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Original Article

Effects of mobile phone electromagnetic fields on cognitive functions and auditory acuity

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ABSTRACT

There are about 1.6 billion GSM cell phones in use throughout the world today. Numerous papers have reported various biological effects in human beings exposed to electromagnetic fields emitted by mobile phones. The current scientific literature is, however, full of inconsistencies. The aim of the present study was to advance our understanding of potential adverse effects of the GSM mobile phones on the human cognition and hearing system. The objective of work is to study the pattern of mobile phone usage among the study subjects, to study the effect of electromagnetic fields of mobile phones on cognitive functions and the hearing of the user on acute mobile phone exposure and to evaluate the auditory acuity in normal subjects using mobile phones by recording the baseline and post exposure soundwave pattern among the study subjects using Pure Tone Audiometry (PTA) and evoked otoacoustic emissions (OAEs). 30 healthy volunteers participated in a double blind cross over clinical trial. The participants were made to take ADAS cognitive function test before and after 30 minute exposure to mobile phone electromagnetic fields. 20 otologically normal subjects aged between 20 and 25 years were submitted to pure-tone audiometry and evoked transient otoacoustic emissions before and after half hour of exposure to mobile phone electromagnetic fields. Statistical analysis revealed no significant differences in the mean HTLs of PTA and mean shifts of TEOAE's before and after mobile phone EMF 30 min exposure. There is also no evidence of change in cognitive functions before and after exposure.

Keywords: GSM cell, Human Cognition, Pure Tone Audiometry

INTRODUCTION

Due to wide spread use of the Global System for Mobile Communications (GSM) mobile phones they have become indispensable as communication tools and therefore any consequent biological effects should be considered as a high-priority environmental health issue. However, to date, there is an inadequate knowledge on what biological systems could be affected by the use of these devices. Biological effects of radio-frequency electromagnetic fields (EMF) transmitted by mobile phones are still a matter of public and scientific discussion. Sensations of burning or warmth around the ear, headache, disturbance of sleep , alteration of cognitive functions and neural activity, as well as alteration of the blood-brain barrier and a relative decrease in regional cerebral blood flow have been reported as effects resulting from mobile phone use. The potential tumorous effect of EMFs is still a subject of debates and research [1, 2]. The hearing system is in the closest proximity to the device so that hearing is potentially the most affected target of thermal and non-thermal effects. Moreover, the hearing system and particularly the cochlear outer hair cells (OHC) are known to be highly sensitive to a great variety of exogenous and endogenous agents and externally applied electric and magnetic fields are known to be able to produce some hearing sensation [3].If it causes subtle cochlear deleterious effects, these may be observable through changes in evoked otoacoustic emissions (OAEs).

The aim of the present study was to assess the acute potential changes in human hearing function as a consequence of exposure to low-intensity EMF's produced by mobile phones at frequencies of 900MHz under double-blind conditions as determined by changes in transient evoked and

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Distortion Product otoacoustic emissions (TEOAEs & DPOAEs) and hearing threshold levels (HTL) in pure tone audiometry (PTA). [4,5]

AIMS AND OBJECTIVES

1. To study the pattern of mobile phone usage among the study subjects.
2. To study the effect of electromagnetic fields of mobile phones on cognitive functions and the hearing of the user on acute mobile phone exposure.
3. To evaluate the auditory acuity in normal subjects using mobile phones by recording the baseline and post exposure soundwave pattern among the study subjects using Pure Tone Audiometry(PTA) and Otoacoustic Emissions(OAEs).

MATERIALS AND METHODS

Study Design: Double blind cross over clinical trial

Study Site: Mysore Medical College & Research institute, Mysore and All India Institute of Speech & Hearing-AIISH, Mysore

Period of study: September-November 2011

No. of Subjects: Thirty

Inclusion Criteria: Third MBBS students who volunteer for the study

Exclusion Criteria: The following will not be included:

- H/O chronic headache
- H/O epilepsy
- H/O consumption of ototoxic drugs in past 3 months
- H/O ear surgeries performed in the past
- H/O recent infection in ear, nose and throat
- Noise induced hearing loss
- Smokers and tobacco users

Informed Consent Procedure: Used the Standard Consent Procedure (Form enclosed).

