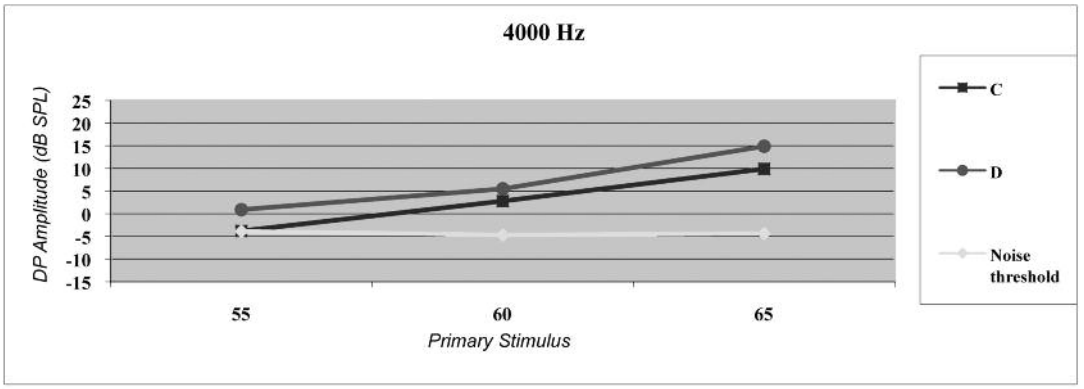

Figure 8. 4000 Hz mean I/O values of neonatal ats; C: Experimental group of neonates exposed to EMA; D: Control group of neonates.

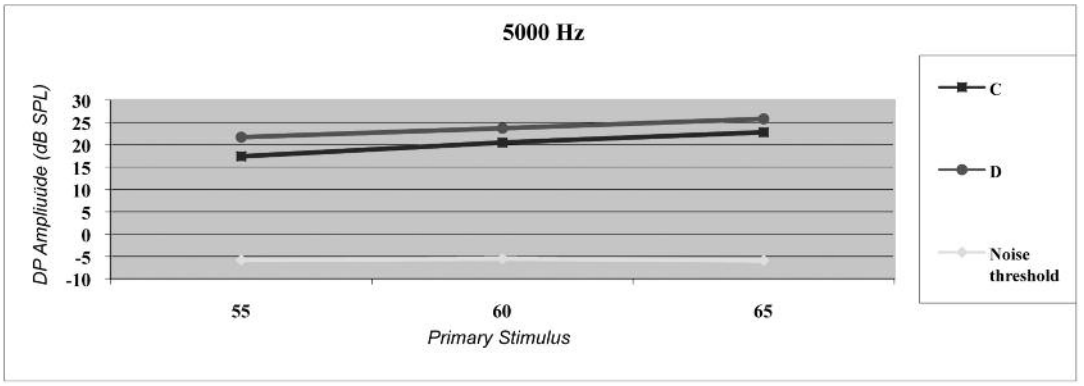

Figure 8. 4000 Hz mean I/O values of neonatal ats; C: Experimental group of neonates exposed to EMA; D: Control group of neonates.

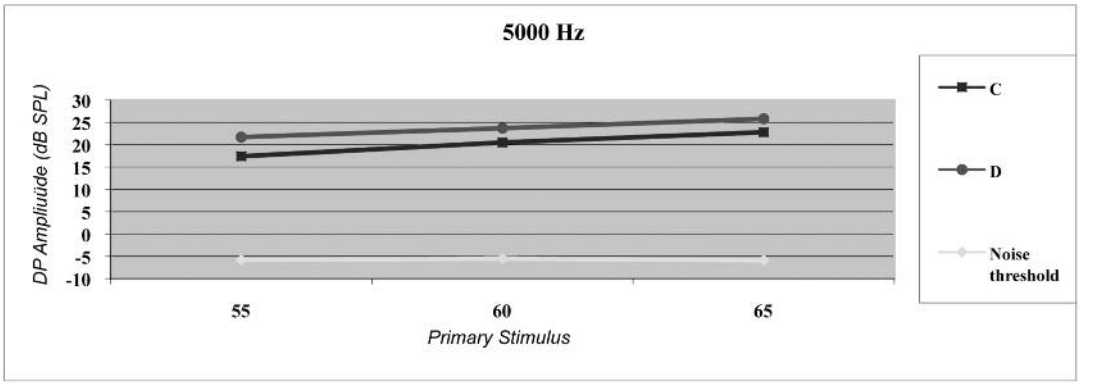

Figure 9. 5000 Hz mean I/O values of neonatal ats; C: Experimental group of neonates exposed to EMA; D: Control group of neonates.

