

Original Article

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Variations in electroencephalography with mobile phone usage in medical students

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Abstract:

Background: Electromagnetic fields (EMFs) emitted by cellular telephones may cause neurological ill effects like cognitive dysfunction, emotional instability, and even brain tumors. Slowing of brain activity on electroencephalography (EEG) has been shown. However, these findings need further validation.

Aims: EEG changes and adverse effects experienced following cell-phone use were studied.

Settings and Design: The study was conducted in the Department of Neurology of a tertiary care university hospital in India on North Indian students of the University, from August 2017 to October 2017.

Materials and Methods: Twenty-one students underwent video-EEG recording before and after application of Samsung GT-56312 dual SIM smart phone in switched off, switched on, and switched on mode with conversation.

Statistical Analysis Used: Average EEG frequencies and amplitudes were calculated for different brain regions. Chi-square tests and t-tests were used for comparison between variables.

Results: The mean age of 7 (33.3%) male and 14 (66.7%) female subjects was 20.76 ± 1.48 years. The average EEG frequencies following mobile phone application with conversation were higher and the amplitudes lower than the baseline values. Frequencies were greater on the right side. Slow waves were detected in the frontal region in 38.1%, in the parietal region in 33.3%, in the occipital and temporal region in 19.1%; and, generalized slow waves were seen in 9.5% students. During the experiment, 23.8% experienced headache, 19% experienced irritation, and 9.5% felt drowsy. Headache and loss of concentration (33.3%), sleep disturbances (28.6%), and fatigue (19%) were frequent in daily life.

Conclusions: Experimental application of mobile phones may lead to some EEG changes and certain ill effects on the well-being. Hence, prolonged use of these gadgets warrants caution.

Key Words:

Cellular phone, mobile phone, electroencephalography, electromagnetic fields, radiofrequency fields

Key Message:

Usage of mobile phones leads to electroencephalographic (EEG) changes that may have effects on the health of subjects using them. The average EEG frequencies following mobile phone application with conversation were higher and the amplitudes lower than the baseline values. Frequencies were greater on the right side of the brain. Slow waves were detected in specified brain areas while using phones. Thus, caution should be exercised during their prolonged usage.

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In the recent ages, the mobile phone usage has become ubiquitous, with India having the second largest telecommunication system in the world.^[1]

These phones emit radiofrequency waves, a type of nonionizing radiation of the electromagnetic spectrum. Hence, when kept close to the ear or body, mobile phones have different exposure of radiofrequency fields to the body.

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Human experimental studies reveal that electromagnetic fields (EMFs) emitted by cellular telephones may be responsible for changes in the electric activity of the brain. Various ill effects like headache, fatigue, muscular pains, loss of appetite, sleepiness, poor memory and concentration, emotional instability, labile cardiovascular function, and nausea have been reported, which may be called "microwave syndrome" or "electro-hypersensitivity."^[2,3] Previous researchers have shown a subtle

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slowing of brain activity related to mobile phone use.^[4] Also, changes in evoked potentials with the use of cell phones have been seen.^[5] There have been studies linking cognitive dysfunction to the use of mobile phones.^[6,7] Some researchers are of the view that exposure to mobile phone EMF does not affect the auditory function,^[8] while others feel that auditory changes do occur with the use of phones.^[9] Also, there have been studies showing no effect on the well-being and resting electroencephalography (EEG) in mobile phone users.^[10]

People have shown an increased risk of brain tumors with the use of mobile phones.^[11-15] Some researchers are of the view that the fear of the effect of mobile phone EMF on the human brain cancer development risk is without any scientific basis.^[16-18] Though less common, there are studies showing a beneficial effect on cognitive processing with the use of mobile phones.^[19,20]

Currently, there is little epidemiological evidence indicating that the mobile phone use causes adverse health effects.^[21]

Some previous studies have been done on “the EEG changes due to experimentally induced 3G mobile phone radiation,”^[22,23] but further studies are required for determining whether or not the duration of the exposure to radiation is related to effects, if any, on the brain.

Hence, this study intended to evaluate the changes in electrical activities of neurons induced by the radiofrequency waves using a video EEG on North Indian students of a tertiary care medical university, where the mobile phone use is very widespread. Also, the adverse effects experienced by the subjects were recorded.

