

Does all-day and long-term exposure to radiofrequency radiation emitted from Wi-Fi affect hearing?

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ABSTRACT

We investigated the long-term effects of radiofrequency radiation (RFR) emitted from Wi-Fi systems on hearing. Sixteen Wistar albino rats were divided equally into two groups: sham control and exposure groups. The rats in the experimental group were exposed to 2.4 GHz RFR emitted from a Wi-Fi generator for 24 h/day for one year. The same procedure was applied to the rats in the sham group, except that the Wi-Fi generator was turned off. All groups were kept in Faraday cages during the 12 months to eliminate external electromagnetic fields. The distance between the Wi-Fi generator antenna and the exposure cages was 50 cm. Pre-exposure distortion product otoacoustic emissions (DPOAE) of all rats were measured at the beginning, 6th and 12th months of the study. The DPOAE values of the sham, baseline and exposure groups were compared statistically. For the 6000 Hz hearing frequency, the DPOAE values in the exposure group were lower than those in the sham group ($p < 0.05$). Similarly, the 6000 Hz hearing frequency values obtained at the end of the 12th month were also lower than the baseline and 6-month values in the exposure group ($p < 0.05$). In contrast, the DPOAE values at the 6th and 12th months of exposure for the 2000 Hz hearing frequency were higher than the baseline value ($p < 0.05$). These results indicated that 12 months of RFR (24 h/day) at 50 cm from a 2.4 GHz Wi-Fi source can affect hearing. However, further studies are necessary.

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Introduction

The biological effects of alternating electromagnetic fields (EMFs) have long been studied. In recent years, there has been an impressive growth in the number of processes and devices that use or emit radiofrequency (RF) and microwaves in developed countries. Such devices are being increasingly used in industry, engineering, telecommunications, medicine, education and home settings [1]. Thus, widespread use of devices generating EMFs has become a major public concern because of findings related to possible hazardous effects of this technology on human health. These technologies include wireless local area networks (WLANs) and Wi-Fi communication systems. Wi-Fi systems, which are used frequently indoors and outdoors, also emit radiofrequency radiation (RFR).

WLANs are networks that operate without physical wires connected to the terminal devices ('clients'). Wi-Fi is the most common WLAN technology, in which devices and computers are connected to the local area network (LAN) wirelessly. The point of entry to the wired network

is termed an 'access point' and is typically positioned in the vicinity, at a distance of a few tens of metres. Wi-Fi equipment transmits and receives radio waves to establish the wireless connection. This technology is popular among a wide range of users.

People using or in the proximity of Wi-Fi equipment are exposed to the radio signals emitted from it and will absorb some of the transmitted energy in their bodies. Thus, the recent increase in the popularity of Wi-Fi devices has become a cause of concern in view of the introduction of wireless computer systems in schools and the extent to which the pupils are exposed to radio waves emitted from such sources [1].

For the reasons mentioned above, one concern in public opinion is the biological effects of RFs emitted from Wi-Fi systems. Despite the intense public interest, usually focused on any relationship between RFR and cancer, there is not sufficient research on RF emitted from Wi-Fi systems. Another important point to be considered is whether RF emissions from Wi-Fi wireless communications affect hearing. The auditory system is the neural organ most frequently and directly exposed to

RFs emitted from mobile phones and other similar equipment.

Otoacoustic emission (OAE) is low-level acoustic signals emitted by the cochlear outer hair cells (OHCs) either spontaneously or evoked by an auditory stimulus and recorded via the external acoustic meatus. OAE was originally described by Kemp [2]. OAE signals are evoked because of the motility of the cochlea's sensory OHCs that make their way outward from the basilar membrane of the cochlea through the middle ear, vibrating the tympanic membrane and propagating into the external auditory canal [3]. OAE testing is commonly used as a method for evaluation of hearing problems. Distortion product otoacoustic emissions (DPOAEs) are evoked OAEs produced by the ear in response to two simultaneous pure tone stimuli. DPOAEs give information about the hearing and are frequently used in studies to investigate hearing problems [4]. Generally, loss of OHCs or impairment of OHC function results in the attenuation of DPOAE amplitudes and sound/noise (S/N) ratios.

Whether RFR emitted from Wi-Fi systems affects hearing is a major concern in the general public. Thus, we investigated the long-term effects of 2.4 GHz RFR emitted from a Wi-Fi wireless system on hearing in rats using DPOAE. To our knowledge, no reported study has examined the long-term effects of Wi-Fi signals on the OHC function of the cochlea so far.