Methodology:

Scope Study- Questionnaire prepared based on scope – data gathering through questionnaire.

Cognitive Function Tests- Using standard ADAS scale

PTA recording of sound wave pattern - before and after half hour exposure to mobile phone electromagnetic fields.

Otoacoustic Emissions (OAEs) recorded before and after half hour exposure to mobile phone electromagnetic fields.

Methodology Descripton: This study was reviewed and approved by the Research Ethics Committee of Mysore Medical College & Research Institute. The study subjects were interviewed using a pretested questionnaire (copy enclosed). Personal profile and the cell phone usage pattern were documented. History of the following symptoms in the past 1 year was recorded-headache, memory loss, mood swings, fatigue, loss of concentration, lack of coordination, nausea, and sleep disorders. Twenty normal-hearing adults (12 males and 8 females) between the ages of 20 and 25 years (mean age 22 years) volunteered to participate in this study. Only the right ear was exposed to EMF and evaluated in this study. After confirming the subject's health status with a complete medical and otologic history, and otoscopic examination was performed to eliminate the possibility of middle ear problems. The criteria for normal hearing were that the pure-tone thresholds be at 20-dB HL or better for the octave frequencies (250-8000 Hz) and for the interoctave frequencies (1500, 3000 and 6000 Hz), and that tympanometry showed normal middle ear function. Volunteers meeting these criteria for normal hearing were enrolled to the study for evoked OAE testing sessions. The mobile telephone utilized in this study was the **Nokia N70**. This mobile telephone transmits and receives radio signals in the **900 MHz** range using the **GSM system**.

For the purposes of monitoring the potential negative effects of EMFs from a mobile telephone on hearing, transiently-evoked (TEOAEs) and distortion-product (DPOAEs) OAEs were recorded consecutively and analyzed utilizing ILO-96 cochlear emission analyzer. Two evoked OAE test sessions were performed separately for each subject. Each evoked OAE measurement session lasted for about 5 to 6 minutes.

The Transiently-evoked OAEs were obtained with stimuli consisting of clicks of 80 μs duration. The stimulus level in the outer ear was set at 80 ± 3 dB pe SPL. The click rate was 50 per second and post-stimulus analysis was in the range of 2 to 20 ms. A total of 260 sweeps was averaged above the noise rejection level of 47 dB. Stimuli were presented in the nonlinear mode, in which every fourth click stimulus is inverted and three times greater in amplitude than the three preceding clicks. A transiently-evoked OAE was defined as a response if its amplitude was > 3 dB above the level of the noise floor. Reproducibility percentages > 60 percent was taken into account as acceptable for the analysis at five successive frequency bands from 1 to 4 kHz. Distortion-product OAEs were measured as DPgram, where the intensity levels of the primary tones are held constant and distortion-product OAE data are recorded for different frequency regions, from 1 to 6.3 kHz and plotted as a function of f2. The resolution of DPgram recording 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 frequencies. Distortion-product OAE measurement at 2f1-f2 was considered significantly different from the background noise if it exceeded by at least 3 dB.

- **Before exposure to elevated mobile phone electromagnetic fields:**
  - Pure tone audiometry before the individual was exposed to mobile phone electromagnetic fields.
  - Measurement of TOAEs before the individual was exposed to mobile phone electromagnetic fields.
- Individuals were made to speak on phone for half an hour (exposure to mobile phone electromagnetic fields)
- After exposure to mobile phone electromagnetic fields:
  - Pure tone audiometry after half hour of exposure
  - Measurement of TOAEs after half hour of exposure
- Cognitive functions were similarly assessed before and after exposure using standard ADAS scale under the following headings:
  1. Word recall task
  2. Naming task
  3. Commands
  4. Constructional praxis
  5. Ideational praxis
  6. Orientation
  7. Word recognition
  8. Remembering Test Instructions
  9. Spoken language ability
  10. comprehension

Data Analysis: Data analysis included calculation of central tendency measures (mean, median and standard deviation). Auditory thresholds and reproducibility of TOAEs before and after exposure to mobile phone electromagnetic fields were compared using Student's t-test (critical t equal to or higher than 1.7) for the difference between two groups before and after exposure to mobile phone electromagnetic fields.