Materials and Methods

The study was conducted in the Department of Neurology, King George’s Medical University, Lucknow, on the North Indian students of the same university, from August 2017 to October 2017.

The subjects were recruited from the first- and second-year MBBS students of the Medical University. Twenty-one apparently healthy young male and female subjects aged from 18 to 25 years were included after taking their informed consent. Subjects on anti-epileptic medication or with a history of seizures or any other neurological illness were excluded from the study.

The Institutional Ethical Committee approved this study.

Procedure

Each student’s history was taken and general examination was done to rule out any medical or neurological illness, any history of seizure or intake of anti-epileptics medication, or any other drug acting on the central nervous system. Also, history of details of mobile phone use was taken. The student was asked to have a proper night’s sleep, to avoid any caffeine containing beverages in the past 4 h, and to avoid alcohol in the preceding 12 h.

EEG of all the students was done using the “Nicolet” V44 video EEG machine. The bipolar montage was used. Settings for the high-pass filter and low-pass filter were 1 Hz and 70 Hz, respectively. A notch filter was also used. The sensitivity was 70 μ V/cm and the paper speed was 30 mm/s.

Samsung GT-56312 dual SIM smart phone that works on an Android version 4.1.2 (Jelly Bean) baseband version S6312DDAML, which has a head specific absorption rate (SAR) of 0.881 W/kg and body SAR of 0.561 W/kg was employed for the study. The call was dialed from a fixed line in another room for the last intervention (phone on with prerecorded audio). The vibration mode in the phone was turned off throughout the intervention.

The electrodes were placed according to the 10–20 international systems approved by the International Federation of Societies for EEG and Clinical Neurophysiology (Jasper 1958). All electrodes were fixed using a conductive plate. Any electronic gadgets were removed from the room. A headband was placed around the head to hold the mobile phone to be used subsequently. The subject was laid down comfortably on the bed with hands by the side and jaws relaxed. A baseline reading for 5 min was taken with the eyes closed. A 30-s gap was given where the student could relax and open the eyes. Then, a mobile phone in switched off position was placed beside the right ear of the student for 5 min and EEG recording was done with the eyes closed. A 30-s gap was given and the procedure repeated with the phone in switched on mode followed by a 30-s gap. Then, a prerecorded audio clip was received by the subject and the EEG recording was done. The students were divided into three groups. The duration of recording with the prerecorded audio clip was 5 min for the first student group, 10 min for the second student group, and 15 min for the third student group.

The average EEG frequencies and amplitudes of different regions of the brain were calculated for the students in different situations of application of mobile phone (baseline, with the phone in switched off mode, with the phone in switched on mode without conversation, and with the phone in switched on mode with conversation or audio clip).

The students were asked to fill a written questionnaire regarding their mobile phone use.

Statistical analysis

The data were analyzed using the Statistical Package for the Social Sciences (SPSS) version 20. Means were calculated for different demographic variables. Frequency and percentage were calculated for various adverse effects reported and chi-square tests were used to analyze the relationship between adverse effects and the amount of daily mobile phone use. For comparing between the two different frequency groups with phones in different situations of the experiment, Wilcoxon signed ranks test was employed. For comparison between the baseline frequency and the frequency following interventions (5, 10, and 15 min), the Wilcoxon signed ranks test was used. A *P* value of <0.05 was considered significant.

Results

Out of 21 students, 7 (33.3%) were males and the rest 14 (66.7%) were females. The average age of students was 20.76 ± 1.48 years. Most of them were using a single cell phone, except for three students, who had two cell phones. They received on an average 7.81 ± 9.114 phone calls per day and the mean duration of calls was 51.33 ± 54.441 min. Only one student kept the mobile phone in the bag and the rest of them kept them in their pockets.

Only 3 (14.29%) students said that they were not aware of the fact that the cell phone usage could be associated with some adverse effects and the remaining 18 (85.71%) said that they were aware of the fact that cell phones could lead to some side effects. The adverse effects of using phones reported by the students along with the relationship between the adverse effects and the amount of daily mobile phone use are mentioned in Table 1.

