The acute auditory effects of exposure for 60 minutes to mobile's electromagnetic field

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ABSTRACT

الأهداف: تقيم التأثير المباشر للتعرض لمدة 60 دقيقة للهاتف المحمول على حاسة السمع وذلك من خلال قياس التشوه الناتج من الانبعاث الاذني وعتبة مستوي السمع.

الطريقة: أجريت دراسة مستقبلية محكمة وذلك في قسم الأنف والأذن والحنجرة، مستشفى جامعة الملك عبدالعزيز، الرياض، المملكة العربية السعودية خلال الفترة من يوليو 2009م حتى يوليو 2011م. حيث تم قياس التشوه الناتج من الانبعاث الأذني وعتبة مستوى السمع قبل البدء باستخدام الهاتف المحمول وبعد 60 دقيقة من الإستخدام لنوع موحد من الهاتف المحمول بالإضافة إلى تعبئة المشاركين لاستبانة لمعرفة الأعراض التي شعروا بها أثناء الاستخدام.

النتائج: كانت الحرارة والألم أكثر الأعراض انتشاراً بين المجموعة المشاركة. وقد وجد تحول واضح وذو قيمة احصائية في عتبة مستوي السمع للتردد 1000 و2000 هرتز بينما لم يتم رصد أي تغير واضح في الأذن التي لم تستخدم الهاتف المحمول ($p<0.05$). كما وجد فرق واضح عند قياس التشوه الناتج من الانبعاث الاذني وذو قيمة احصائية وذلك عند التردد 1000و 1400 و 2000 هرتز بينما لم يسجل اي اختلاف في الأذن التي لم تفحص.

خاتمة: أن التعرض لستون دقيقة من الموجات الكهرومغناطيسية المنبعثة من الهاتف المحمول كان ذو تأثير مباشر علي كل من التشوه الناتج من الانبعاث الاذني وعتبة مستوى السمع في العينة التي خضعت للدراسة بالإضافة إلى ظهور بعض الأعراض في الأذن نتيجة استخدام الهاتف المحمول.

Objectives: To assess the immediate consequences of 60 minutes exposure to mobile phones on hearing function by determining changes in distortion product otoacoustic emission (DPOAE) and hearing threshold levels (HTLs).

Methods: This prospective control clinical trial study was carried out at the Ear, Nose and Throat Department, King Abdulaziz University Hospital, Riyadh, Kingdom of Saudi Arabia from July 2009 to July 2011. The data collected included age, symptoms experienced after exposure, and HTLs and DPOAE were recorded before, and immediately after 60 minutes of exposure to the same model of mobile phone.

Results: Heat/pain was the most commonly reported symptom. In the test-ears, significant shift ($p<0.05$) was noticed in HTLs at 1000 and 2000 Hz but not at other frequencies, while non test-ears did not reveal significant shift in HTLs. Additionally, test-ears revealed significant differences ($p<0.05$) in DPOAE at 1000 Hz, 1400 Hz, 2000 Hz, and at the average of all frequencies, while non test-ears did not show significant differences.

Conclusion: Sixty minutes of close exposure to electromagnetic fields emitted by a mobile phone had an immediate effect on HTL assessed by pure-tone audiogram and inner ear (assessed by DPOAE) in young human subjects. It also caused a number of other otologic symptoms.

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Mobile phones have become a necessary communication tool. Most studies have been conducted in countries with some restriction on the use of mobile phones, as well as on the duration of their use. In these studies, duration of mobile phone use did not exceed 30 minutes.[1-5] The use of mobile phones has increased rapidly, raising concerns regarding the potential consequences of electromagnetic field (EMF) emitted by mobile phones on human health. The changes to the blood-brain barrier and a relative decrease in regional cerebral blood flow have been reported, following mobile phone use.[6] Moreover, the potential involvement of EMF in tumourigenesis remains a subject of debate and research.[7] Mobile phones are usually held in close proximity to the external ear and therefore, EMF exposure at the ear is high due to radiation from the remote earpiece. From the anatomical point of view, the cochlea, which is enclosed by very dense compact bone is located relatively deep within the ear, and is filled with perilymph and endolymph. These structures help shield it from the mobile phone's EMF.[1] However, the outer hair cells (OHCs) of the inner ear are known to be the most sensitive and vulnerable elements of the auditory pathway. If subtle cochlear involvement occurs, this might be detected by changes in otoacoustic emissions (OAEs), which directly reflects the function of the cochlear OHCs. Even minor changes in the integrity of OHCs caused by various noxious factors are known to considerably affect OAE amplitude.[8] The OAEs represent the acoustic responses of OHCs, which act as mechanoreceptor that amplifies sound at finite range of frequencies along basilar membrane, which in turn increases sensitivity and frequency selectivity, especially at mid to low sound intensity.[9] It has been found that the piezoelectric properties of OHCs, which is important for hearing might be damaged easily by external EMF emitted by mobile phones.[2] There was no statistical significant changes using distortion product otoacoustic emission (DPOAE) in OHCs functionality in adult and developing rats exposed for as long as 30 days for one to 2 hours per day to EMF at 900 megaHertz (MHz) and 1800 MHz frequencies.[10,11]Potential effects of mobile phone EMF radiation on hearing should be considered a major research priority in the attempt to determine the potential adverse effects of mobile phone use. The aim of this study is to assess potential acute changes in human hearing function as a consequence of prolonged exposure to EMFs produced by mobile phones.