Subjects and methods

Subjects and animal care

Sixteen Wistar Albino adult male rats with an initial average weight of 313 ± 25 g were obtained from the Medical Science Application and Research Center of Dicle University (Diyarbakir, Turkey). The rats were fed with standard pelleted food (TAVAS Inc., Adana, Turkey) in standard Plexiglas cages. The final average weight of the animals was 348 ± 288 g. They were separated into two groups, sham exposed ($n = 8$) and exposure ($n = 8$), and kept on a 14/10-h light/dark regime. During the study, the ambient temperature (22°C) and relative humidity (45%) were maintained in the normal range for these animals. All animal procedures were consistent with the Principles of Laboratory Animal Care and the rules of the Scientific and Ethics Committee of Dicle University Health Research Center.

Exposure and field measurements

A generator that emitted 2.4 GHz RFR was used to represent exposure to Wi-Fi systems. Rats in the sham and exposure groups were confined in a Plexiglas cage

(55 cm \times 32 cm \times 20 cm). The rats were kept freely in the cage and no movement restriction was applied. The rats in the sham and exposure groups lived in the cages under normal daily circumstances. The rats in the exposed group were exposed to 2.4 GHz RFR 24 h/day for 12 months. The rats in both groups were kept 50 cm from the antennas of the generators. The same experimental conditions were applied to the rats in the sham group, except that the generator was turned off. The power density and the electric field inside the Plexiglas cage were measured using an EMR 300 radiation meter (NARDA L3 Communications Company, Pfullingen, Germany). The study was performed in Faraday cages to eliminate external EMFs during the 12 months.

Distortion product otoacoustic emissions (DPOAE)

OAE recordings were performed in a quiet room (<50 dB background noise) at the Animal Health and Research Center of Dicle University (DUSAM). Before the DPOAE was measured, the ear was examined under an operating microscope to assess the external auditory canal and tympanic membrane. DPOAEs were measured from the right and left ears in animals of both groups using a standard commercial cochlear emission analyser (ILO-96 OAE, Otodynamics Ltd., London, UK). The animals were anesthetized by injection of xylazine (7 mg/kg, im) and ketamine (44 mg/kg, im) before DPOAE measurements. The primary tones were applied in the animals' outer ear canal through an insert earphone, using a plastic adapter that sealed the probe in the outer ear canal. For DPOAE measurements, the intensities of primary stimuli were set as equilevel ($L1 = L2$) at 65 dB. DPOAEs are evoked with sets of two pure-tone frequencies, designated $f1$ and $f2$. The frequencies ($f1$ and $f2$) were adjusted in such a manner that $f2/f1 = 1.21$. DPOAEs were determined as distortion product (DP)-grams. The intensity levels of the primary tones were held constant, and DPOAE data were recorded for different frequency regions, ranging from 1001 to 6006 Hz (1001, 1416, 2002, 2832, 4004 and 6006 Hz), and plotted as a function of $f2$. The hearing status of all animals was determined with DP-grams and S/N ratio measurements. The amplitude of the DPOAE above the noise floor (S/N ratio) was noted for each of the six test frequencies. DPOAE values and S/N ratios of both groups of animals at six frequencies were recorded at three time points: baseline (before beginning the study), and at the 6th and 12th months of exposure. Each DPOAE test took ~ 3 min to perform. The DPOAE results of sham and exposure groups were compared statistically. DPOAE values measured at baseline and after 6 and 12 months of exposure were also compared among themselves.

Statistical analysis

The data were analysed using SPSS for Windows Ver. 24 (SPSS Inc., Chicago, IL, USA) statistical software. Repeated-measures analysis of variance (ANOVA) was used. Student's *t*-test was also used for the analysis of the differences between the groups. *P*-values of less than 0.05 were considered to indicate statistical significance.

Results and discussion

WLAN technology involves rather short-range communication between an access point (base station) and many personal devices. WLANs use EMFs in the RF bands around 2.4, 5.2 and 5.8 GHz. Such EMFs could represent a new source of concern about possible adverse effects on human health due to exposure to radiation. Because studies specifically focused on WLAN frequencies are needed, we undertook this study to observe long-term (1 year) effects of Wi-Fi RFR on the hearing of adult Wistar Albino rats.