The average EEG frequencies and maximum amplitudes of different regions of the brain in baseline, and with mobile phones in switched off, switched on, and switched on with conversation situation were assessed. The *P* values of significance of difference between the average baseline frequency and amplitude, and the average frequency and amplitude with the phone switched on with conversation; and, of significance of difference between the average baseline frequency and amplitude, and the average frequency and

amplitude of the last minute with phone switched on with conversation were analysed using Wilcoxon signed ranks. These test are mentioned in Tables 2 and 3.

On comparison of right and left sides of the brain, the *P* values obtained are shown in Figures 1 and 2.

The comparison between frequencies and amplitudes of different regions of the brain when mobile phones were applied for different durations is depicted in Tables 4 and 5, respectively.

Out of the 21 the students, frontal slow waves were observed in the maximum number of students (in 8), followed by parietal slow waves (in 7) and occipital and temporal slow waves (in 4), and generalized slow waves were seen in only 2 students.

A total of five (23.8%) students experienced a headache, four (19%) experienced irritation, and two (9.5%) experienced

Table 1: Adverse effects reported by the students after using the mobile phones

Adverse effects	Number and percentage of students experiencing adverse effects	The <i>P</i> for the relationship between adverse effects and number of daily phone calls (using chi-square tests)	The <i>P</i> value for the relationship between adverse effects and the average duration of calls (using chi-square test)	The <i>P</i> value for the relationship between adverse effects and number of mobile phones used (using chi-square test)
Fatigue	4 (19)	0.732	0.506	0.023
Sleep disturbances	6 (28.6)	0.608	0.324	0.115
Dizziness	1 (4.8)	0.948	0.618	0.012
Loss of concentration	7 (33.3)	0.226	0.334	1.000
Memory loss	0 (0.0)	-	-	-
Headache	7 (33.3)	0.609	0.540	1.000
Muscle ache	1 (4.8)	0.013	0.900	0.676
Tinnitus	0 (0.0)	-	-	-
Tingling sensation	0 (0.0)	-	-	-
Giddiness	1 (4.8)	0.013	0.050	0.676

Table 2: Average electroencephalography frequencies of different regions of the brain in relation to the application of mobile phones

The region of the brain where leads were placed	The average baseline frequency	The average frequency with the phone switched off	The average frequency with the phone switched on without audio	The average frequency with the phone switched on with audio	The average frequency of the last minute with the phone switched on with audio	The <i>P</i> value of the significance of the difference between the average baseline frequency and the average frequency with the phone switched on without audio (Wilcoxon signed ranks test)	The <i>P</i> value of the significance of the difference between the average baseline frequency and the average frequency with the phone switched on with audio (Wilcoxon signed ranks test)	The <i>P</i> value of the significance of the difference between the average baseline frequency and the average frequency of the last minute with the phone switched on with audio (Wilcoxon signed ranks test)
Left frontal	9.522±1.091	9.152±0.9652	9.724±1.6413	9.833±1.5752	9.81±1.601	0.970	0.537	0.566
Right frontal	9.400±1.1781	9.562±1.2690	9.705±1.3411	9.748±1.6204	9.76±1.609	0.278	0.320	0.650
Left parietal	9.733±0.6851	9.543±0.8947	9.800±0.8462	9.819±1.0410	9.52±1.537	0.844	0.692	0.513
Right parietal	9.781±0.6478	9.790±1.1823	9.876±1.1126	9.871±0.9429	10.38±1.499	0.760	0.466	0.031
Left temporal	9.581±0.8761	9.590±0.8136	9.771±0.9639	9.719±0.8807	9.81±1.569	0.419	0.318	0.760
Right temporal	9.686±0.9024	9.457±1.0414	9.743±0.7801	9.557±1.0171	9.71±1.521	0.757	0.336	0.693
Left occipital	9.733±0.7330	9.771±1.0494	9.810±0.9664	10.014±1.0809	9.86±1.424	0.919	0.125	0.462
Right occipital	9.676±0.9787	10.133±1.5262	9.924±0.8955	9.929±0.8951	9.86±1.459	0.156	0.152	0.410

Table 3: Average electroencephalography amplitudes of different regions of the brain in relation to the application of mobile phones