RESULTS AND OBSERVATIONS

Table1: Gender Wise Distribution of Study Subjects

Gender	Number	%
Males	17	56.66
Females	13	43.33
Total	30	100

The number of males was slightly more than the number of female participants. The median age of study subjects was 22 years

Table 2: Duration of cell phone use

Duration of cell phone use	Number	%
Less than one year	1	3.33
1-3 yrs	15	50
More than 3 years	14	46.66
Total	30	100

Majority of the study subjects (46.66%) are using the cell phones for more than 3 years. Only 3.33% of them have started using cell phones in the recent past.

Table 3: Multiple uses of cell phone

Purpose of cell phone use (N=30)	Number
Communication only	14
Listening to music	4
Games	2
All	10

Majority of the study population used cell phones for purposes other than communication also. This trend is bound to increase the duration of exposure to cell phone radiation.

Table 4: Active Daily exposure to cell phone

Average duration of cell use per day:	Number	%
Less than one hour	20	33.33
1 – 3 Hours	12	40
>3 hours	8	26.66
Total	30	100

A quarter of the study group indulged with their cell phones for more than 3 hours a day. This duration included call time as well as games and music.

Table 5: Use of hands free

Hands free	Number	%
Used	10	33.33
Not Used	20	66.66
Total	30	100

More than 50% of study population does not use hands free or other equipment while using cell phone.

Table 6: Transport of cell phone

Mode of carrying cell phone*	Number
In bag/purse	11
Trouser pocket	15
Shirt pocket	3
Dangling in front of chest	1

*There were multiple modalities of transport for some individuals

The above table shows that the cell phone has become a necessary accessory of our bodies. The proximity of the phone to the body is an important factor influencing its effect on our health.

Table 7: Status of cell phone during night

Mode	Number	%
Off	3	10
On	27	90
Total	30	100

Majority of study population don't switch off the cell phone during night.

Table 8: Location of cell phone during sleep

Distance of Cell phone from the body	Number	%
Within one meter distance	24	80
More than one meter	6	20
Total	30	100

The cell phone is kept in close proximity during sleep and it is not switched off in majority of the cases.

Table 9: Symptoms associated with cell phone use

Symptoms	Number
Head ache	5
Sensation of heat in head	6
Ringing in ears	3
ANY OTHER (sensation o heat in ears)	4

Sensation of heat in the head and head ache are the common symptoms associated with cell phone use.

Table 10: Clinical history

Symptomatic episodes in the past year	Number
Head aches	9
Memory loss	3
Fatigue	4
Loss of concentration	12
Lack of coordination	2
Sleep disorders	4
ANY OTHER (Pain in the neck)	1

The history was sought out of academic interest. Majority of the study subjects experienced varied symptomatic episodes which might have been influenced by their cell phone. Interestingly people who were using cell phones for multiple purposes and had longer exposure rates were most commonly affected by the above symptoms. However because of the confounders involved cannot be considered with the present study design.

Cognitive Functions: Using the ADAS for assessment of effect of mobile phone electromagnetic fields on cognitive functions, the data did not provide any evidence of an electromagnetic field effect on human cognition with respect to the following parameters:

- Word recall task
- Naming task
- Commands
- Constructional praxis
- Ideational praxis
- Orientation
- Word recognition
- Remembering Test Instructions
- Spoken language ability
- comprehension

Analysis of Evoked Otoacoustic Emissions: The subjects tested in the study tolerated the EMF exposure of mobile phones quite well. There were no subjective complaints after the exposure. As all of the subjects tested in the study had a normal hearing, recordings of TEOAEs were obtained (6–10 dB) above the noise floor through 1 – 3 kHz test frequency range for all sessions. Reproducibility of TEOAEs was >60% (91 ± 3 % in average). The mean SNR (Signal-Noise Ratio) shifts of the TEOAE measurements of pre/post exposure and pre/post exposure DPOAEs after contralateral ear suppresion are presented in Table1.

T-Test: Paired Samples Statistics

		Mean	N	Std. Deviation	Std. Error Mean
Pair 1	preSNR	9.4263	19	2.70244	.61998
	postSNR	8.3526	19	3.47441	.79708
Pair 2	preCONSUPR	1.6000	19	2.10871	.48377
	postCONSUP	.0737	19	2.14317	.49168

Table 1. Baseline mean SNR and standard deviation at different frequencies.