The obtained results for the 6000 Hz hearing frequency showed that the exposure group DPOAE values were lower than those in the sham group ($p < 0.05$) at 12 months, which indicates deterioration of OHCs functions. For the other frequencies, DPOAE values were not found to be statistically significant different between the groups ($p > 0.05$). However, the DPOAE values obtained from rats in the exposure group showed that 2.4 GHz RFR could alter the DPOAE values at some hearing frequencies, such as 2000 and 6000 Hz. For the 2000 Hz hearing frequency, the DPOAE values measured at the 6th and 12th months of exposure were found higher than the baseline value in the exposure group ($p < 0.05$), indicating better OHCs functions. For the 6000 Hz hearing frequency, the DPOAE values at the 12th month of exposure were found to be lower than the values measured at baseline and at the 6th month of exposure ($p < 0.05$), which is again indicative of deteriorating OHCs functions. The DPOAE values and the statistical analysis of the exposure group are given in Tables 1 and 2 and Figures 1–3.

The average power density was measured as 0.00036 mW/cm², while the maximum power density in the cage was 0.00073 mW/cm². The average electrical field (*E*) was measured as 1.143 V/m, while the maximum electrical field in the cage was 1.674 V/m. Because of the free movement of the rats within the cage during the study and the low-field levels in the cage, we did not perform measurements of the specific absorption rate.

The microwave auditory phenomenon has been widely recognized as an interesting biological effect of

Table 1. DPOAE values (S/N) measured in ears of rats exposed to 2.4 GHz Wi-Fi RF radiation.

Hz	Time of measurement	Control		Exposure		Control vs. exposure	
		Mean	SD	Mean	SD	<i>t</i>	<i>p</i>
1000	Baseline	-8.48	5.92	-7.30	3.46	-0.484	0.636
	6 months	-8.83	3.74	-10.19	3.50	0.752	0.464
	12 months	-6.78	2.68	-9.25	3.47	1.593	0.134
1400	Baseline	-7.15	4.33	-6.75	3.34	-0.207	0.839
	6 months	-5.26	2.98	-8.29	6.07	1.268	0.226
	12 months	-7.19	2.83	-7.79	5.82	0.265	0.795
2000	Baseline	-9.081	4.89	-13.99	1.94	2.641	0.019
	6 months	-6.65	3.06	-6.22	4.99	-0.205	0.840
	12 months	-6.39	4.45	-5.42	6.79	-0.198	0.739
2800	Baseline	-0.006	9.92	0.15	4.62	-0.042	0.967
	6 months	6.17	8.27	4.19	4.96	0.579	0.572
	12 months	4.64	11.09	2.88	8.39	2.141	0.350
4000	Baseline	8.48	3.22	9.27	6.59	-0.198	0.846
	6 months	14.75	9.40	13.38	5.62	0.355	0.728
	12 months	12.48	10.93	12.3	9.67	2.261	0.450
6000	Baseline	22.50	6.64	23.16	6.30	-0.203	0.842
	6 months	25.77	6.76	24.56	3.38	0.451	0.659
	12 months	23.10	9.13	7.21	12.04	2.973	0.010*

SD, standard deviation.

*Statistically significant difference.

Table 2. Comparisons of the groups found to be statistically significantly different ($P < 0.05$).

Compared groups	Frequency	<i>P</i>
Baseline of exposure group/6th month of exposure	2000 Hz	$P^a = 0.0237$
Baseline of exposure group/12th month of exposure	2000 Hz	$P^a = 0.0154$
Baseline of exposure group/12th month of exposure	6000 Hz	$P = 0.010$
6th month of exposure/12th month of exposure	6000 Hz	$P = 0.0312$

^a Bonferroni corrected.

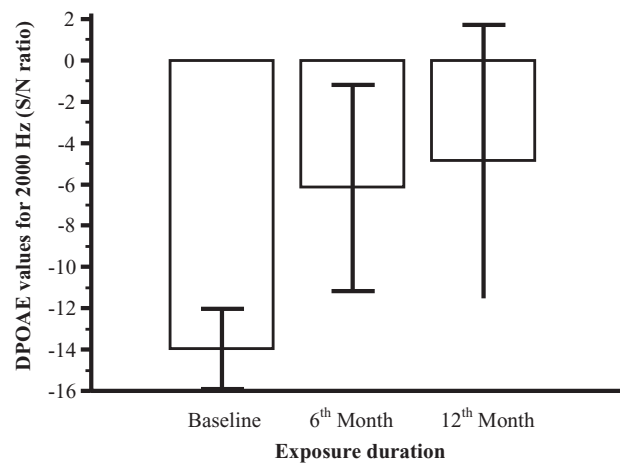


Figure 1. DPOAE values (S/N) measured in the exposed group.