The region of the brain where the leads were placed	The average baseline amplitude	The average amplitude with the phone switched off	The average amplitude with the phone switched on without audio	The average amplitude with the phone switched on with audio	The average amplitude of the last minute with the phone switched on with audio	The <i>P</i> value of significance of the difference between the average baseline amplitude and the average amplitude with the phone switched on without audio (Wilcoxon signed ranks test)	The <i>P</i> value of significance of the difference between the average baseline amplitude and the average amplitude with the phone switched on with audio (Wilcoxon signed ranks test)	The <i>P</i> value of significance of the difference between the average baseline amplitude and the average amplitude of the last minute with the phone switched on with audio (Wilcoxon signed ranks test)
Left frontal	40.57±1.74	40.37±1.74	37.80±15.25	38.63±16.74	39.70±14.88	0.104	0.170	0.507
Right frontal	37.80±16.24	37.93±12.94	38.80±14.97	37.86±13.94	40.67±14.38	0.614	0.848	0.571
Left parietal	47.10±22.54	43.48±22.71	43.36±19.11	44.88±22.41	45.15±23.78	0.135	0.082	0.232
Right parietal	44.96±23.53	42.65±19.94	42.45±20.78	43.78±22.57	41.65±20.93	0.230	0.330	0.030
Left temporal	46.59±18.18	43.93±16.63	45.62±19.67	47.11±22.85	46.26±25.11	0.689	0.945	0.872
Right temporal	44.28±16.31	41.55±14.42	42.22±16.34	45.07±18.77	44.95±20.05	0.097	0.348	0.520
Left occipital	57.56±21.02	51.51±20.47	51.92±20.73	53.64±23.62	56.32±23.85	0.002	0.026	0.334
Right occipital	59.51±23.51	58.64±23.42	54.25±22.62	73.04±77.07	57.63±22.30	0.058	0.614	0.251

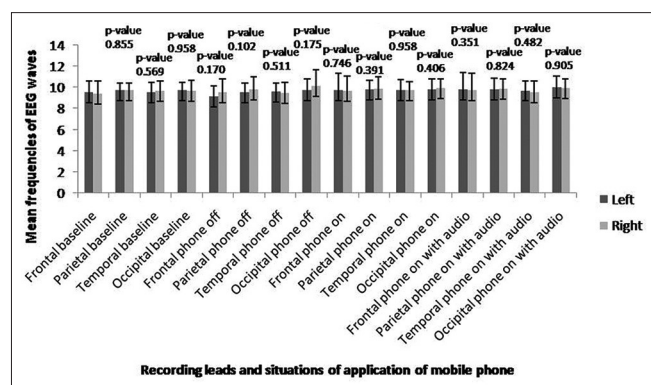


Figure 1: Mean electroencephalography frequencies in different situations of application of mobile phone and comparison of the frequencies of right and left sides of the brain

drowsiness during experimental application of mobile phones (*P* values for the relationship between the adverse effects and the duration of experimental application of mobile phone being 0.974, 0.175, and 0.458, respectively).

Discussion

The mobile phone use has increased dramatically in recent years. Nowadays, the third-generation (3G) technology or Universal Mobile Telecommunication System, using the 1.9–2.1-GHz frequency, is being used, as well as the fourth-generation technology.^[24] The phone used in this study was a 3G phone. Mobile phones generate a modulated radiofrequency EMF. In general, mobile phones transmit and receive high-frequency EMFs of around 1 GHz and emit low frequency electromagnetic pulses (217 Hz) from the phone's circuitry and battery currents.^[25] Unlike ultraviolet and higher frequency radiation such as X-ray, mobile phone radiation is unable to cause ionizations in atoms or molecules and is classified as nonionizing radiation. However, nonionizing radiations are associated with two major potential hazards – electrical and biological. EMFs are reported to induce

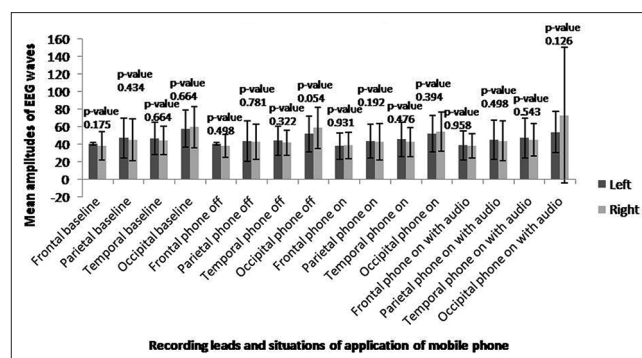


Figure 2: Mean electroencephalography amplitudes in different situations of application of mobile phone and comparison of the frequencies of right and left sides of the brain

an electric field and a current in the body. A strong electric field, depending on its frequency, might warm up tissues or disturb the neuronal functions. The radiowaves emitted by a GSM handset can have a peak power of 2 W and CDMA phone uses lower output power, usually below 1 W.^[26]