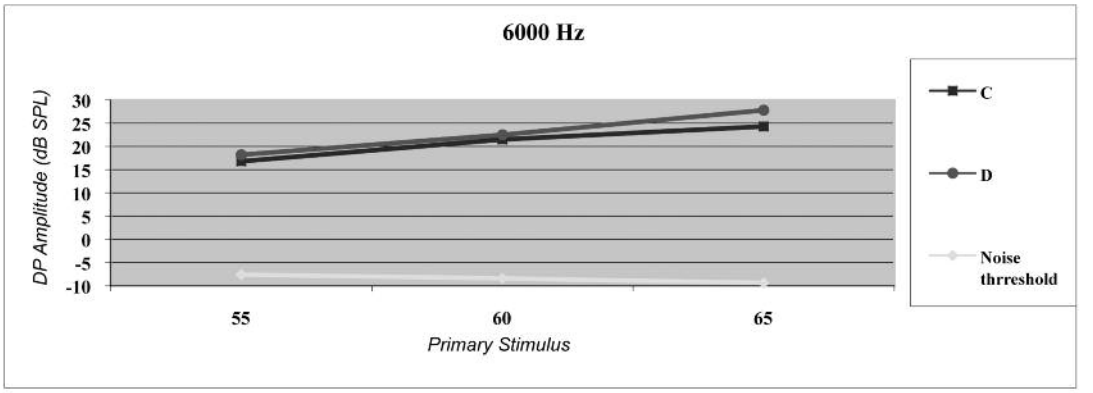

Figure 10. 6000 Hz mean I/O values of neonatal rats; C: Experimental grou‹p of neonates exposed to EMA; D: Control group of neonates.

Discussion

Many advantages compared to wired communication technologies in the wireless communication technologies have shown great improvement and has become widely used. Effects of electromagnetic waves originating from bluetooth systems on the inner ear and hearing of rats were investigated using a DPOAE instrument.

The reliability of DPOAE as an objective test method with useful frequencies in the evaluation of cochlear funtions has been recommended.[11] Wit and Ritsma argued that OAE could not be estimated in experimental animals as the emission latency would be too short due to the small size of the cochlea.[12] This argument is not valid for DPOAE which can be easily applicable even in very small exprimental animals.[13] However, in the rat the otoacoustic emission measurements are difficult due to the narrowness of the outer ear canal which creates problems in placing a probe. To overcome this difficulty, a rubber tympanometry probe of the smallest size was attached at the tip of the instrument used in this study, which enabled measurements without any artifacts.

The Bluetooth technology operates on unlicensed frequency range of 2400 -2480 MHz. The equipment is divided into three Power Classes from 1 to 3, with maximum output power of 100 mW, 2.5 mW and 1 mW, respectively.[1] Bluetooth was intended for portable equipment and its applications. The category of applications is outlined as the wireless personal area network (WPAN). Wi-Fi uses the same radio frequencies as bluetooth.

There are many ongoing studies on the damaging effects of exposure to EMA on human health. Some studies have shown changes in the endocrine system due to exposure to EMA. [14,15]

While there are some studies reporting increases in risks for glioma and acoustic neuroma after using mobile phones [16,17], another study on the cancer risk of exposure to EMA did not detect a relation between short- and medium-term mobile phone use and the glioma.[18,19]

However, Lai and Singh showed that continuous or pulsatile waves of RF energy of 2450 MHZ frequency may cause DNA damage in the brain cells of rats.[20]

Literature survey shows the research results on the effects of long term use of mobile telephones on the inner ear.[21,22] Electromagnetic field from mobile phones are shown to affect sleep. [23]

The effects of electric fields on the auditory functions of rabbits are examined via transient evoked otoacoustic emission (TEOAE) recordings and the cochlear functions are not effected significantly. [24]

There are presently no scientific data supporting the concept of vulnerability of children and adolescents to high-frequency EMF such as cordless phones, wireless local area Networks (WLAN) and bluetooth. [25]

Özturan et al. have not seen a significant difference in the OAE values of their experimental participants before and after exposure for 10 minutes to electromagnetic waves on the mobile telephone. They have concluded that 10 minutes use of the mobile phone did not have any effects on hearing and inner ear functions.[26]

Davidson and Lutman have not observed any relative increase in the incidence of tinnitus, loss of hearing or imbalance when comparing long term users and non users of mobile phones.[27] Galloni et al. by using DPOAE, evaluating the hearing of rats exposed to electromagnetic waves from the mobile phone, concluded that there were no differences in the emissions recorded between different experimental groups.[21,22]

Sievert et al. studied the effects of EMA of mobile phones on biological systems, and reported that the temperature rise caused by the electromagnetic wave emission from mobile phones did not result in functional changes in the hearing system of the inner ear, the vestibular receptors or the inferior colliculus at the brain stem.[28]

The effects of low frequency electromagnetic fields on the outer hair cells of the organ of Corti in a guinea pig model are analysed by electric response audiometer and prolonged exposure to electromagnetic fields produced no functional or morphological alteration in the outer hair cells of the guinea pig organ of corti. [29,30]

In this study we investigated the effects of bluetooth systems operating at 2400 MHz frequency, widely and increasingly used in our daily lives, on the inner ear functions and hearing of adult and neonatal rats after longterm exposure. We used DPOAE to evaluate the effects on the inner ears and hearing of exposing both the neonates and the adults to 4 hours per day for 40 days, which is acceptable as a long term exposure to EMA. In conclusion there were not any statistically significant result.

The present study on the effects of exposure for a long period to EMA of bluetooth systems at 2400 MHz frequency on the inner ear and hearing is the first of its kind. The effects of electromagnetic pollution used in daily life upon hearing are among questions to be answered.

Conclusion

This study shows that a 4 hours exposure for 40 days of neonatal and adult rats to 2400 MHz frequency EMA does not have observable effects on the inner ear functions and hearing. But this conclusion cannot be extrapolated to periods as long as 5-10 years. Also, this study demonstrated the effects of commercially available DPOAEs. Measurements at higher frequencies may give more detailed and reliable results. Since the bluetooth systems are getting used on an increasingly wider scale, it must not be overlooked that even very small health problems can become serious public health concerns.

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