microwave and RFR [5,6]. This phenomenon refers to the hearing of short pulses of microwave radiation and RF. The first report on the microwave auditory phenomenon appeared in 1956 [7]. After this report, human auditory responses to pulse-modulated radiation have been

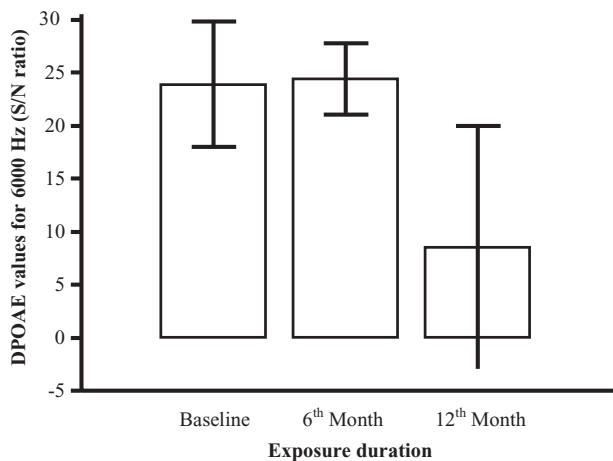


Figure 2. DPOAE values (S/N) measured in the exposed group.

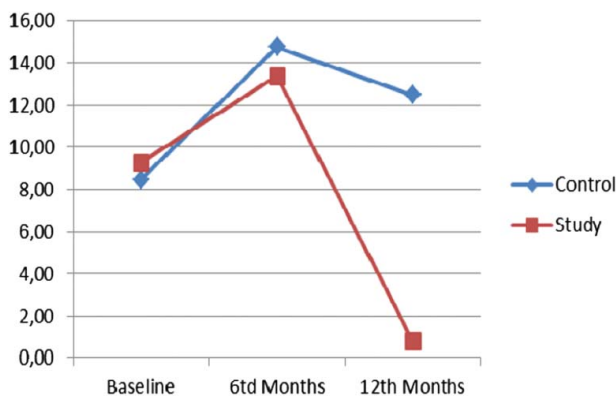


Figure 3. DPOAE values (S/N) measured in the study (exposure) and control group at 6000 Hz.

studied systematically [7]. These systems were mostly used in industrial and military settings as well as in consumer and medical applications. Since the physical features of systems such as the radar differ greatly from those of Wi-Fi systems on a large scale, the biological effects of the former may not apply to the effects of Wi-Fi systems. The common connection between radar and Wi-Fi is the emission of RFR.

There are a few studies on RFR emitted from Wi-Fi communication systems, and there are some studies simulating the effects of wireless technologies on hearing. Meric et al. [8] showed that the frequency of noise-induced hearing loss at the '4-kHz notch' in people exposed occupationally to RF was more common than in unexposed individuals. Similarly, Dasdag et al. [9] observed that 10% of technicians working in television broadcasting stations suffered from hearing loss. However, Dasdag et al. [10] also indicated that 10% of technicians working in radio link stations also suffered from inability to hear. Oktay et al. [11] found that occupational RF emitted from radio broadcasting antennas promoted

sensorineural hearing loss and affected cochlea parts related to 4000 and 8000 Hz. Oktay and Dasdag [12] reported a higher degree of hearing loss associated with long-term exposure to EMFs emitted from cellular phones. Meric et al. [13] investigated the effects of radio broadcasting antennas on the hearing of children living in employee residential houses at the station. They found no actual hearing loss in the RF-exposed children living in employee residential houses. However, they suggested continued monitoring of hearing function once per year because of the hearing loss observed in six children at a minimal level, which was found to be statistically insignificant. The studies mentioned above may have simulated the effects of RF on the hearing system. However, Yorgancilar et al. [14] found that long-term exposure to 900 MHz RF exposure (3 h/day over a 6-month period) did not affect cochlear function in rats.

In the literature, there are a few reports about the effects of Wi-Fi on human tissues. Dasdag et al. [15] observed that 2.4 GHz Wi-Fi radiation emitted from wireless Internet equipment altered the expression of two of five miRNAs. Thus, it may lead to adverse effects, such as neurodegenerative diseases, originating from changes in miRNA expression. In an animal study, Hassanshahi et al. [16] demonstrated that Wi-Fi radiation had possible adverse effects on cross-modal and unimodal novel object recognition.