In the present study, the average frequencies of waves of most of the regions of the brain following the application of mobile phones with the audio were higher than the baseline frequencies. This is in contrast to some previous studies, which have shown no effect on EEG following cell phone usage.^[9] There have been some studies, however, showing an increase in frequencies to the extent that beta waves have been recorded following the usage of mobile phones.^[22,27-29] Also, the mean frequencies of the last minute's recording with audio were higher in comparison to baseline frequencies, though the results were not very significant. An increase in the frequencies of the waves, though still in the alpha range, could have been due to increased brain activity in the use of mobile phones with audio due to increased concentration. However, the frequencies of waves did increase following the application of mobile phones without any communication, proving thereby that the electromagnetic waves emitted from the mobile phones

Table 4: Average electroencephalography frequencies of different regions of the brain in relation to the application of mobile phones for different durations

	Left frontal	Right frontal	Left parietal	Right parietal	Left temporal	Right temporal	Left occipital	Right occipital
The average baseline frequency in 5 min group	8.520±1.3084	8.480±1.2538	9.520±1.1541	9.800±0.4690	9.040±1.2837	9.200±1.1045	9.120±1.0545	9.160±1.4241
The average frequency of the last minute with the phone switched on with audio in 5 min group	8.60±1.817	9.60±1.673	9.00±1.00	10.60±0.548	9.40±0.894	9.20±0.837	9.40±1.673	10.00±0.707
The <i>P</i> value of the difference between baseline and last minute following audio using Wilcoxon signed ranks test in 5 min group	0.893	0.138	0.581	0.102	0.465	0.492	0.713	0.223
The average baseline frequency in 10 min group	9.825±0.8242	10.050±1.1502	9.875±0.2816	9.925±0.8207	9.750±0.7982	9.875±1.0899	9.925±0.5849	9.875±0.9968
The average frequency of the last minute with the phone switched on with audio in 10 min group	10.12±1.808	10.00±2.138	9.62±2.264	10.50±2.268	10.12±2.295	9.88±2.167	9.88±1.808	10.00±2.000
The <i>P</i> value of the difference between baseline and the last minute following audio using Wilcoxon signed ranks test in 10 min group	0.779	0.622	0.612	0.325	0.733	0.623	0.735	0.779
The average baseline frequency in 15 min group	9.925±0.8812	9.325±0.8067	9.725±0.6671	9.625±0.5898	9.750±0.5831	9.800±0.4660	9.925±0.4528	9.800±0.5757
The average frequency of the last minute with the phone switched on with audio in 15 min group	10.25±0.886	9.62±1.061	9.75±0.886	10.12±0.991	9.75±1.035	9.88±1.126	10.12±0.835	9.62±1.302
The <i>P</i> value of the difference between baseline and the last minute following audio using Wilcoxon signed ranks test in 15 min group	0.399	1.000	0.932	0.141	0.497	0.892	0.599	0.865

may actually have been responsible for an increase in brain activation, rather than the effect of audio only.

The average amplitudes of most of the regions of the brain following application of mobile phones in switched on position without conversation were lower in comparison to the average baseline amplitudes; however, the differences were significant only for the occipital region. This was expected, as an increase in the frequency of brain waves is usually associated with a decrease in amplitude as well.^[30]

On comparison of left and right sides of the brain, the frequencies were slightly more on the right side; however, the difference in frequencies, as well as amplitudes, was not very significant. This could be because the right side of the brain could be better than the left side for localizing sounds and hence the effect of hearing sounds would be more on the right side.^[31]

When we compared the baseline frequencies with those following audio in the last minute, in groups with different

duration of application of mobile phones, the differences in values were not very significant, probably because the time of application might not have been long enough to detect the responses. The amplitude difference was, however, significant for some of the regions of the brain.