Methods. This prospective control clinical trials which included 60 subjects was carried out at the Ear, Nose, and Throat Department, King Abdulaziz University Hospital, Riyadh, Kingdom of Saudi Arabia (KSA) from July 2009 to July 2011. The inclusion criteria included normal hearing in both ears and normal results on ear examination. Participants with ear diseases, previous ear surgery, and those taking any medication with ototoxic effects were excluded from the study. An otolaryngologist ensured that the subjects met the inclusion criteria by having normal ontological examination before conducting the study. The study was approved by the College of Medicine Research Center, King Saud University, Riyadh, KSA. Furthermore, the risks and benefits of the study were explained to them, and they gave their informed consent to participate in the study. The subjects underwent baseline-hearing assessments including a pure-tone audiogram (PTA) at different frequencies (250, 500, 1000, 2000, 3000, 4000, 6000, and 8000 Hz) to determine hearing threshold levels (HTLs) at each frequency. In addition, DPOAE amplitude was measured (at 1000, 1400, 2000, 2800, and 4000 Hz) to determine the function of the OHC of the cochlea. To determine HTLs, a descending method as per American National Standards institute[12] for hearing thresholds measurement was used by a licensed audiologist. To determine the amplitude of DPOAE, the emission amplitude in decibel sound pressure level (dBSPL) above the noise level was measured and recorded. All equipment were appropriately calibrated by a licensed biomedical engineer to make sure that it meet the standards. The sound treated booth used in the study meets the ambient noise requirements approved by the American National Standards Institute (ANSI, 2003).[13] Mobile phones model (Nokia N95, which operates on 4 frequency bands, 850, 900, 1,800, and 1,900 MHz frequency bands [Nokia Corporation, Espoo, Finland]) was used by all subjects. The test was conducted in a sound treated audiometric booth with no noise or distraction during testing. A mobile phone was placed on the subjects' test-ear with receiver slightly and constantly pressed against the test-ear for 60 minutes. A rubber soft band was used to hold the mobile phone in place to confirm continuous and fixed placement, and to relieve the subject from discomfort that might result from holding the mobile phone by hands. A second mobile phone was used to place a call to the test mobile phone. Both phones were put on silence to avoid the possible effect of acoustic energy on the results of the study. The communication between the 2 phones was kept continuous for a total duration of 60 minutes. Immediately after the 60 minutes of mobile phone use ended, a second assessment of hearing in both ears was completed using the same procedure that was carried out before the use of a mobile phone. To avoid the possibility of bias in the study, the audiologists were not informed, which ear was the test-ear. After the testing was completed, volunteers were also asked to report all the symptoms they experienced after using the mobile phone.

Equipment. Interacoustics AC 40 audiometer (Interacoustics A/S, Assens, Denmark) was used to obtain HTLs. The DPOAEs on the other hand were obtained using the ILO 292 system (Otodynamics Ltd, Hatfield, Herefordshire, United Kingdom). All equipment were calibrated according to manufacturer's specification.

Statistical analysis. Data were entered into a personal computer and analyzed using the Statistical Package for Social Sciences software version 11 (SPSS® Inc, Chicago, IL, USA). Tests of normality were carried out to check the distribution of data using Shapiro-Wilk test. Means and standard deviations were produced. In addition, Wilcoxon signed rank test was used where appropriate for non-parametric variables, and paired t test was used for parametric variables. The level of significance was set at $p \leq 0.05$.