Statistical analysis with the T-test did not reveal any statistically significant differences in mean (preexposure-postexposure) SNR and mean (preexposure-postexposure) SNR after contralateral suppression ($p < 0.01$) as shown in Table2.

Paired Samples Test

		t	df	Sig. (2-tailed)
Pair 1	preSNR – postSNR	2.316	18	.033
Pair 2	preCONSUPR - postCONSUP	2.773	18	.013

Table 2. t values and significance value for different frequencies

The results of the present study suggest that 30-min exposure to EMFs emitted by GSM mobile phone did not cause any detectable alterations in neither PTA nor TEOAEs.

DISCUSSION

A rapid worldwide expansion of mobile telephones raises questions regarding possible effects of the emitted radiofrequencies on the health of the consumers. Of all anatomical structures, the ear has one of the closest proximity to mobile telephones. 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 was studied, there is 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 EMF. This exposure was achieved by having subjects hold the activated mobile telephone for 30 minutes with conversation.

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, not revealed in pure-tone audiometry, cause obvious changes in distortion-product OAEs. Evoked OAEs are also a well-described method for detecting the effects of ototoxic drugs on the cochlea. The high test-retest reliability of OAE measures permits the utilization of these emissions to monitor dynamic changes in cochlear responsiveness.

The measurement of the evoked OAEs is non-invasive, painless and quick and it does not require active participation of individuals. For these reasons, OAE measurements appeared to be well suited for the investigation of potential cochlear involvement from the exposure of the mobile telephone EMF.

Radiofrequency electromagnetic radiation is emitted from mobile telephone's antenna. It can penetrate into the 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 to the ear. This energy radiated by a mobile telephone is low. GSM telephones always emit the maximum power for a few seconds during initiation of the connection with the mobile telephone. The telephone rings only after the telephone has received this powerful transmission and the power decreases to the level which is just enough for the connection. This protective feature of the GSM mobile telephones may have a role for the negative results of the study.

The rate of absorption and the distribution of EMF energy in a tissue depend on many factors. These include: the dielectric composition of the irradiated tissue, e.g., the bone having a lower water content absorbs less energy than muscle; the frequency of the EMF; shape, geometry, and orientation of the object; and closeness of the source. 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. In deep tissues, like the brain, maximum temperature rise due to mobile telephone EMF exposure was calculated to be no more than about 0.1o C. 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 since the cochlea is enclosed by very dense compact bone, located relatively deep and congested with the perilymph and endolymph, it is realtively shielded from the EMF radiation generated by the mobile phone.

As the study protocol was based on the comparison of the measures of the audiological tests obtained before and immediately after EMF exposure, only a relatively long-term or chronic alteration in hearing function could be detected by the present investigations. Some potential transitory, i.e. reversible, alterations in hearing function lasting for only a short time during the EMF exposure cannot be detected by these methods. Therefore,

the simultaneous measurement of hearing function during the mobile phone's EMF emission would be of scientific interest. However, these implications could be considered as guidelines for further investigations.

CONCLUSION

It could be concluded that though the transient evoked otoacoustic emissions (TEOAEs) and distortion product otoacoustic emissions (DPOAEs) testing were efficient in detecting minor temporary changes in auditory thresholds following exposure to mobile phone electromagnetic fields for 30 minutes, there was no immediate statistically significant after-effect on measurements of HTL of PTA and TEOAEs in young adult human subjects and no measurable hearing deterioration at least at outer and middle ear and cochlear levels was detected in our study. In addition, on using the ADAS for assessment of effect of mobile phone electromagnetic fields on cognitive functions, the data did not provide any evidence of an electromagnetic field effect on human cognition.

SUGGESTIONS:

The following prudent use of mobile telephones is recommended:

- Use mobile telephones for as short of periods as possible, only for essential purposes, with low SAR values and with hands-free devices provided that they have been proved to reduce SAR exposure.
- Health education of the public on a massive scale regarding the possible adverse effects of cell phones. Cell phone etiquette should be developed by experts
- Switching off cell during sleep should be encouraged
- Standardization of handsets and ISO certification should be considered.
- Legislation pertaining to radiation standards can be considered.
- Usage by pregnant women and children should be restricted
- More research both in laboratory and field should supplement policy making.

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