An important issue is the level of RF exposure from Wi-Fi in schools and public areas [17–19]. The International Commission on Non-Ionizing Radiation Protection published guidelines regarding the limits of exposure to non-ionizing radiations [20]. A few studies have shown that the exposure to RF fields from Wi-Fi in public places is expected to be much lower than these limits. For example, Karipidis et al. [17] measured typical and peak RF levels from Wi-Fi and other sources in 23 schools in Australia. They found that the RF exposure in children from Wi-Fi at school was very low and comparable to, or lower than, other sources in the environment. However, cumulative exposure and duration of RF exposure emitted from Wi-Fi are also important. Although WLANs usually operate at a lower output power than mobile phones, the exposure duration is often longer. Moreover, they may also cause the total level of exposure to increase because of the superposition of EMFs emitted by multiple sources and/or exposure to more than one source at the same time. There are, indeed, questions about the potential health effects associated with exposure to these new systems and devices that have not been tested in terms of health risks [21,22].

Another important point is the distance between the Wi-Fi source and the individual. In our study, the distance between the rats and the Wi-Fi device was a

maximum of 50 cm. In practice, Wi-Fi equipment is usually placed in the home or office at a distance of more than 50 cm, except in extreme situations. As Wi-Fi technology has been widely adopted by consumers and businesses, indeed, Wi-Fi 'hot spots' are found in many coffee houses, airports, train stations, and other heavily travelled areas throughout the world, as well as in the homes of many individual users [23]. However, this technology has raised public concerns about health and safety hazards related to exposure to RF energy, with WLANs having been removed from schools in the UK due to health concerns [23]. Moreover, the Council of Europe recommends restrictions on the use of mobile phones and Internet access in all schools across the continent to protect young children from potentially harmful radiation [24].

Radio waves penetrate less into body tissues as the frequency increases. The electric field component of a wave penetrating the body is reduced to 36% of its initial value after a distance known as the skin depth [1]. The average power density was 0.00036 mW/cm², while the maximum power density in the cage was 0.00073 mW/cm² in this study. The average electrical field (*E*) was 1.143 V/m, while the maximum electrical field in the cage was 1.674 V/m in this study. It is clear that the electrical field and power density measured 50 cm away from the Wi-Fi equipment in this study were much lower than the commonly acceptable values.

In this study, we sought to observe the effects of maximum Wi-Fi exposure on hearing. In practice, nobody is exposed to RF radiation emitted from Wi-Fi equipment during the entire day (24 h) for 12 months, except in extraordinary circumstances. Thus, our study was representative of extraordinary conditions. We considered that this type of exposure would simulate the maximum exposure of Wi-Fi and, thus, the results would provide information in terms of hearing and Wi-Fi exposure. As mentioned above, DPOAE values of rats in the sham and exposed groups were measured at the beginning of the study (baseline), and at 6 and 12 months in the study. At the end of the study, we found a statistically significant difference between the DPOAE values in the rats in the sham and exposure groups at the 6000 Hz hearing frequency ($p > 0.05$). Additionally, the DPOAE values at baseline, and at 6 and 12 months in the exposed group showed that 2.4 GHz RF radiation could affect the DPOAE values at some hearing frequencies (Table 2). Interpreting the results in the exposure group is difficult. For example, the DPOAE results measured at the 2000 Hz hearing frequency indicated that 2.4 GHz RFR emitted from Wi-Fi could 'improve' the hearing ($p < 0.05$). In contrast, the DPOAE results at 6000 Hz hearing frequency indicated that 2.4 GHz RF decreased the

hearing after 12 months of exposure, as compared to the DPOAE values measured at baseline and after 6 months of exposure ($p < 0.05$). Thus, we claim that long-term exposure to 2.4 GHz RFR (24 h/day over 12 months) affected hearing.

To our knowledge, no reported study on Wi-Fi exposure and hearing is available for comparison with our results. Thus, we suggest that further studies on the long-term effects of Wi-Fi exposure on hearing are needed, especially with a longer duration than this study.

Conclusions

The present study was designed to observe the long-term (one year) effects of continuous Wi-Fi signals to OHC functions. The obtained results indicated that 24 h/day long-term (one year) exposure to 2.4 GHz RFR can significantly affect the hearing in adult Wistar rats. These effects can occur at high frequencies such as 6000 Hz. Finally, further studies are needed to elucidate this topic.

Disclosure statement

No potential conflict of interest was reported by the authors.

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