Some previous studies have reported slow waves following exposure to mobile phones.^[3,23,32]

The frontal slow waves were most often detected in these students, probably because this area might be the one showing the most effect due to attention which has to be paid once the phone is applied but also probably because of some effect of electromagnetic waves itself on the brain. As these findings were seen in phone on phase without conversation as well and this might be a finding which may be linked to decreased attention span in these students, hence the complaints of decreased concentration. This finding has also been reported previously.^[33] However, in our study, the other areas of the brain also showed various findings, not shown earlier. These findings could probably be linked

Table 5: Average electroencephalography amplitudes of different regions of the brain in relation to the application of mobile phones for different durations

	Left frontal	Right frontal	Left parietal	Right parietal	Left temporal	Right temporal	Left occipital	Right occipital
The average baseline amplitude in 5 min group	30.07±1.18	30.20±9.16	46.92±17.08	53.16±34.08	45.88±9.74	46.08±5.67	57.48±20.68	63.56±24.22
The average amplitude of the last minute with the phone switched on with audio in 5 min group	32.6±1.66	36.67±4.04	44.40±24.50	47.80±30.84	40.20±13.92	35.00±8.98	61.75±25.12	63.00±19.61
The <i>P</i> value of difference between baseline and last minute following audio using Wilcoxon signed ranks test in 5 min group	0.715	0.109	0.684	0.345	0.225	0.068	0.715	0.715
The average baseline amplitude in 10 min group	38.33±18.19	38.01±18.70	52.29±33.25	41.24±26.94	43.42±23.07	38.80±16.68	54.93±26.23	51.44±28.02
The average amplitude of the last minute with the phone switched on with audio in 10 min group	36.71±17.69	39.29±20.39	51.30±30.48	37.57±23.63	50.86±31.98	38.71±11.21	54.29±27.59	46.86±22.54
The <i>P</i> value of difference between baseline and last minute following audio using Wilcoxon signed ranks test in 10 min group	0.499	0.735	0.396	0.063	0.128	0.498	0.735	0.063
The average baseline amplitude in 15 min group	49.38±16.75	42.35±17.07	43.00±17.79	43.55±11.24	50.20±18.19	48.63±20.14	60.23±17.71	65.05±18.37
The average amplitude of the last minute with the phone switched on with audio in 15 min group	46.75±8.55	43.38±11.14	39.38±12.46	41.38±11.08	46.00±26.17	55.38±25.92	55.38±22.76	64.38±22.22
The <i>P</i> value of difference between baseline and last minute following audio using Wilcoxon signed ranks test in 15 min group	0.484	0.889	0.484	0.327	0.611	0.123	0.208	0.779

to the long-term effects on the functioning of other regions of the brain as well.

Among the adverse effects, muscle ache and giddiness were found to be significantly associated with the number of phone calls received per day, and giddiness was significantly associated with the average duration of calls. Fatigue was, however, more significantly seen in those subjects who were using more number of mobile phones. This is also in consensus with the previous studies, which have shown that radiofrequency exposure might produce various symptoms like headaches, fatigue, loss of appetite, sleepiness, difficulty in concentration, poor memory, and emotional instability called as the microwave syndrome.^[2,5,6,21]

In the present study, a very high percentage of students reported that they were aware of the side effects following the use of cell phones, which is even higher than that reported earlier. Hence, the awareness about the adverse effects might be increasing.^[34]

After experimental application of mobile phones also, headache was the most frequent side effect followed by irritation and drowsiness, though these were not significantly related to the duration of application of mobile phones. This is in contrast to some of the previous studies, which conclude that there is little epidemiological evidence indicating that the use of mobile phones causes adverse health effects.^[20]

All the study subjects were personally interviewed with regard to the amount of daily cell phone usage and any side effects of cell phone use as well as the adverse effects they experienced following the experimental application of mobile phone. This is a major strength of this study.

The limitation of the study is that the number of students was less, probably due to an unwillingness to participate in the study due to fear of some adverse event arising out of the experimental application of mobile phones and also since the time period was limited. If the study participants could be increased, probably the results would have been more applicable to the groups or population at large. Also, if the time of application of mobile phones could be increased, probably the results could have been more significant.

Conclusions

Hence, it may be concluded that the experimental application of mobile phones does lead to some changes in the EEG and does have some ill effects on the health and well-being in general, and there is a need for exhibiting caution before using these gadgets for prolonged periods.

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Conflicts of interest

There are no conflicts of interest.

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