Results. The mean age of subjects was 21.23 years with a range between 18-26 years (45% were females and 55% were males). A total of 85.7% held the mobile phone against their right ear, and 14.3% against their left ear. Heat/pain was the most common symptom experienced by the subjects, however, 46% reported no symptoms. **Figure 1** shows HTLs before and after exposure to mobile phone in both test- and non test-ears. In the test-ears, significant values were noticed at 1000 and 2000 Hertz (Hz) but not at other frequencies (that is; 250, 500, 3000, 4000, 6000, and 8000 Hz). The mean values of HTL were 10.25 (at 1000 Hz) and 9.08 (at 2000 Hz) prior to mobile phone exposure, and they increased dramatically to reach 14.42 (at 1000 Hz) and 13.42 (at 2000 Hz) after exposure. The mean value of HTL of the average of all frequencies was 10.51 before exposure to cell phone radiations, but it increased significantly after exposure to reach 11.0. There are significant increases in the mean values of HTL after mobile phone exposure at 1000 (p=0.000), 2000 (p=0.000), and average Hz (p=0.018) among the test-ears. On the other hand, no significant change was noticed in the non test-ears on any frequency after exposure to cell phone radiation. The differences of HTLs between test- and non test-ears are shown in **Table 1**. There are statistically significant differences between test- and non test-ears regarding post-exposure and pre-exposure differences in HTLs at 1000, 2000 and average Hz (p=0.000). At 1000 and 2000 Hz, the difference in the mean values for HTL post-exposure was 4.17, and pre-exposure was 4.33 among the test-ears. On the other hand, there are no statistical significant difference between test- and non test-ears regarding post-exposure and pre-exposure differences in HTLs at 250, 500, 3000, 4000, 6000, and 8000 Hz (p>0.05). **Figure 2** revealed DPOAE at different frequencies before and after mobile phone exposure in both test- and non test-ears. In the test-ears, significant results were noticed at 1000 Hz, 1400 Hz, 2000 Hz, and at the average of all frequencies. At 1000 Hz, the mean value of DPOAE was 10.84 before exposure, while after exposure to mobile phone decreased significantly to be 9.14. The same trend appeared at 1400 Hz, 2000 Hz, and the average of all frequencies with significant decrease in the mean values after exposure to mobile phone (p<0.05), while there were no significant differences at other frequencies (2800 and 4000 Hz). In non test-ears, there was no significant difference of DPOAE at all frequencies (p>0.05). **Table 2** shows the differences in mean values of DPOAE before- and after mobile phone

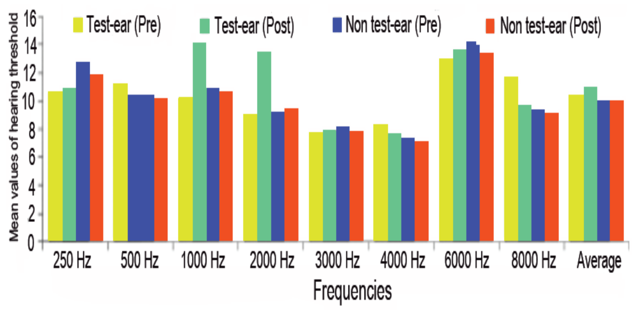

Figure 1 - Mean values of hearing threshold in Hertz (Hz) before and after exposure to mobile phone in both test and non test-ears (n=60).

Table 1 - Hearing threshold level mean differences (post - pre) for both test- and non test-ears (n=60 pairs).

Frequency, Hertz	Hearing threshold difference* Non test-ear	Test-ear	*P*-value†
	Difference (mean)		
250	-0.82 (5.24)	-1.73 (5.12)	0.176
500	-1.17 (4.26)	-0.75 (4.3)	0.448
1000	0.000 (2.51)	4.17 (3.8)	0.000
2000	0.25 (2.97)	4.33 (3.96)	0.000
3000	-0.33 (3.99)	0.17 (3.79)	0.518
4000	-1.25 (3.97)	-0.58 (3.58)	0.291
6000	-0.83 (4.5)	0.67 (3.62)	0.056
8000	-0.23 (7.04)	2.0 (8.2)	0.197
Average	-0.58 (1.43)	0.53 (2.1)	0.000

*post reading less than the pre reading. † Wilcoxon signed rank test for non-parametric variables

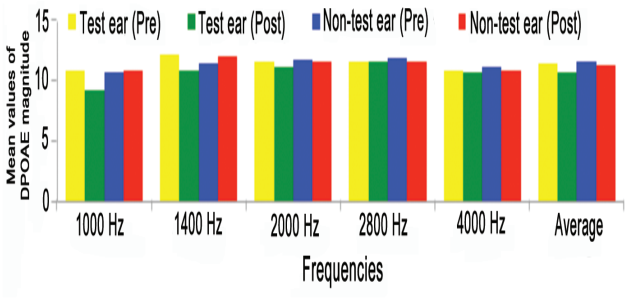

Figure 2 - Mean values of distortion product otoacoustic (DPOAE) emission magnitude at different frequencies in Hertz (Hz) before and after exposure to mobile phone in both test and non test-ears (n=60 pairs).

Table 2 - Distortion product otoacoustic emission (DPOAE) magnitude mean differences (post - pre) at different frequencies for both test- and non test-ear (n=60 pairs).

Frequency, Hertz	DPOAE difference (post-pre)* Non test-ear	Test-ear	*P*-value†
	Difference (mean)		
1000	0.097 (0.87)	-1.7 (2.35)	0.000
1400	-0.48 (2.05)	-1.47 (1.82)	0.011
2000	-0.21 (2.57)	-0.39 (2.9)	0.011
2800	-0.198 (1.6)	0.103 (2.8)	0.942
4000	-0.29 (1.5)	-0.24 (1.9)	0.735
Average	-0.215 (0.97)	-0.74 (1.17)	0.000

*post reading less than the pre reading. †Wilcoxon signed rank test for non-parametric variables

exposure between test- and non test-ears at different frequencies. Significant differences were noticed at 1000 Hz, 1400 Hz, 2000 Hz, and the average of all frequencies ($p<0.05$). At 1000 Hz, 1400 Hz, 2000 Hz, and the average of all frequencies, The differences and for test-ears were 1.7 (1000 Hz), 1.47 (1400 Hz), 0.39 (1400 Hz), and 0.74 (at the average of all frequencies), and they were significantly higher than the differences calculated for non test-ears at different frequencies.

Discussion. The results of this study revealed that mobile phone use for 60 minutes had significant effects on HTLs and DPOAE in the test-ears, while non test-ears did not show any significant effect. The present results show a significant effect after a prolonged period of mobile phone use (60minutes) on 1000 Hz and 2000 Hz, and average PTA on the test-ears. At the same time, DPOAE amplitudes decreased significantly at 1000, 1400, and 2000 Hz and average amplitudes in test-ears after exposure. Similar results were reported by previous research, for example, mild hearing loss in mobile phone users was reported.[14-16] On the other hand, our results differ from those reported by other investigators[1-5] demonstrating that 10, 15, 20, and 30 minutes of GSM mobile exposure did not induce a measurable effect on the human auditory system. The longer duration of exposure in our study might account for some, or all of that difference. In addition, 2 studies based on auditory brainstem response and middle latency response concluded that 30 minutes of mobile phone use has no short-term adverse effects on the human auditory system.[17,18] It is unclear why 1000 and 2000 Hz thresholds got affected, and not all other frequencies. The possible reason might be due to the fact that the human auditory system is most sensitive to frequencies in the middle, as evidenced by the minimum audibility curve. Sensitivity of the cochlea at different frequencies was indirectly measured using cochlear microphonic (CM). The CM was recorded from round window to different tone bursts. The minimum recordable CM was plotted at each frequency.[19] Results of their work revealed that the cochlea was most sensitive at frequencies 1000-2000 Hz. Both OAE and CM represent OHCs activation and essentially measures the same thing, however CM represents the electrical response, and the OAE represents the acoustic response of OHCs activity. Other possible explanation for the significant effect could be related to the relationship between long-term stress caused by mobile phone use and self-reported hearing loss.[20]

Hearing thresholds shift at 1000 and 2000 Hz was also accompanied by the drop of DPOAE magnitudes at the same frequency range (1000, 1400, and 2000 Hz). This indicates that EMF affected the function of OHCs, and produced sensory hearing loss at that specific range of frequencies. The presence of documented physiological effect on OHCs as documented by a decrease in DPOAE magnitude is yet another evidence that hearing threshold shifts in our study were not psychological in nature, but resulted from direct physical insult to OHCs. In addition, if hearing thresholds shift resulted from stress, we expect drop of thresholds at all test frequencies and not only at 1000 and 2000 Hz.

Our results revealed no significant effect on the non test-ears' hearing thresholds and DPOAE at any frequency. Non test-ears could be more protected because they are relatively far away from the EMF source and the heat of the mobile phone as compared to the test-ears. The skull and the brain tissues provide a thick barrier that possibly decreases the EMF magnitude. Other otological symptoms including heat/pain, headache, vertigo, tinnitus, fullness, and deafness were also reported by our subjects, which might be due to the direct effect of heat on the head.

The limitations of the current study include inability to investigate if the shift in HTLs and/or the drop in DPOAE magnitude are/is only a temporary effect. Future studies that follow the subjects over time to measure how long the effect symptoms lasts is highly recommended.

In conclusion, mobile phones had an immediate and adverse effect on hearing documented subjectively and objectively on young human subjects. It also caused other otologic symptoms. Future research is recommended to assess the recovery and progress of the acute changes in the auditory system.

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